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SAFETY EVALUATION OF PRIORITY TECHNIQUES FOR HIGH-OCCUPANCY VEHICLES

February 1979
Final Report

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Prepared for
FEDERAL HIGHWAY ADMINISTRATION
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Traffic Systems Division
Washington, D.C. 20590

FOREWORD

This report reviews the safety problems associated with the operations of priority techniques for high occupancy vehicles (HOV). The report should be of interest to transportation planners, highway designers, traffic engineers, and legislators who are considering the implementation of preferential treatments for carpools and buses.

From the review of the operations of 22 HOV projects, the researchers developed a set of design and operation recommendations for both freeway and arterial applications. These recommendations include highway geometrics and traffic control devices needed to provide safe traffic flows on the HOV facilities and the adjacent roadways. Although the installation of an HOV lane may introduce new safety problems due to geometric restrictions, it may have the potential for reducing accident rates if the overall traffic operations are improved.

One copy of this report is being sent to each FHWA regional office, FHWA division, and State highway agency. The division and State copies are being sent directly to the division office.

Charles F. Scheffey
Director, Office of Research

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16. Abstract

Priority treatments for high-occupancy vehicles (HOV) can introduce new safety problems due to operational or geometric modifications. At the same time, they can reduce the accident potential by improving overall traffic operations.

The research focused on five major areas of HOV projects: 1) an examination of the pertinent accident rates, 2) an analysis of causative factors influencing safety, 3) an identification of difficult maneuvers and potential safety problems, 4) the development of recommendations to improve safety, and 5) a review of the legal authority and legal liability issues faced by HOV projects.

Twenty-two HOV projects on 16 highway facilities were visited by the research team. These projects encompass virtually every type of preferential treatment strategy currently deployed in the United States on both freeways and arterial facilities. For each HOV project, data on safety, operations and geometrics were collected and analyzed. These data and qualitative information can be used to describe the current experience relating to the HOV safety issue.

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PREFACE

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
BD	both directions
CBD	central business district
CHP	California Highway Patrol
DOT	Department of Transportation
EB	eastbound
FHWA	Federal Highway Administration
HOV	high occupancy vehicle
HOVL	high occupancy vehicle lane
IB	inbound
kph	kilometers per hour
min/km	minutes per kilometer
min/mi	minutes per mile
mph	miles per hour
MPM	million person-miles
MUTCD	Manual on Uniform Traffic Control Devices for Streets and Highways
MVK	million vehicle-kilometers
MVM	million vehicle-miles
NB	northbound
OB	outbound
PDO	property damage only
pph	persons per hour
SB	southbound
3 ppv	three persons per vehicle
2 ppv	two persons per vehicle
UMTA	Urban Mass Transportation Administration
WB	westbound

CHAPTER ONE

INTRODUCTION

STUDY DESIGN

Presently, the number of high-occupancy vehicle (HOV) preferential treatment projects is increasing. This trend is a result of the proven success of the early priority projects, an increasing awareness of the people-moving capabilities of transportation systems, and an evolving emphasis on energy conservation. This trend has recently been accelerated through the philosophy regarding transportation system management (TSM) that was established by the U. S. Department of Transportation in 1975. Transportation officials in urban areas are increasingly investigating travel corridors (involving freeway, arterial and even local street travel) where such projects can be implemented. As diversification in the design of HOV preferential treatment projects continues, the issue of safety of HOV facilities takes on greater importance, and the need for developing safe HOV facilities becomes essential.

The objectives of this research, "Safety Evaluation of Priority Techniques for High Occupancy Vehicles," are to:

1. conduct an in-depth accident analysis of operational projects where high-occupancy vehicles are given priority treatment; and

2. analyze the potential liability problems associated with accidents on priority treatment projects.

The accident study analyzes for each HOV priority treatment (Chapters 2-10) 1) the accident rates of typical projects, 2) any causative factors influencing safety, 3) any difficult maneuvers and potential safety problems and 4) any recommendations to improve safety. Two basic legal issues are also analyzed (Chapter 11): 1) the authority of a particular agency to conduct an HOV project, and 2) the risks of legal liability which are faced by the agency when traffic accidents occur causing damages and injury.

Twenty-two HOV projects on 16 highway facilities were visited by the research team. These projects are listed, and key features of each are identified in Table 1. These projects encompass virtually every type of preferential treatment strategy currently deployed in the United States on both freeways and arterial facilities. For each HOV project, data on safety, operations and geometrics were collected and analyzed. In few cases, quantitative data were scarce or non-existent; however, a broad spectrum of highly relevant and useful qualitative information was readily-available. These data and qualitative information can be used to describe the current experience relating to the HOV safety issue.

Accident data from the different projects were compared using the accident rates as the primary basis of comparison. Accidents per million vehicle miles (MVM) and per million passenger miles (MPM) were the primary accident rate units. The assumption was made, as is normally the case, that accidents occur randomly and, therefore, that the Poisson distribution and negative exponential distribution can be used to describe the occurrence of accidents. The accident rate is used in both of these distributions, along with the appropriate time interval, to determine the model parameters. Statistical testing was done

TABLE 1

HOV PROJECTS INCLUDED IN SAFETY RESEARCH

PROJECT/LOCATION	FREEWAY: Separate Roadway	FREEWAY: Concurrent Flow Lane	FREEWAY: Contraflow Lane	FREEWAY: Toll Plaza Lane	FREEWAY: Ramp Treatment	ARTERIAL: Concurrent Flow Lane	ARTERIAL: Contraflow Lane	ARTERIAL: Bus Preemption	PROJECT DESCRIPTION
Shirley Highway, Washington, D.C.	●								page 10
San Bernardino Freeway, Los Angeles, California	●								10
Moanalua Freeway, Honolulu, Hawaii		●							25
Interstate 95, Miami, Florida		●							34
Santa Monica Freeway, Los Angeles, California		●							25
Route 101, San Francisco, California		●	●						34/ 47
Interstate 495, Hudson County, New Jersey			●						46
Long Island Expressway, New York City, New York			●						47
San Francisco/Oakland Bay Bridge, California				●					65
Santa Monica, Golden State and Harbor Freeways, Los Angeles, California					●				76
Interstate 5, Seattle, Washington					●				77
Washington CBD, Washington, D.C.						●			94
U.S. 1/South Dixie Highway, Miami, Florida						●	●		94/116
Kalanianaole Highway, Honolulu, Hawaii						●	●		95/117
N.W. 7th Avenue, Miami, Florida						●	●	●	95/117/141
Ponce de Leon/Fernandez Juncos Avenues, San Juan, Puerto Rico							●		117

using the normal distribution to approximate the Poisson distribution. In this approximation, the accident rate of the Poisson distribution is both the mean and the variance of the normal distribution. The standard "t" tests were used to compare the accident rates on different projects on a statistical basis. It should be noted that this approximation is not as valid when sample sizes (MVM or MPM) are very small. When this is the case, qualifying comments regarding any statistical inferences are given in the report.

HOV FACILITY ON FREEWAY OR ARTERIAL STREET

Priority treatments for high occupancy vehicles (HOV) can introduce new safety problems due to operational or geometric modifications. At the same time, they can reduce the accident potential by improving overall traffic operations.

The influence of HOV priority treatments on roadway safety can be entirely different on freeways than on arterial streets. In many respects, safety on freeways is of greater concern than on arterial streets because of higher travel speeds, increased congestion, and the limited availability of refuge areas off the roadway. However, in other respects safety on arterial streets is of greater concern because of the multiplicity of traffic restrictions in existence and the less control and regimentation occurring in the traffic movements.

Physical Layout

Current national standards on geometric features for freeways and arterial streets are established by AASHTO's A Policy on Geometric Design of Urban Highways and Arterial Streets.[1] This document does not represent geometric features or standards specifically applicable to an HOV lane, but it does discuss in general terms the use of reserved bus lanes on city streets and arterials and design specifications in general, which apply equally to HOV facilities. Geometric design elements that could affect roadway safety include 1) the number of lanes, 2) lane width, 3) curb or shoulder, 4) median, 5) alignment, 6) design speed, 7) sight distance, 8) roadside hazards and 9) pedestrian facilities. Table 2 presents the AASHTO standard, if established, for each design element.

The geometric features of the terminal treatments of an HOV lane can also impact safety. The HOV lane can be established either by 1) adding a lane, or 2) designating an existing traffic lane as the HOV lane. At the terminal locations of the HOV lane, lane changing into and out of the HOV-designated lane may occur. The types of terminal treatments vary greatly with the specific type of HOV treatment; thus there are no explicit geometric standards which apply universally.

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1. American Association of State Highway and Transportation Officials (AASHTO), A Policy on Geometric Design of Urban Highways and Arterial Streets (1973 edition), published by AASHTO, Washington, D.C.

TABLE 2

AASHTO DESIGN STANDARDS

FREEWAY

1. Lane Width: 12 feet
2. Ramp Width: 25 feet for linear ramps, variable for curved
3. Shoulder Widths:
   a. Right: Desired 12 feet; minimum of 10 feet (or 8 feet if low truck volume)
   b. Left: 4 to 6 feet minimum for four lanes; 10 feet for six or more lanes
4. Type Shoulder: Paved, flush
5. Medians with Barrier:
   a. Type: Clearance with safety profile or double "W" corrigated steel
   b. Clearance: 6 feet minimum for four lanes; 10 feet minimum for six or more lanes
6. Design Speed: 40 to 55 mph
7. Sight Distance: Speed dependent
8. Roadside Hazards: 20 feet minimum to edge of right-of-way, 6 to 10 feet to obstacles

ARTERIAL STREET

1. Lane Width: 12 feet
2. Design Speed: 30 to 60 mph
3. Sight Distance: Speed dependent
4. Roadside Hazards: 20 to 30 feet distance from roadway

Metric Conversion

1 foot = 0.3 meters
1 mile = 1.61 kilometers

TABLE 3

MUTCD STANDARDS FOR PREFERENTIAL LANE

1. Signalization: Lane-use controls on reversible lanes
2. Signing:

	Roadside	Overhead
a. Advanced Warning:	R3-10	R3-13
b. Restricted Lane:	R3-11	R3-14
c. End of HOVL:	R3-12	R3-15

3. Lane Demarcation: Solid or skipped white line[a]
4. Special Markings: Diamond symbol, spaced frequently enough to be in constant view
5. Delineators: Plastic posts (reversible and contraflow lanes only)

a. There is some question concerning the use of solid lines. While the MUTCD is not explicit, solid lines should be used on HOV lane projects which are either bus-only or 24-hour operations.

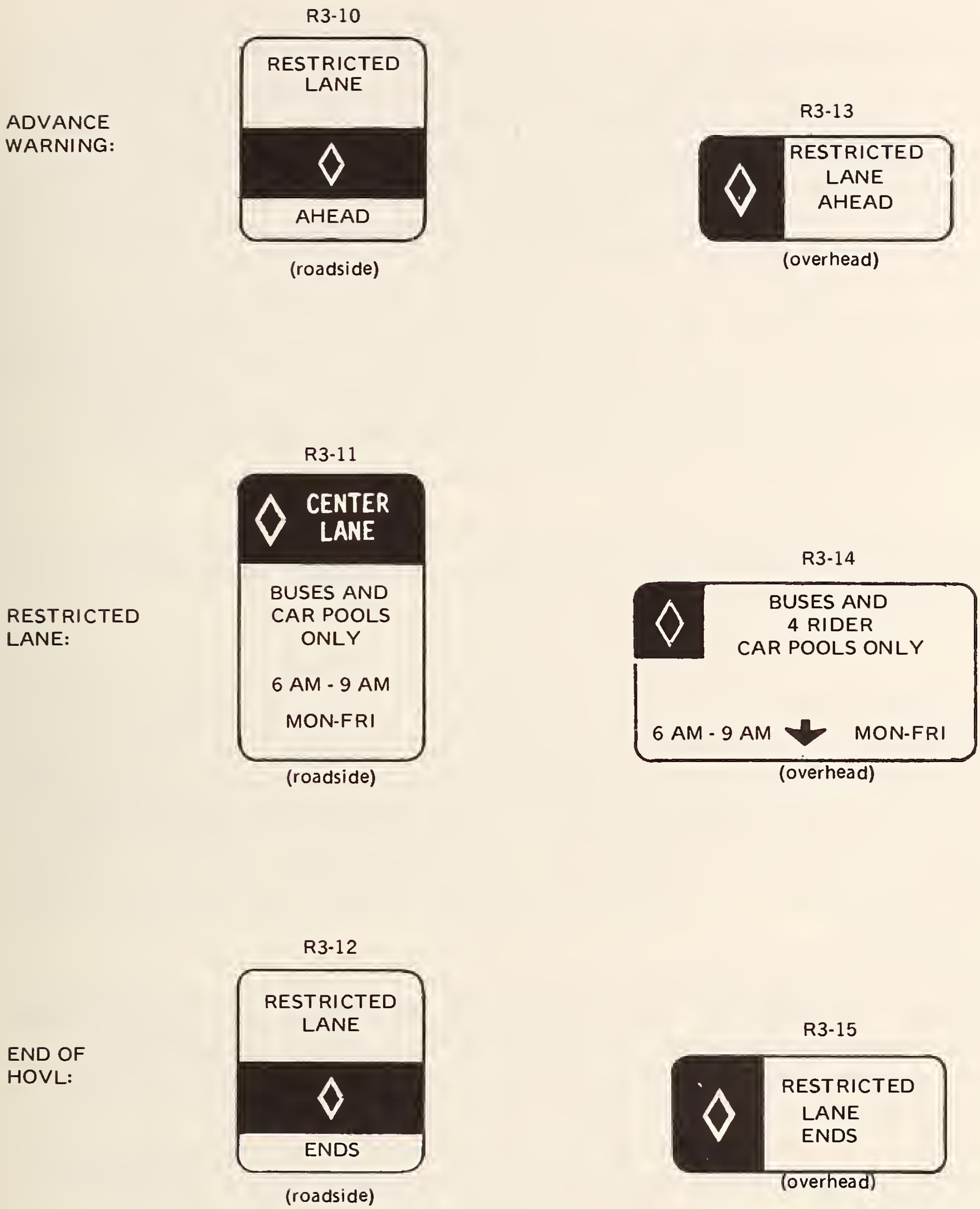

FIGURE 1

MUTCD RECOMMENDED PREFERENTIAL LANE-USE CONTROL SIGNS

Traffic Control Measures

Current national standards on traffic control devices for freeways and arterial streets are established by FHWA's Manual on Uniform Traffic Control Devices (MUTCD).[2] The MUTCD has established special pavement markings and signing for preferential lane-use control. The pavement marking is an elongated "diamond" symbol formed by white lines. The frequency of the diamond marking is a matter of engineering judgement, but the MUTCD suggest an appropriate spacing of 1,000 feet (303 m) for freeways and as close as 80 feet (2 4 m) for arterial streets. The signing regulations include 1) sign shape, color and reflectorization, 2) legend format and sequence, and 3) mounting applications. The type of preferential lane signs include lane-use control signs, advance notification signs, and lane-end signs. The MUTCD suggests that the diamond marking symbol "should be incorporated into the body of the signs as a white symbol on a black background. The sign size, location and spacing are dependent upon the conditions under which it is used, but should be consistently applied." Table 3 and Figure 1 presents the MUTCD standard for each traffic control element established for preferential lane control. A compliance date of January 1, 1976, was established for the MUTCD special markings and signing for preferential lane-use control.

An HOV lane on a freeway may require additional signing (e.g. warning signs for motorists opposing contraflow lanes) in order to improve traffic safety and capacity. The positioning of the signs associated with a freeway HOV project may be overhead or post-mounted in the median.

Similarly, an HOV lane on an arterial street could very well have additional signing requirements for turning and parking restrictions in order to improve traffic safety and capacity. Violations of these restrictions can impact safety greater than violations of the occupancy restriction of the HOV lane. The positioning of the signs associated with an HOV project on an arterial street often may be along the roadside or in the median if one exists. Roadside signing may be less visible to the motorist than overhead signing because of the existence of other signing, storefronts, and other background diversions. The distance to the affected motorist can be critical, especially if the HOV lane is in the median. Some HOV projects on arterial streets have found the need to install supplemental overhead signing in order to make the HOV signing more visible.

The placement of delineators on an HOV lane project that operates during the peak periods requires appropriate system activation and deactivation at the appropriate times. There is a potential safety problem due to a truck with work crew traveling slowly in the HOV lane. System activation or deactivation can require up to one hour from start to finish and cannot occur precisely at the times specified by fixed-message signing; thus, the supporting signs (and signals) are usually changed along with the placement or recovery of the delineators. One project side-stepped this timing problem by using signs that read "NO LEFT TURN WHEN CONED."

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2. United States Department of Transportation (Federal Highway Administration), Manual on Uniform Traffic Control Devices—Official Rulings on Requests, Volume VI, June 1975, pp. 7-8 and 41-42.

   Federal Highway Administration, "Changes in the Manual on Uniform Traffic Control Devices to Provide Pavement Marking and Signs for Preferential Lane Use Control," FHWA Notice N 5160.8, March 17, 1975.

Transit Operations Strategy

HOV lanes can be associated with carpooling, express bus service and/or local bus service. The major involvement of transit agencies, aside from being designated users of the HOV system, is to train the drivers in the proper procedures to enter/exit the HOV lane and to operate in the lane. Drivers must be aware of any special potential hazard associated with operating in the lane. The safety of the transit operations tend to improve with experience in using the HOV facility. From a safety standpoint, it is preferable that the same drivers always be assigned on the HOV lane routes; however, because of operational conditions or institutional reasons, this is not always possible.

Enforcement Strategy[3]

HOV lane operations generally place additional emphasis on the enforcement of the particular facility. This is especially true for a peak period operation where the traffic control measures are temporary. More policing and manpower may be required for system monitoring.

Enforcement of the HOV lane can occur through a routine (standard) patrol or a special patrol. Because of the extra policing and monitoring which might be required by an HOV lane, a special enforcement patrol may be assigned to the project. HOV enforcement is made more difficult if the facility lacks a refuge area, vantage point or a physical separation between the HOV lane and general travel lanes.

HOV enforcement personnel are generally concerned with violations of the bus/carpool restrictions. Violations of this restriction may be very prevalent because of the difficulty of detecting the number of occupants in the cars. Violations of a bus-only restriction are less common because a non-bus vehicle traveling in the bus-only lane is very conspicuous to police officers. On a bus-only lane operation on an arterial street, the main concern for enforcement personnel can be with potential violations of any associated turning or parking restrictions.

An enforcement program on an HOV facility can have a substantial effect on safety. These safety impacts can occur 1) through the enforcement personnel detecting, apprehending and detaining violators or 2) by violators maneuvering to avoid enforcement. Violators of HOV-related restrictions can contribute heavily to the operations problems the traffic engineer has attempted to solve.

Recommendations

There are certain general recommendations for safety on HOV priority treatment projects which are common to all freeway and arterial street applications. Specific recommendations on the particular HOV priority treatments are presented in Chapters 2-10. The general recommendations are:

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3. For a complete evaluation of enforcement of HOV priority treatments, see Beiswenger, Hoch and Associates, Enforcement Requirements for High-Occupancy Vehicle Facilities, Federal Highway Administration, DOT-FH-11-9240, 1978.

Planning

- Every affected agency and the public should be included in the planning and decision-making stages. Enforcement agencies have an obvious interest as they will be largely responsible for the operation later, but equally important, they can often also foresee potential safety problems resulting from the operation.

- Public hearings should be held and environmental impact statements should be prepared to insure public understanding of the advantages, disadvantages, and safety considerations of the HOV operation.

- Decision-makers should be well advised of the impacts of the project, perhaps including first-hand exposure to other ongoing projects.

Design

- Whenever possible, the HOV lane should be an added lane and not be established by the taking of an existing general traffic lane. Oftentimes, this recommendation cannot be followed due to right-of-way, cost or schedule considerations.

- AASHTO and MUTCD standards should be rigorously adhered to as much as possible. Existing deficiencies should not be exaggerated by the HOV project design. Every effort should be made to maximize the quality of the geometrics including medians and shoulder areas. The traffic control devices should be highly visible and frequently spaced. At decision points (particularly terminals and cross-overs), these devices should be prominent to remove confusion as to proper lane use.

- Lane widths for all lanes should be 12 feet (3.7 meters) and the HOV lane can even be wider. If lane width adjustments are necessary, old lane lines should be thoroughly eradicated, longitudinal joints should not conflict with lane lines and when this is not possible, resurfacing should be considered. If the HOV lane is newly constructed, the surface of the HOV lane should closely match the existing surface.

Implementation

- The opening of an HOV lane should be well publicized using a variety of media and including "news" features. Radio traffic reports, hand-outs, roadside billboards and traffic information systems (if available) are all effective ways of directing publicity at habitual users of the facility. Area-wide coverage is also important.

- Signing should be masked, but not bagged prior to opening, so the public can become familiar with the signs and relate them to the publicity. The lane (if newly constructed) should be well barricaded up until the opening date. If at all possible, the entire HOV lane, at least by direction, should be opened simultaneously. Partial openings requiring temporary terminal operations should be avoided.

- If lane transitions, lane drops or cross-overs are required, police officers should be initially stationed in the proximity to assist in the traffic movement.

Operation

- HOV lane sections should be particularly well maintained. The unusual conditions make it imperative to keep the roadway clear and traffic control devices highly visible. Lighting should be kept at high levels for visibility and occupancy detection during hours of darkness.

- Drivers should be assigned on a permanent basis to the bus routes using the HOV lane. This daily experience of driving in the lane would increase driver-awareness of potential safety problems. Regardless, all drivers should be thoroughly trained in the potential hazards of the HOV lane operation.

- Where buses are required to weave across multiple lanes, consideration should be given to installing more distinctive turn signals on the bus and overhead signing. Headlights and flashers on the front of the bus may be used to make the buses more conspicuous to leading traffic, which may be considering merging into the lane. Flashers should not be used on the rear of the bus as this may create confusion among trailing motorists (except on contraflow lanes, where they <u>should</u> be used).

- Lower bus headways tend to make the motorists more aware of the HOV lane operation, especially in regard to a bus-only lane. A bus headway of ½ minute may be necessary to accomplish this objective. For many express bus operations, it may not be financially feasible to operate with headways of ½ minute, since bus volume is a function of ridership demand.

- Incidents should be detected and removed from the facility, especially the HOV lane, as quickly as possible. Conventional detection systems, such as mobile enforcement patrols, CB radio and radio traffic spotters are generally adequate. On-call tow trucks stationed in the project area are also very useful in this regard.

<u>Enforcement</u>

- The enforcement plan should be formally planned in advance. Preferably, enforcement will not be constrained by physical and/or operational problems, but in all cases, officers should be knowledgeable of the HOV operation, well briefed on any potential problems and firmly committed to the programmed level of enforcement. An enforcement manual is of great benefit in this area.

- Whenever necessary, increased enforcement should be provided. If the locality does not have the capacity to generate new funds and resources within the enforcement agency itself, the transportation authority should program special funds to be provided to the enforcement agency.

- If conventional apprehension techniques are used, the officers should make every effort to minimize disruption to traffic. On-site (stationary) monitoring is effective in reducing violations, but it can also slow traffic.

- Aggressive enforcement should begin <u>immediately</u> upon the opening of the HOV lane(s), even if only warning citations are issued initially. The impression must be made that the HOV restrictions are serious and meaningful. A grace period may be used initially during which only warnings are issued, but the apprehension process should start upon opening of the lane(s), provided disruption to traffic is minimal. Enforcement of the HOV project should be well publicized.

CHAPTER TWO

SEPARATE HOV FACILITY ON FREEWAY

DETAILED DESCRIPTION

Separate HOV facilities are roadways or lanes which are physically separated from the general freeway lanes. These facilities are designated for exclusive use by specified HOV vehicles and all other vehicles are expressly prohibited. The separation can be either permanent or partial.

The separate roadway can lie within the median of the freeway or it can be entirely removed from the freeway. Completely separated roadways are really independent highways with no interaction with the general lanes, except at the terminal points. Thus, they should have all the geometric attributes of separate highways including full lane widths, shoulders and appropriate lane striping (if more than one lane). If they are aligned adjacently to the general-use highway, they should be separated by barrier walls and should have full shoulders on both sides. This configuration obviously requires a wide right-of-way.

Partially separated lanes can have shared medians or shoulders which reduces right-of-way requirements. In this design, the restricted lanes are accessible (illegally) from the general lanes and this increases the likelihood of violations. This joint-use shoulder can be penetrated by both violators and HOV vehicles. Indeed, crossing the shoulder-separator by any vehicle is a violation which compounds the enforcement requirement and represents a safety hazard.

Because separate HOV facilities are generally separated physically and have limited (discrete) access/egress points, they possess many of the operational characteristics of "tunnel" facilities, one of which is an irrevocable commitment to using the facility. This attribute often makes it difficult for emergency vehicles to travel quickly to the scene of an accident or incident.

Two separate HOV facility projects were investigated in detail as part of this research. One project—the San Bernardino Freeway—had two distinctly different sections and in the safety analysis later, these sections are treated individually. Project descriptions are given below and in Figures 2 to 4.

- Shirley Highway, Fairfax County, Virginia (Figure 2)
  Major reconstruction of the Shirley Highway (I-395) in the late 1960's and early 1970's produced an eight-lane facility, with three general lanes in each direction and two reversible lanes in the median. The reversible lanes are reserved for buses and carpools of four or more persons per vehicle (ppv). The reversible facility operates inbound (NB) from 11 PM to 11 AM and outbound (SB) from 1 to 11 PM. In the outbound mode, general traffic is allowed to cross through the median barrier into the reversible lanes prior to a major interchange downstream to reduce demand in the two general lanes. Thus, the HOV treatment operates for only about six miles (9.7 km) outbound and 11.5 miles (18.5 km) inbound. Bus-only operations began on the partially completed facility in September, 1969, and carpools were admitted to the completed facility in September, 1973.

- San Bernardino Freeway, Los Angeles, California (Figures 3 and 4)
  This was an eight-lane urban freeway when a portion of a railroad right-of-way in the median was acquired and a lane was added in each direction for exclusive use by buses. This mode of

HOV operation began in January, 1973, and the lanes were restricted 24 hours a day. In October, 1976, carpools of at least 3 ppv were allowed to use the lanes inbound (WB) from 6-10 AM and outbound (EB) from 3-7 PM, Monday-Friday (but this has since been changed to include all days). Buses still use both lanes at all times. As shown in Figure 3, the HOV lanes are separated from the general lanes by a common shoulder in one section 7.0 miles (11.3 km) long. Although the shoulder is fully striped and has vertical tubular posts, vehicles can violate the restriction by crossing through the safety area. The other section of 4.2 miles (6.8 km) is completely separated as shown in Figure 4.

Tables 2 and 3 present the national standards regarding geometrics and traffic control devices applicable to HOV priority treatments. Figures 2 to 4 show how each project addresses these items.

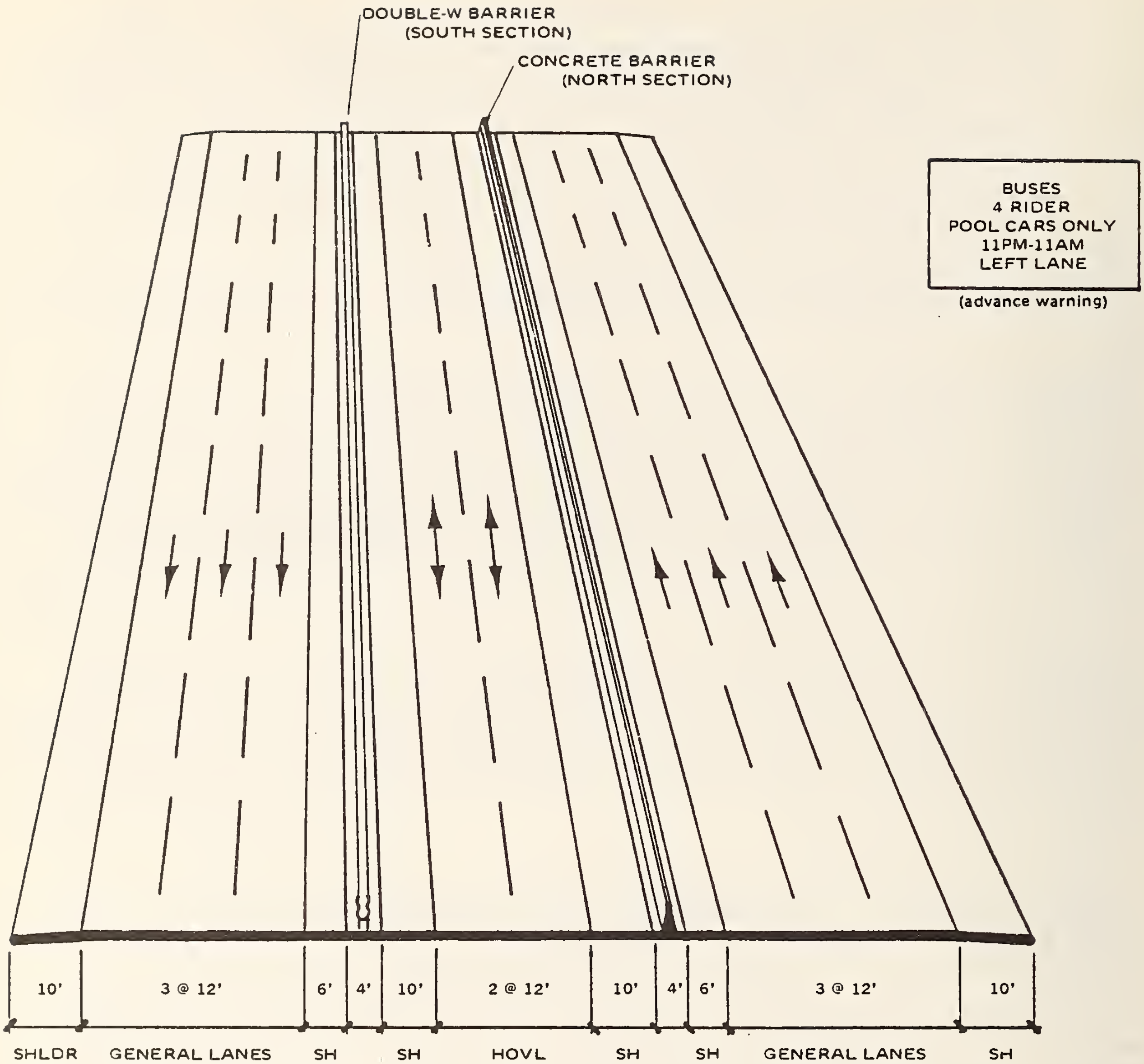
On the Shirley Highway project, there are no deficiencies in the geometric design either on the mainline or the connecting ramps. There are ten connecting ramps, which are either reversible or one-way, and one slip connector through the median wall. Traffic control is basically restricted to the access/ egress points since the HOV facility is otherwise inaccessible. No signalization is used in conjunction with access control, but rather signs indicate the periods during which the ramps are available for access in each direction. Manually operated gates are used to block the ramps to oncoming traffic during periods when the opposing direction of travel is in operation. This is a technical violation of the MUTCD, which specifies lane-use signals, but the barricades are a far more positive type of control since they physically block the closed ramp. All signing is non-standard and there are no mainline restricted lane-use signs. A typical warning sign reads, "BUSES—4 RIDER POOL CARS ONLY—(with operating times)," and has an arrow directed at the ramp. The diamond symbol is not used. The project predates the standards and signing has not been upgraded, but there appears to be relatively little problem with motorists misunderstanding the restrictions.

On the San Bernardino Freeway project, the only geometric design deficiencies are two 11 feet (3.8 m) general traffic lanes in each direction and limited shoulder widths in a few areas. All traffic control devices generally conform to design standards except for a technical violation of using solid yellow edge lines on the median shoulder. This marking should be white to indicate concurrent traffic and that crossing the line is permissible in an emergency. Lane-use control signs are posted at one-mile intervals, which is perhaps less than would normally be required for separated HOV lanes; however, the separate HOV lanes on the San Bernardino Freeway are accessible along the mainline by illegally crossing the common shoulder.

OPERATING CHARACTERISTICS

The extent of the safety impact for an HOV project is dependent, in part, on the operational effectiveness of the project. The major impact of an HOV priority treatment occurs during peak periods when congestion is high and most of the traffic stream is composed of daily commuters. The operational results of each project are displayed in Table 4. Only one peak period is presented—that which experienced the most serious safety problem, or for the period which had the most data. From Table 4, several of the more significant results are:

- Travel speeds in the separate facility HOV lane(s) are greatly superior to the travel speeds in the general lanes. For the Shirley Highway, the speed is 51 mph (82 kph) in the HOV lane compared to 30 mph (48 kph) in the general lanes. For the San Bernardino Freeway,



METRIC CONVERSION
1 in = 2.54 cm
1 ft = 0.3 m
1 mi = 1.61 km

AASHTO DESIGN FACTORS

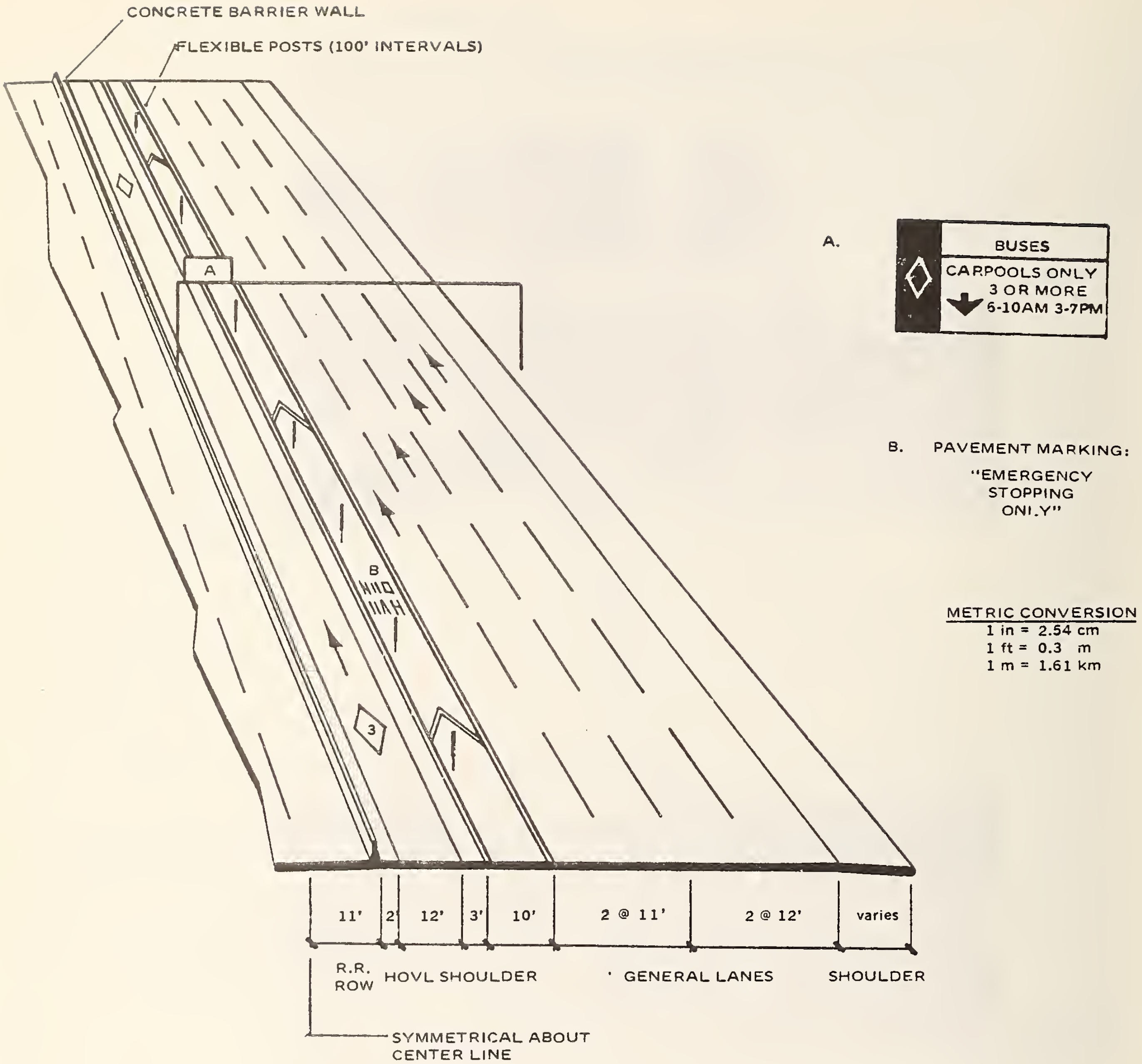
ALIGNMENT: linear
VERTICAL SIGHT DISTANCE: good
POSTED SPEED: 55 mph
ROADSIDE HAZARDS: none
OTHER HAZARDS: crossover for general traffic southbound

MUTCD DESIGN FACTORS

LANE-USE CONTROL SIGNALS: none
ADVANCED WARNING SIGNS: non-standard
RESTRICTED LANE SIGNS: none
END OF HOVL SIGNS: none
DIAMOND SYMBOL: none
HOVL DELINEATION: barrier walls

SHIRLEY HIGHWAY, FAIRFAX COUNTY, VIRGINIA
FIGURE 2

SHIRLEY HIGHWAY, FAIRFAX COUNTY, VIRGINIA
FIGURE 2 (CONT.)



AASHTO DESIGN FACTORS

ALIGNMENT: linear
VERTICAL SIGHT DISTANCE: good
POSTED SPEED: 55 mph
ROADSIDE HAZARDS: walled sections

MUTCD DESIGN FACTORS

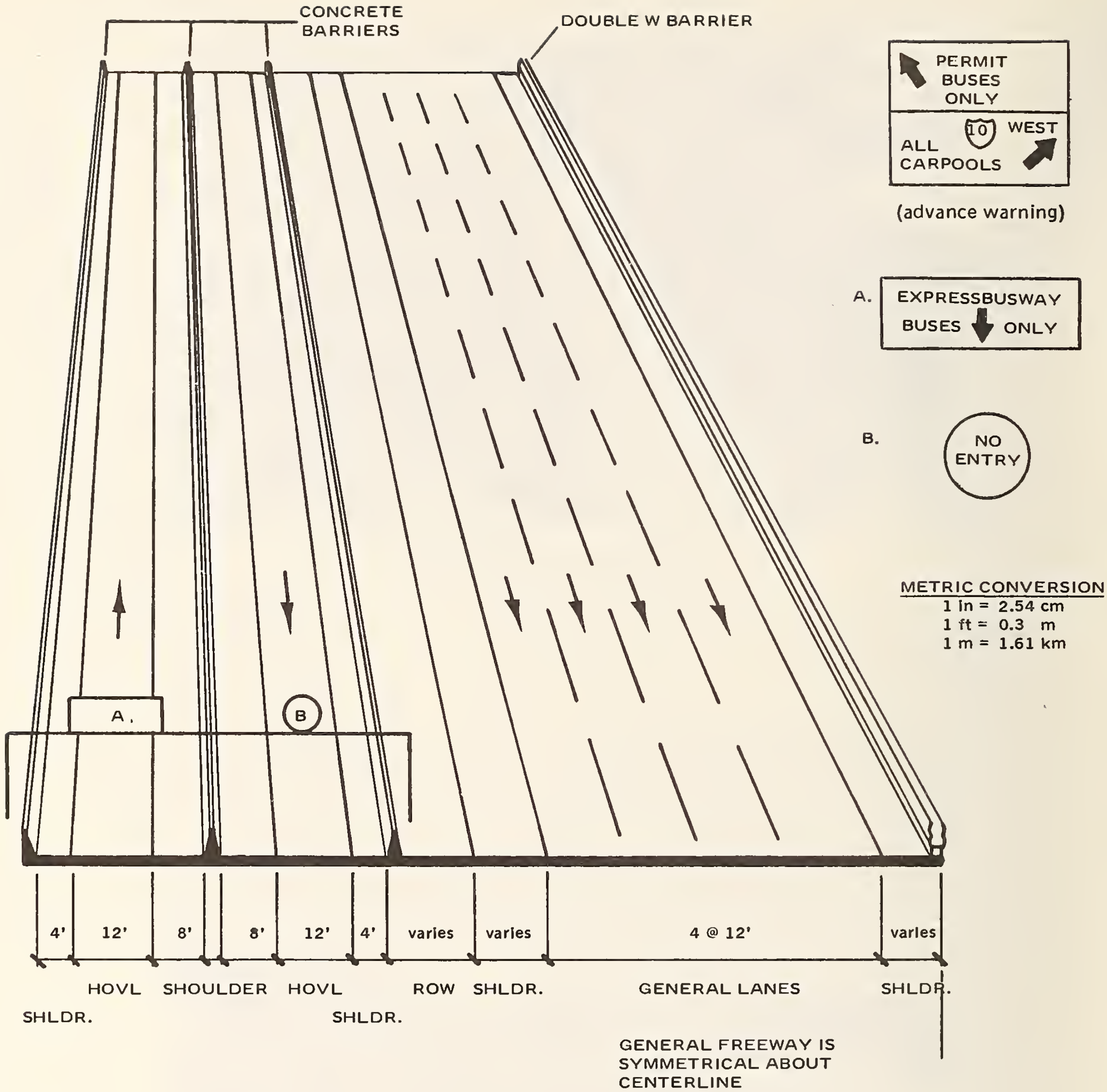
LANE-USE CONTROL SIGNALS: none
ADVANCED WARNING SIGNS: standard
RESTRICTED LANE SIGNS: standard
END OF HOVL SIGNS: standard
DIAMOND SYMBOL: standard (500' intervals)
HOVL DELINEATION: shared shoulder with double yellow lines, safety posts and other marking

SAN BERNARDINO FREEWAY (PARTIALLY SEPARATED SECTION), LOS ANGELES, CALIFORNIA
FIGURE 3

See figure 3, page 14

See figure 4, page 16

SAN BERNARDINO FREEWAY, LOS ANGELES, CALIFORNIA
FIGURES 3 and 4 (CONT.)



AASHTO DESIGN FACTORS

ALIGNMENT: linear
VERTICAL SIGHT DISTANCE: good
POSTED SPEED: 55 mph
ROADSIDE HAZARDS: walled sections

MUTCD DESIGN FACTORS

LANE-USE CONTROL SIGNALS: none
ADVANCED WARNING SIGNS: non-standard
RESTRICTED LANE SIGNS: none
END OF HOVL SIGNS: none
DIAMOND SYMBOL: none
HOVL DELINEATION: concrete barrier walls

SAN BERNARDINO FREEWAY (FULLY SEPARATED SECTION), LOS ANGELES, CALIFORNIA
FIGURE 4

TABLE 4

OPERATING CHARACTERISTICS

(Separate HOV Facilities on Freeways)

		PROJECT/CONDITION			
		Shirley Highway[a]	San Bernardino Freeway		
VARIABLE	UNIT	Bus/4 ppv Carpool	Before[b]	Bus-Only	Bus/3 ppv Carpool
Critical Peak Period	—	6:30 - 9 AM	3 - 7 PM	3 - 7 PM	3 - 7 PM
Length of HOV Lane	Miles	11.5	—	7.0	7.0
Total Peak Directional Lanes	Lanes	5	4	5	5
Number of HOV Lanes	Lanes	2	—	1	1
Volume - All Lanes	Vehicles	18,400	28,018	28,018	28,346
Volume - HOV Lanes	Vehicles	1,948	—	168	906
Volume - HOV Lanes (bus only)	Vehicles	400	—	168	164
HOV Lanes/Total Volume	%	10.6	—	0.6	3.2
Auto Occupancy - All Lanes	PPV	1.57	1.30	1.25	1.28
Auto Occupancy - HOV Lanes	PPV	4.46	—	—	3.09
Person Throughput - All Lanes	Persons	46,388	40,096	40,096	41,543
Person Throughput - HOV Lanes	Persons	24,902	—	5,240	7,780
HOV Lanes/Total Throughput	%	53.7	—	13.1	18.7
Speed - General Lanes	MPH	30.2	35.0	37.0	39.0
Speed - HOV Lanes	MPH	51.0	—	57.1	57.1
Travel Time - General Lanes	Minutes	22.8	12.0	11.4	10.8
Travel Time - HOV Lanes	Minutes	13.5	—	7.4	7.4
Violation Rate	%	2.5	—	0	9.1

Metric Conversion

1 mile = 1.61 kilometers

a. No before data available.

b. No explicit before data were available; however, published reports and graphs indicate there was little change in volume or person trips between the before and bus-only stages, so the latter data are assumed to apply to both.

the speed in the HOV lane is 57 mph (91 kph) compared to 39 mph (62 kph) in the general lanes.

- Because of these higher travel speeds, persons traveling in the HOV lane experience travel time savings over general lane travel. For the Shirley Highway, the average travel time savings is 9.3 minutes over the 11.5 miles (18.5 km). For the San Bernardino Freeway, the travel time savings is 3.4 minutes over the 7.0 miles (11.3 km).

- The HOV lanes on both projects illustrate the efficiency of the operation. For the Shirley Highway, the HOV lanes carry 54 percent of the persons in 11 percent of the vehicles. The volume in the peak period (6:30 to 9:00 AM) is 1,948 vehicles, of which 400 are buses. For the San Bernardino Freeway, the HOV lane carries 19 percent of the persons in 3 percent of the vehicles. The volume in the peak period (3:00 to 7:00 PM) is 906 vehicles, of which 164 are buses.

- The violation rate (percentage of the total HOV lane(s) traffic that does not quality) is 3 percent on the Shirley Highway and 9 percent on the San Bernardino Freeway under bus/carpool operation. Under the bus-only operation on the San Bernardino Freeway, the violation rate was zero percent.

ACCIDENT ANALYSIS

The accident data on the two separate HOV facility projects that were studied in detail is analyzed by 1) peak period accident rates, 2) daily accident rates, and 3) accident characteristics. It is also pertinent to compare the 24-hour accident rates on the HOV facilities with some control base for which data are generally available. Accident rates were computed in terms of accidents per million vehicle-miles (MVM) and million person-miles (MPM) of travel. These rates automatically take into consideration the effects of differing stage lengths and demand levels. Accident rates were tested with the "t" statistic to determine the statistical significance of any apparent change.

The two projects studied in detail represent HOV operations in several specific conditions, and it is useful to discuss individually the completely-separated and partially-separated sections of the San Bernardino Freeway project. The "before" condition is prior to implementation of the HOV treatment.

For the Shirley Highway project, only 1975 accident data were available, making "before" and "after" comparisons impossible. Furthermore, the available traffic volume data, from which vehicle-miles were computed, were for the years 1977 and 1978. These figures had to be extrapolated to estimate 1975 data. Thus, the accident rate analyses for Shirley Highway is somewhat tenuous and any conclusions involving accident rates should be viewed with this understanding. No PM occupancy data were available for the MPM accident rate.

Peak Period Accident Rates

Table 5 presents the total facility peak-period accident rates for the AM (inbound) and PM (outbound) peak periods. The results are summarized for accident rates based on both MVM and MPM. From the available data, the following general conclusions can be developed:

- The peak period accident rates during HOV operations range from a low of 0.9 accidents/MVM (0.6 accidents/MVK) on the completely separated section of the San Bernardino Freeway to a high of 2.9 accidents/MVM (1.8 accidents/MVK) on the Shirley Highway.

- The PM peak period accident rates on separate HOV facilities is higher than the AM peak period rates in all comparisons except one.

- The Shirley Highway project experienced the highest accident rates in both peak periods. It is of interest to add that the accident rate in the southern section, where general traffic is allowed on the reversible roadway, was lower at 1.9 accidents/MVM (1.2 accidents/MVK) probably due to the reduced congestion and increased capacity available to general traffic.

- In the completely separated section of the San Bernardino Freeway, the only change in accident rates which was statistically significant was the increase in the afternoon peak period accident rate over the "before" condition when the new HOV lanes were opened to buses. Since there was little change in the operation of the general lanes, this accident rate increase is contrary to expectations and remains unexplained.

- In the partially separated section of the San Bernardino Freeway, the accident rates in both peak periods increased when the HOV operation changed from a bus-only condition to a bus/carpool condition. However, these increases were not statistically significant.

- By converting the accident rates from vehicle-miles to person-miles, the rates were lower, however the relationships stated above did not change.

Daily Accident Rates

Total facility accident rates for the full 24 hours, seven days a week are given in Table 6 for the "before" and "after" conditions. The control accident rates for each project are also given as an indication of the overall effects of the HOV treatments compared with the control area. From the available data, the following general conclusions can be developed:

- The 24-hour accident rates range from a low of 0.9 accidents/MVM (0.6 accidents/MVK) on the partially separated section of the San Bernardino Freeway under bus/carpool condition to a high of 2.3 accidents/MVM (1.6 accidents/MVK) on the Shirley Highway.

- In the completely separated section of the San Bernardino Freeway, the total accident rate decreased when the new HOV lanes were opened to buses when compared to the "before" condition. This decrease was statistically significant.

- In the partially separated section of the San Bernardino Freeway, the total accident rate decreased when the HOV operation changed from a bus-only condition to a bus/carpool condition. This decrease was statistically significant and opposite to the trend experienced in the peak period accident rate.

- For the San Bernardino Freeway project, the control area had a consistently lower accident rate than the HOV priority sections. While the accident rates for both were decreasing, the accident rate on the HOV facility decreased faster.

TABLE 5

PEAK-PERIOD FACILITY ACCIDENT RATES

(Separate HOV Facilities on Freeways)

PROJECT \ VARIABLE	TIME PERIOD	AM PEAK PERIOD			PM PEAK PERIOD		
		Number of Accidents	Accident Rate[a] (acc/mvm)	Accident Rate[a] (acc/mpm)	Number of Accidents	Accident Rate[a] (acc/mvm)	Accident Rate[a] (acc/mpm)
Shirley Highway[b]							
• Bus/Carpool	1975	87	2.0	0.6	43	2.9	b
San Bernardino Freeway (completely separated section):							
• Before	1/73 - 4/74	30	1.0	0.7	34	0.8	0.6
• Bus-Only	5/74 - 10/76	54	0.9 ns	0.7 ns	100	1.2 *	0.8 *
San Bernardino Freeway (partially separated section):							
• Before	1/71 - 12/72	156	c	c	90	c	c
• Bus-Only	1/73 - 4/74	79	1.2	0.9	70	1.0	0.7
• Bus/Carpool	10/76 - 12/76	19	1.9 ns	1.4 ns	13	1.3 ns	0.9 ns

a. Statistical significance of accident rates compared to the before condition:
ns indicates difference is not significant
* indicates a 95 percent level of significance
**indicates a 99 percent level of significance
b. No before data available.
c. Measured vehicle miles are not available.

Metric Conversion
1 mile = 1.61 kilometers
1 acc/mvm = 0.62 acc/mvk

TABLE 6

DAILY FACILITY AND CONTROL ACCIDENT RATES

(Separate HOV Facilities on Freeway)

PROJECT \ VARIABLE	TIME PERIOD	HOV FACILITY					Control Accident Rate[a,d] (acc/mvm)
		Inbound Direction		Outbound Direction		Total	
		Number of Accidents	Accident Rate[a] (acc/mvm)	Number of Accidents	Accident Rate[a] (acc/mvm)	Accident Rate[a] (acc/mvm)	
Shirley Highway[b]							
• Bus/Carpool	1975	391	2.3	206	2.3	2.3	—
San Bernardino Freeway (completely separated section):							
• Before	1/73 - 4/74	187	1.6	157	1.4	1.4	1.1
• Bus-Only	5/74 - 10/76	284	1.2 **	264	1.1 ns	1.2 **	0.9
San Bernardino Freeway (partially separated section):							
• Before	1/71 - 12/72	656	c	558	c	c	—
• Bus-Only	1/73 - 4/74	375	1.5	371	1.5	1.5	1.1
• Bus/Carpool	10/76 - 12/76	41	1.1 *	32	0.9 **	1.0 **	0.9

a. Statistical significance of accident rates compared to the before condition:
ns indicates difference is not significant
* indicates a 95 percent level of significance
**indicates a 99 percent level of significance
b. No before data available.
c. Measured vehicle miles are not available.
d. Control Facility: San Bernardino - all freeways in Caltrans District 7.

Metric Conversion
1 mile = 1.61 kilometers
1 acc/mvm = 0.62 acc/mvk

Accident Characteristics

Table 7 presents the injury-producing accident rates for each facility. On either project, there were no significant changes between the "before" and "after" conditions or the HOV operating conditions. The percentage of accidents that are injury-producing ranges from 8 to 32 percent in the PM peak period and 19 to 38 percent in the 24-hour period (outbound only).

For the combined peak periods, table 8 presents the percentage breakdown of the accidents as to 1) vehicle type, 2) location, 3) pre-collision events, and 4) accident types.

There were no discernable changes in the distribution of vehicle types involved in accidents on the San Bernardino Freeway. The number of accidents involving buses was too small in each condition to be significant. There was no similar data for the Shirley Highway.

On the Shirley Highway during both peak periods of 1975, there were only two accidents or 2 percent of the total facility accidents reported to occur in the HOV lanes. Thus the HOV lanes were considerably safer than the general lanes. Additionally, it is of interest to examine the accidents in the southbound section where general traffic is allowed in the reversible roadway. During the PM peak period there were six accidents in this section (27 percent of the total) and four of these were in the immediate area of the general traffic crossover. Thus, it would appear that the HOV lane operation experienced fewer safety problems than mixed-mode reversible lane operations.

On the San Bernardino Freeway, only 2 percent of the total facility accidents occurred in the HOV lane. Additionally, for the outbound (EB) input to the HOV lane, there is a one-mile (1.6 km) approach lane on the left of the facility. This approach lane is established as an unseparated concurrent flow HOV lane. Violators often used this lane to bypass the recurring congestion that occurs in the PM peak due to substandard geometrics and a major on-ramp located downstream. Accident rates increased from 2.4 accidents/MVM (1.5 accidents/MVK) to 6.3 accidents/MVM (3.9 accidents/MVK) in this section when the HOV lanes were opened. This change is statistically significant. These accidents occurred in several ways. First, HOVs and violators merged into the higher speed lane from the congested general lanes, and the relative speed difference between the two lanes led to rearend accidents. Secondly, the violators attempted to return to the general lanes near the exit and created shock waves in the traffic stream. Finally, these violators were often trapped in the HOV lane and had to stop before being able to leave the lane.

Pre-collision movements and accident types are often indicators of accident causes. The distribution of pre-collision movements was generally consistent between the projects.

SAFETY CHARACTERISTICS

Causative Factors Influencing Safety

Both the Shirley Highway and San Bernardino Freeway generally had excellent geometric features. As a consequence, there are no major safety concerns related to the geometric design of separated facilities.

TABLE 7

INJURY ACCIDENT RATES
(Separate HOV Facilities on Freeway)

PROJECT \ VARIABLE	TIME PERIOD	PM PEAK PERIOD Number of Accidents	PM PEAK PERIOD Accident Rate[a] (acc/mvm)	24-HOUR OUTBOUND Number of Accidents	24-HOUR OUTBOUND Accident Rate[a] (acc/mvm)
Shirley Highway:[b]					
• Bus/Carpool	1975	4	0.3	39	0.4
San Bernardino Freeway (completely separated section):					
• Before	1/73 - 4/74	13	0.3	50	0.4
• Bus-Only	5/74 - 10/76	32	0.4 ns	99	0.4 ns
San Bernardino Freeway (partially separated section):					
• Before	1/71 - 12/72	22	c	137	c
• Bus-Only	1/73 - 4/74	18	0.3	99	0.4
• Bus/Carpool	10/76 - 12/76	1	0.1 ns	9	0.2 ns

a. Statistical significance of accident rates compared to the before condition:
ns indicates difference is not significant
* indicates a 95 percent level of significance
**indicates a 99 percent level of significance
b. No before data available.
c. Measured vehicle miles are not available.

Metric Conversion
1 mile = 1.61 kilometers
1 acc/mvm = 0.62 acc/mvk

TABLE 8

ACCIDENT CHARACTERISTICS BY PERCENTAGE (COMBINED PEAK PERIODS)
(Separate HOV Facilities on Freeway)

CHARACTERISTIC \ FACILITY	Shirley Highway[a]	San Bernardino Freeway (completely-separated section)		San Bernardino Freeway (partially-separated section)		
	Bus/Carpool	Before	Bus-Only	Before	Bus-Only	Bus/Carpool
Vehicle Type						
• auto	b	78	79	83	85	84
• truck	b	19	18	14	13	10
• bus	b	0	0	0	0	2
• other	b	3	3	3	2	5
Location						
• HOV lane	2	0	2	b	b	b
• other lanes	98	100	98	b	b	b
Pre-Collision Events						
• stopped	b	20	16	15	23	26
• going straight	44	46	46	44	45	39
• changing lanes	9	8	8	7	6	3
• slowing/stopping	44	16	18	24	21	16
• other	3	10	12	10	5	16
Collision Type						
• sideswipe	18	18	18	11	10	10
• rear-end	75	35	54	57	76	77
• broadside	b	12	12	2	1	4
• hit object	5	24	11	12	7	2
• other	2	10	4	18	6	7

a. No before data available.
b. Data is not available.

All traffic control devices except the grass median separation on the San Bernardino Freeway, appeared to be adequate from a safety perspective. This partial separation permitted illegal lane changes to be made across the common shoulder and this led to some accidents. The fact that some devices were non-standard or absent (notably signing and absence of the diamond symbol on the Shirley Highway) did not appear to have an adverse effect on safety.

The extensive degree of restriction and physical separation generally precluded implementation problems on either project. However, the separate roadway treatment can be very disruptive to general traffic when the HOV lanes are constructed in the median. Construction-related accidents did occur on both projects, particularly the Shirley Highway.

Separated HOV facilities on freeways generally operated with a relatively high degree of safety, particularly within the HOV lanes. Bus-only operations provided a higher degree of safety on the HOV lanes than bus/carpool operations. Only where interactions with general lanes occurred were problems of any consequence detected.

Several site-specific problems were created by the HOV treatment. On the Shirley Highway, termination of HOV operations and admission of general traffic to the reversible lanes in the outbound operating mode seemed to cause increased accidents in the lanes. On the San Bernardino Freeway, an unseparated concurrent flow HOV approach lane to the HOV facility created a significant localized safety problem due to frequent violators blocking this lane. On this same project, there was a moderate problem with vehicles (both violators and HOVs alike) illegally crossing the shoulders separating the HOV lanes from the general lanes. There was insufficient data to quantify the extent of this problem but a separate study[1] stated that 60 percent of HOV lane-related accidents involved vehicles leaving the HOV lanes by illegally crossing the median and colliding with vehicles in the left general lanes. The opposite maneuver accounted for 30 percent of the accidents. The remaining 10 percent were rearend accidents in the HOV lane.

Difficult Maneuvers and Potential Safety Problems

An HOV priority treatment might be expected to generate potential safety problems on a transportation facility. Project personnel for the separate HOV facility projects identified several possible difficult maneuvers and safety problems that could be associated with this type of treatment. Such safety problems included:

- The limited access operation of separated HOV facilities concentrates weaving in the general lanes to particular locations upstream of HOV access terminals and downstream of HOV egress terminals.
- On completely separated facilities, the HOV roadway has many characteristics of a tunnel because once on the HOV facility, all vehicles are irrevocably committed to driving the full length. Incidents occurring in these "pipeline" sections can seriously interfere with traffic flow, if roadway and shoulder widths are insufficient to allow storage of disabled vehicles.

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1. Crain and Associates, "San Bernardino Freeway Express Busway, Evaluation of Mixed-Mode Operations, Interim Report—Stage 1," Prepared for the Southern California Association of Governments, May, 1976.

- On partially separated facilities, motorists can make illegal maneuvers through the separation between the HOV and general lanes, and thereby create merging problems by entering the facility at unassigned locations. This hazardous situation could be further compounded by the speed differential between the HOV lanes and general lanes.

RECOMMENDATIONS

The previous sections have shown that separated HOV facilities can be operated safely, but several safety problems have occurred on the projects studied as part of this research. General recommendations on safety of HOV priority treatments are presented on page 7. Specific recommendations that may improve the safety of a separate HOV facility on a freeway include the following:

- The ideal terminals to and from the separated HOV lanes are exclusive ramps. However, where a median crossover is required at the input terminal, a concurrent flow HOV lane with shoulder may be provided for the approach to the crossover so violators are not "trapped" in the HOV lanes. At the output terminal, it is best to add a lane or provide an adequate acceleration lane for HOV vehicles merging into general traffic. When operations are not 24 hour, terminals should be closed during non-HOV operating periods.

- Totally separated HOV facilities generally require restrictive traffic control devices only at the input terminals to identify the authorized users, times, etc. At outputs it may be necessary to bar wrong-way entry, and this should be accomplished with highly visible gates or barricades and/or flashing beacons and no entry signs. On partially separated sections, HOV lane use signs should be periodically installed along the route as a continuous discouragement to violators.

- On partially separated HOV lanes, supplemental signing should be provided at inputs to identify the legal exits from the limited access facility. This is to avoid erratic maneuvers by drivers needing to exit at locations other than the HOV lane terminals. A possible message is "RESTRICTED LANE EXITS ONLY AT (location)."

- On partially separated facilities having a common shoulder, the shoulder should have distinctive solid white edge lines on both sides. Double lines are even more forceful. The shoulder should contain chevrons or cross-hatching and word messages to discourage crossing. Tubular safety posts should be placed at 40 feet (11.9 m) intervals to further discourage crossing.

CHAPTER THREE

CONCURRENT FLOW HOV LANE ON FREEWAY

DETAILED DESCRIPTION

Concurrent-flow HOV lane priority projects on freeways generally involve the designation of the median lane(s) for use by buses alone or by buses and carpools. Since this treatment commonly addresses "rush-hour" congestion, the operation is usually in the peak direction only during the peak period. The minimum carpool occupancy requirement varies from two to four persons among projects of this type but three persons is the most common. Access to the restricted lane is most often continuous, that is, there is no physical separation or other barrier between the HOV lane and general lanes. The lack of physical separation of the HOV lane from the general lanes is the source of several operational and safety problems not experienced in other HOV treatments on freeways. If there is physical separation, the operational and safety requirements and problems are drastically different and this case was discussed in Chapter 2. Therefore, this chapter will address only the continuously accessible configuration.

Concurrent HOV lanes can be created by either reserving an existing lane for HOVs or, more commonly, by constructing new lanes in the median. These two approaches have differing effects on the operation of the facility. First, the addition of lanes increases capacity but in order to do so often eliminates or reduces median shoulders or refuge areas, which could formerly be used by disabled motorists and enforcement operations. Secondly, the "taking a lane" for HOVs will reduce capacity for general traffic and increase the congestion in the general travel lanes. The public acceptance of the concurrent HOV treatment has been much better when new lanes are constructed for the HOVs.

In either case, the resulting geometric configuration is quite similar, except possibly at terminal locations. The inside or median lane operates as the HOV lane and HOVs (and violators) can enter and leave the lane anywhere along its length. Such continuous access/egress permits these lanes to serve a variety of origins and destinations along the freeway.

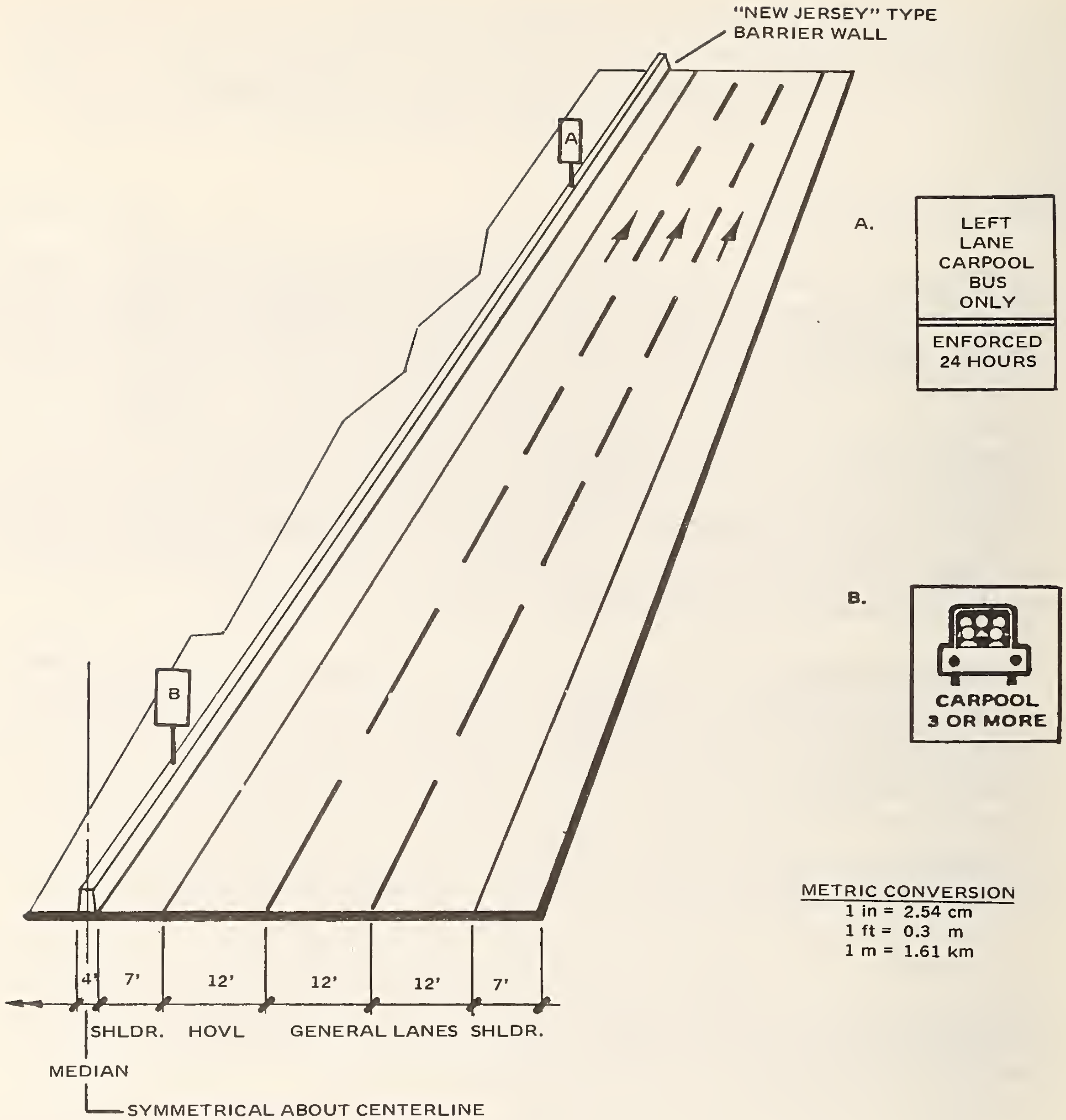
Four concurrent flow HOV lane projects were investigated in detail as part of this research. Project descriptions are given below and in Figures 5 to 8.

- Moanalua Freeway, Honolulu, Hawaii (Figure 5)

  This was an arterial highway which was upgraded to freeway standards with HOV lanes included in the upgrade. The project was implemented in October, 1974, with an HOV lane provided in each direction for buses and carpools of three or more persons per vehicle (ppv). The inbound HOV section is 2.7 miles (4.3 km) in length while the outbound HOV section is 1.3 miles (2.1 km) long. The HOV restrictions apply 24 hours each day.

- Santa Monica Freeway, Los Angeles, California (Figure 6)

  In March, 1976, the existing median lanes for 12.5 miles (20.2 km) of this eight-lane facility were redesignated as restricted lanes for buses and carpools of 3 ppv or more during the peak periods in both directions. The operating hours were originally 6-10



METRIC CONVERSION
1 in = 2.54 cm
1 ft = 0.3 m
1 m = 1.61 km

AASHTO DESIGN FACTORS

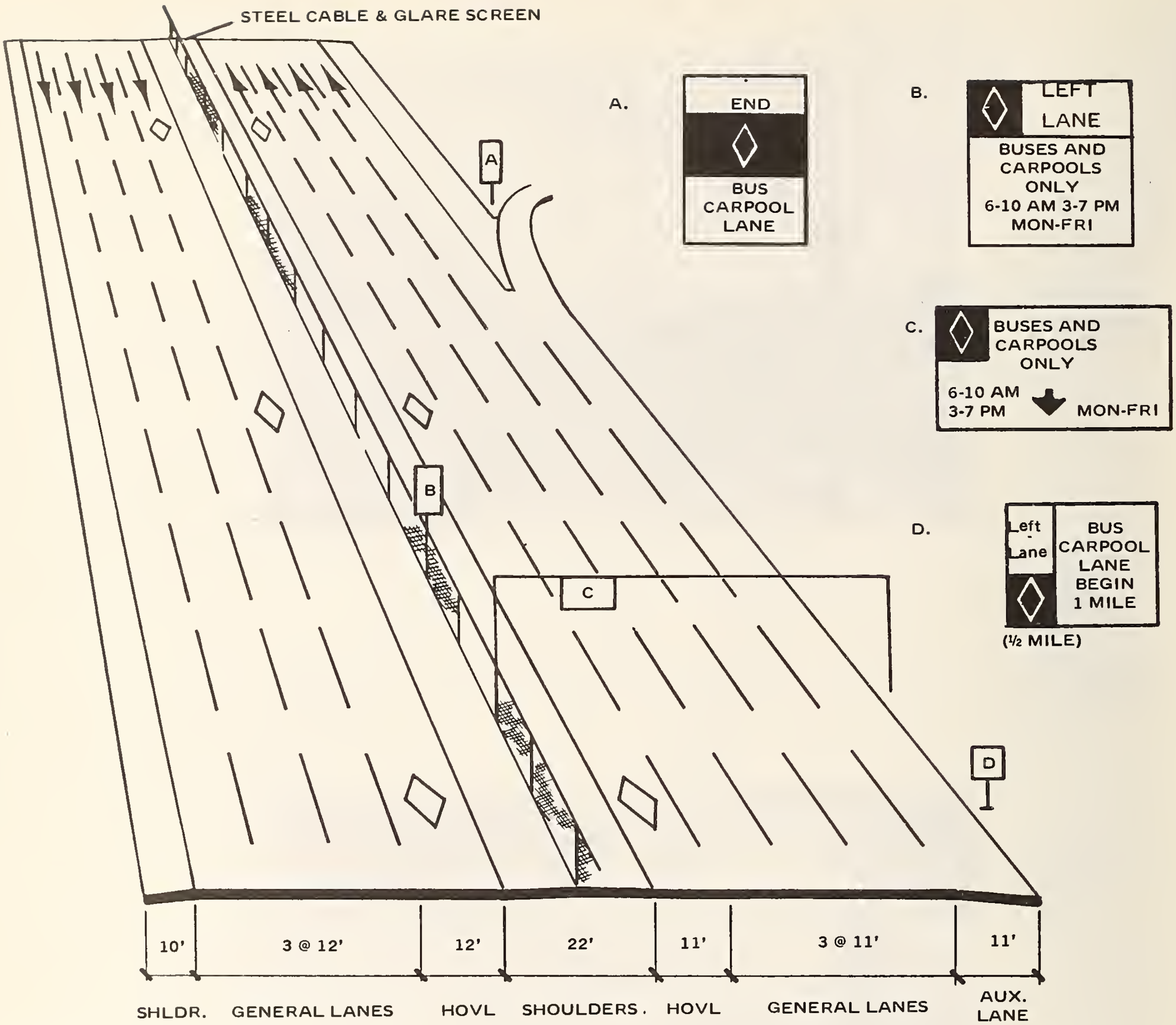
ALIGNMENT: curvilinear
VERTICAL SIGHT DISTANCE: good for posted speed
POSTED SPEED: 45 mph
ROADSIDE HAZARDS: narrow shoulders in certain locations

MUTCD DESIGN FACTORS

LANE-USE CONTROL SIGNALS: none
ADVANCED WARNING SIGNS: non-standard
RESTRICTED LANE SIGNS: non-standard
END OF HOVL SIGNS: non-standard
DIAMOND SYMBOL: none
HOVL DELINEATION: white skip marking

MOANALUA FREEWAY, HONOLULU, HAWAII
FIGURE 5

MOANALUA FREEWAY, HONOLULU, HAWAII
FIGURE 5 (CONT.)



METRIC CONVERSION
1 in = 2.54 cm
1 ft = 0.3 m
1 m = 1.61 km

AASHTO DESIGN FACTORS

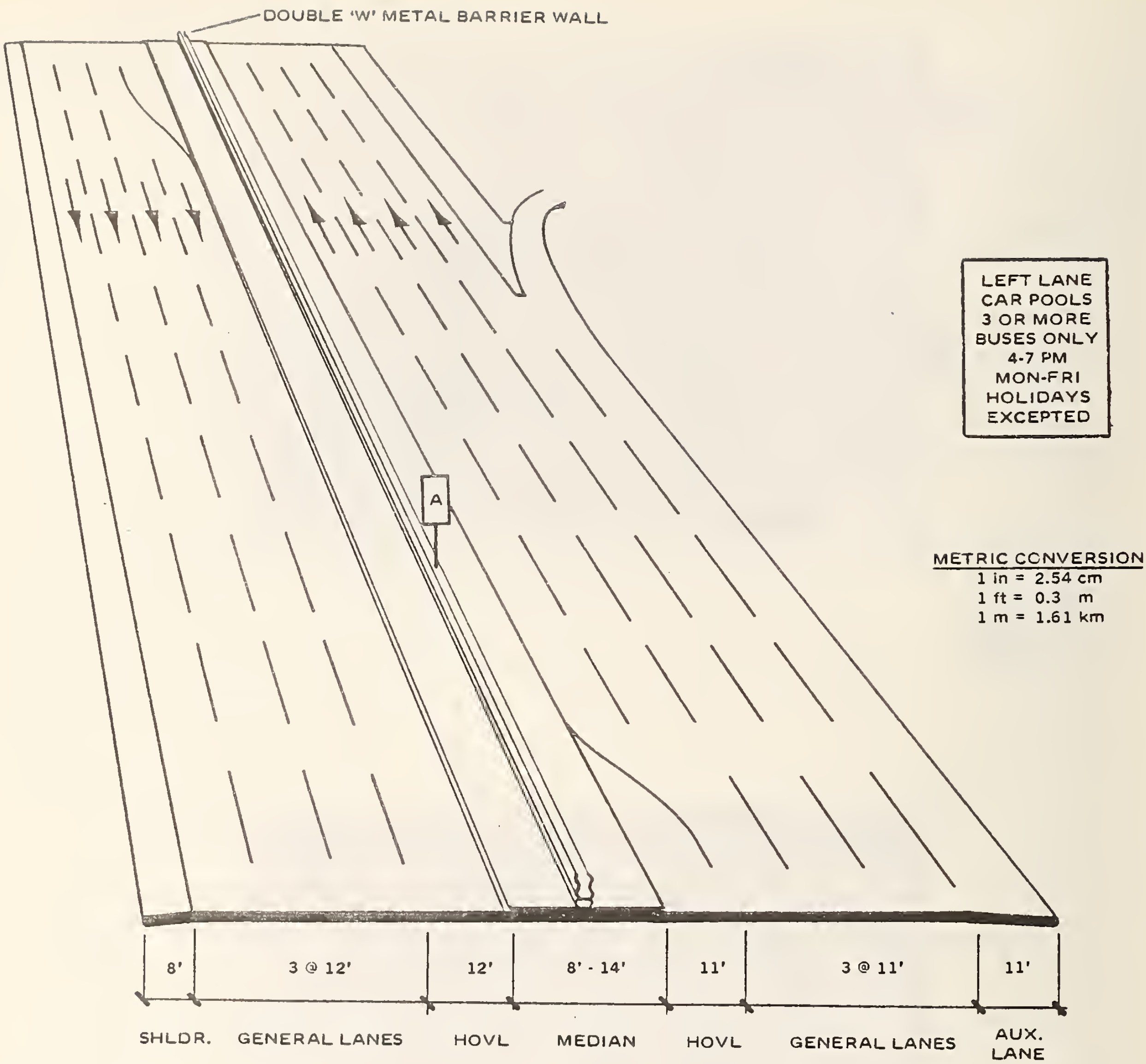
ALIGNMENT: linear
VERTICAL SIGHT DISTANCE: good
POSTED SPEED: 55 mph
ROADSIDE HAZARDS: none
OTHER HAZARDS: none

MUTCD DESIGN FACTORS

LANE-USE CONTROL SIGNALS: none
ADVANCED WARNING SIGNS: standard
RESTRICTED LANE SIGNS: standard
END OF HOVL SIGNS: standard
DIAMOND SYMBOL: ¼ mile
HOVL DELINEATION: 4" white skip line with raised buttons

SANTA MONICA FREEWAY, LOS ANGELES, CALIFORNIA
FIGURE 6

SANTA MONICA FREEWAY, LOS ANGELES, CALIFORNIA
FIGURE 6 (CONT.)



AASHTO DESIGN FACTORS

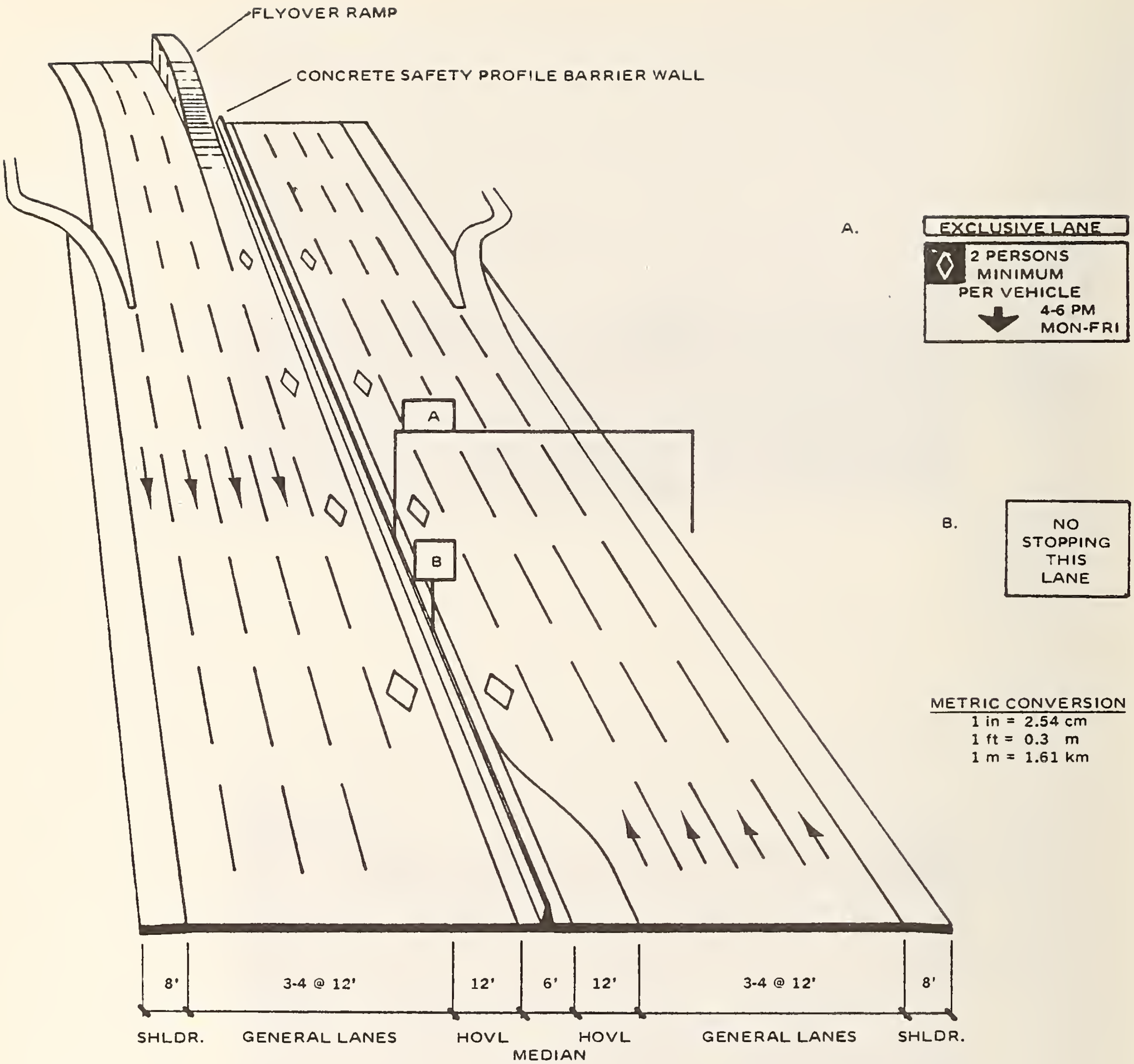
ALIGNMENT: linear
VERTICAL SIGHT DISTANCE: good
POSTED SPEED: 55 mph
ROADSIDE HAZARDS: none
OTHER HAZARDS: raised median

MUTCD DESIGN FACTORS

LANE-USE CONTROL SIGNALS: none
ADVANCED WARNING SIGNS: non-standard (NB), none (SB)P
RESTRICTED LANE SIGNS: non-standard
END OF HOVL SIGNS: none
DIAMOND SYMBOL: none
HOVL DELINEATION: 4" round buttons in skip pattern

ROUTE 101 (CONCURRENT FLOW LANE), MARIN COUNTY, CALIFORNIA
FIGURE 7

ROUTE 101 (CONCURRENT FLOW LANE), MARIN COUNTY, CALIFORNIA
FIGURE 7 (CONT.)



METRIC CONVERSION
1 in = 2.54 cm
1 ft = 0.3 m
1 m = 1.61 km

AASHTO DESIGN FACTORS

ALIGNMENT: linear
VERTICAL SIGHT DISTANCE: limited by bridges
POSTED SPEED: 55 mph
ROADSIDE HAZARDS: none
OTHER HAZARDS: no left shoulder/refuge area

MUTCD DESIGN FACTORS

LANE-USE CONTROL SIGNALS: none
ADVANCED WARNING SIGNS: standard
RESTRICTED LANE SIGNS: standard
END OF HOVL SIGNS: none (NB), non-standard (SB)
DIAMOND SYMBOL: standard (250' interval)
HOVL DELINEATION: 3" white skip line

INTERSTATE 95, MIAMI, FLORIDA
FIGURE 8

INTERSTATE 95, MIAMI, FLORIDA
FIGURE 8 (CONT.)

AM and 3-7 PM, but the morning times were reduced to 6:30-9:30 AM. Strong public opposition faced the project, and on August 9, 1976, a federal court suspended the project pending further environmental impact studies.

- <u>Route 101, Marin County, California (Figure 7)</u>

  This was an eight-lane inter-regional freeway connecting San Francisco and suburban residential areas in Marin County. In December, 1974, a new lane was added in the existing median in each direction over a 3.7 mile (6.0 km) section and was initially reserved for buses only from 6-9 AM inbound (SB) and 4-7 PM outbound (NB). In June, 1976, carpools of 3 ppv or more were allowed to use the lanes.

- <u>I-95, Miami, Florida (Figure 8)</u>

  This was a 6-10 lane urban freeway prior to the HOV lane project. An HOV lane opening in December, 1975, was constructed in the existing median in each direction over a 6.7 mile (10.7 km) section. The HOV lanes were reserved for buses and carpools of 3 ppv or more in the inbound (SB) direction from 6-10 AM and in the outbound (NB) direction from 3-7 PM. In January, 1977, the minimum carpool occupancy level was reduced to 2 ppv and the priority time periods to 7-9 AM and 4-6 PM.

Tables 2 and 3 present the national standards regarding geometrics and traffic control devices applicable to HOV priority treatments. Figures 5 to 8 show how each project addresses these items.

The Moanalua Freeway has several design deficiencies: 1) narrow shoulders in some sections and 2) some alignment deficiencies due to topography. The first deficiency produces reduced refuge areas for disabled vehicles. The speed limit is set at 45 mph (72 km/hr) to compensate for this, and more importantly, to compensate for the alignment deficiencies. Signing of the HOV lane is non-standard on this project and the diamond symbol is not used.

On the Santa Monica Freeway, the one deficiency is lane widths of 11 feet (3.3 m) in sections having auxiliary lanes. In all other geometric and traffic control respects, this facility conformed well to AASHTO and MUTCD standards.

On the Route 101 project, the major deficiencies in the geometric design are the reduced width of traffic lanes and left shoulders in sections having an auxiliary lane. The HOV lane signing is non-standard and HOV lane-end signs are not used. The diamond marking symbol is not used because of the adverse publicity which this symbol received on the Santa Monica Freeway "Diamond Lane" project in Los Angeles.

On the I-95 project, the one deficiency in the geometric design is the lack of median shoulders or refuge areas which resulted from the addition of HOV lanes. This is a serious deficiency and has had an adverse effect on both safety and enforcement. The project is in general conformance with the MUTCD standards for HOV facilities, except that there are no HOV lane-end signs. (In the inbound direction, there are "LANE ENDS" signs due to the median lane being terminated.)

OPERATING CHARACTERISTICS

The extent of the safety impact for an HOV project is dependent, in part, on the operational effectiveness of the project. The major impact of an HOV priority treatment occurs during peak periods when congestion is high and most of the traffic stream is composed of daily commuters. The operational results of each project are displayed in Table 9 . Only one peak period is presented—that which experienced the most serious safety problem, or for the period which had the most data. From Table 9 , several of the more significant results are:

1. On the Santa Monica Freeway project, the peak period volume was reduced by about 25 percent when the HOV lane was established by taking a lane. On the I-95 project, the peak period volume increased by 13 percent when the HOV lane for carpools of 3 ppv was established by adding a lane. When the minimum carpool eligibility was reduced to two persons, the volume rose to 35 percent higher over the before condition. Thus, two major factors which determine the changes in peak period volumes are the carpool eligibility level and whether the HOV lane is added to the freeway or merely redesignated. An unsatisfied traffic demand would have to exist before a volume increase would take place.

2. Depending on the HOV lane eligibility restrictions, the HOV lane was used by 1.5-15 percent of the vehicles traveling the facility.

3. The total passenger throughput declined by 17 percent on the Santa Monica Freeway where the HOV lane was taken from general use. Where the HOV lane was added to the facility, the total passenger throughput increased by 0.5 percent to 50 percent, with the HOV lane reserved for buses and 2 ppv carpool having the greatest increase.

4. The speed in the HOV lanes ranged near 50 mph (80 km/hr) on all projects except the Moanalua Freeway, where the HOV lane speed averaged 12 mph (19 km/hr). Due to the congested type of operation in the general lanes, all projects except the Moanalua Freeway had a speed differential of 9-14 mph (15-23 km/hr) between the HOV lane and general travel lanes.

5. The violation rate (percentage of the HOV lane traffic that does not qualify) ranged from 7 percent on the Moanalua Freeway project to 61 percent on the I-95 project.

ACCIDENT ANALYSIS

The accident data on the four concurrent flow HOV projects, that were studied in detail, is analyzed by 1) peak period accident rates, 2) daily accident rates, and 3) accident characteristics. It is also pertinent to compare the 24-hour accident rates on the HOV facilities with some control base for which data are generally available. Accident rates were computed in terms of accidents per million vehicle-miles (MVM) and million person-miles (MPM) of travel. These rates automatically take into consideration the effects of differing stage lengths and demand levels. Accident rates were tested with the "t" statistic to determine the statistical significance.

The four projects studied in detail represent HOV operations in several specific conditions, and it is useful to discuss individually each operating condition provided sufficient data was available. The "before" condition is prior to implementation of the HOV treatment.

Peak Period Accident Rates

Table 10 presents the peak-period accident rates for the AM (inbound) and PM (outbound) peak

TABLE 9

OPERATING CHARACTERISTICS

(Concurrent Flow Lane on Freeway)

VARIABLE	UNIT	Moanalua Freeway		Santa Monica Freeway			Route 101			Interstate 95		
		Bus/3 ppv Carpool[a]	Bus/3 ppv Carpool[b]	Before	Bus/3 ppv Carpool	After Termination	Before	Bus-Only	Bus/3 ppv Carpool	Before	Bus/3 ppv Carpool	Bus/2 ppv Carpool
Critical Peak Period	—	6-8 AM	6-8 AM	3-7 PM	3-7PM	3-7 PM	4-7 PM	4-7 PM	4-7 PM	4-6 PM	4-6 PM	4-6 PM
Length of HOV Lane	Miles	2.7	2.7	—	12.5	—	—	3.7	3.7	—	6.7	6.7
Total Peak Directional Lanes	Lanes	3	3	4	4	4	3	4	4	3-4	4-5	4-5
Number of HOV Lanes	Lanes	1	1	—	1	—	—	1	1	—	1	1
Volume - All Lanes	Vehicles	7,200	6,425	28,250	21,158	28,013	13,600	13,137	13,089	11,355	12,825	15,290
Volume - HOV Lanes	Vehicles	1,220	1,850	—	1,853	—	—	191	647	—	618	2,057
Volume - HOV Lanes (bus only)	Vehicles	6	11	—	64	—	—	148	150	—	23	23
HOV Lanes/Total Volume	%	16.9	28.8	—	8.8	—	—	1.5	4.9	—	4.8	13.5
Auto Occupancy - All Lanes	PPV	1.70	1.92	1.27	1.35	1.32	1.30	1.30	1.36	1.28	1.37	1.42
Auto Occupancy - HOV Lanes	PPV	3.21	3.23	—	3.25	—	—	2.21	2.96	—	2.23	1.79
Person Throughput - All Lanes	Persons	12,230	12,305	35,878	29,781	36,977	24,439	24,567	25,365	14,875	18,221	22,338
Person Throughput - HOV Lanes	Persons	3,920	5,980	—	7,117	—	—	5,719	7,172	—	1,981	4,347
HOV Lanes/Total Throughput	%	32.1	48.6	—	23.9	—	—	23.3	28.3	—	10.9	19.5
Speed - General Lanes	MPH	—	8.9	42.1	36.0	46.3	34.1	43.3	47.6	29.6	35.6	41.6
Speed - HOV Lanes	MPH	—	11.5	—	49.6	—	—	53.4	53.4	—	50.0	50.4
Travel Time - General Lanes	Minutes	—	13.9	17.8	20.8	16.2	6.5	5.1	4.7	13.5	11.3	9.6
Travel Time - HOV Lanes	Minutes	—	12.9	—	15.1	—	—	4.2	4.2	—	8.0	8.0
Violation Rate	%	18.8	6.8	—	15.9	—	4.2	9.6	12.8	5.1	4.7	2.4

a. One month after opening of project (November, 1974)
b. Two years after opening of project (October, 1976)

Metric Conversion
1 mile = 1.61 kilometers

periods. The results are summarized for accident rates based on both MVM and MPM. From the available data, the following general conclusions can be developed:

- The peak period accident rates during HOV operations range from a low of 2.2 accidents/MVM (1.4 accidents/MVK) on the Moanalua Freeway to a high of 12.8 accidents/MVM (7.9 accidents/MVK) on Route 101 under bus/carpool operation.

- Only the I-95 project experienced decreasing trends in the accident rates from the before condition. The other projects experienced increasing trends in the accident rates.

- On the Moanalua Freeway a statistically significant increase in the number of accidents occurred between 1975 and 1976 as more traffic was using the freeway. The HOV lane operated in both 1975 and 1976.

- On the Santa Monica Freeway, the accident rates experienced statistically significant increases during the peak periods when HOV operations were in effect.[1] When the HOV restrictions were terminated, the accident rates reverted to a level which was about the same as the before condition in the morning peak period but was actually lower than the before condition in the evening peak period. A similar trend was found in the off-peak directions, where HOV restrictions were also in effect.

- On Route 101, the accident rate in the PM peak experienced a statistically significant increase. In the AM peak during bus-only operations, the increase from the before condition was statistically significant, while the increase when carpools were added was not statistically significant due to a small sample size in the latter stage.

- On I-95, the PM peak accident rate experienced a statistically significant decrease in each HOV condition. In the morning peak, the rates also declined but the changes were not statistically significant.

- By converting the accident rates from vehicle-miles to person-miles, the rates were lower, however, the relationships stated above did not change.

<u>Daily Accident Rates</u>

Since the concurrent lane HOV treatment can have an effect during off-peak hours, such as by eliminating a shoulder or refuge area, daily accident rates were also analyzed. Additionally for each project,

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1. Conclusions on the Santa Monica project must be viewed with caution for the following reasons:

   a) The Santa Monica "Diamond Lanes" operated for only 21 weeks. Had the project operated longer, the accident rates would probably have declined to steady-state levels although it appears the rates would still have been higher with the "Diamond Lanes" than without them. (In examining the time series history of accidents, the weekly rate did tend to decline; however, the probability of an accident occurring in the HOV lanes did not decline as significantly as in the general lanes).

   b) It has been suggested by project personnel on both the Santa Monica Freeway and Route 101 projects that the increased presence of enforcement personnel during HOV operations may have also increased the frequency of reporting minor accidents, thereby artifically raising the accident rates from the before condition. This is conjecture and cannot be proven or disproven. An examination into this phenomenon on the Santa Monica Freeway was conducted and it was concluded that such was probably not the case. (See Billheimer, J. W., et. al., "The Santa Monica Freeway Diamond Lanes: An Evaluation," Systan Corporation, Los Altos, California, June, 1977.)

TABLE 10

PEAK PERIOD FACILITY ACCIDENT RATES

(Concurrent Flow HOV Lane on Freeway)

PROJECT \ VARIABLE	TIME PERIOD	AM PEAK PERIOD Number of Accidents	AM PEAK PERIOD Accident Rate[a] (acc/mvm)	AM PEAK PERIOD Accident Rate[a] (acc/mpm)	PM PEAK PERIOD Number of Accidents	PM PEAK PERIOD Accident Rate[a] (acc/mvm)	PM PEAK PERIOD Accident Rate[a] (acc/mpm)
Moanalua Freeway							
• Before	—	b	—	—	b	—	—
• Bus/Carpool	1975	11	2.2	1.3	b	—	—
• Bus/Carpool	1976	29	6.3 *	3.4	b	—	—
Santa Monica Freeway							
• Before	na - 3/76	260	2.6	2.2	363	2.6	2.1
• Bus/Carpool	3/76 - 7/76	105	6.2 **	4.9 **	197	9.5 **	6.7 **
• After termination	8/76 - 12/76	55	2.8 ns	2.3 ns	49	1.9 *	1.5 *
Route 101							
• Before	na - 12/74	42	1.4	0.7	163	4.2	2.3
• Bus-Only	12/74 - 3/76	31	2.5 *	2.2 **	158	9.6 **	5.2 **
• Bus/Carpool	6/76 - 12/76	15	2.8 ns	1.4 ns	89	12.8 **	6.6 **
Interstate 95							
• Before	5/74 - 8/74	29	4.3	3.4	32	5.1	3.9
• Bus/Carpool (3 ppv)	3/76 - 1/77	75	3.7 ns	2.7 ns	92	4.7 ns	3.3 ns
• Bus/Carpool (2 ppv)	1/77 - 5/77	33	2.9 ns	2.2 ns	27	2.4 *	1.6 **

a. Statistical significance of accident rates compared to the before condition:
ns indicates difference is not significant
* indicates a 95 percent level of significance
** indicates a 99 percent level of significance
b. No data available.

Metric Conversion

1 mile = 1.61 kilometers
1 acc/mvm = 0.62 acc/mvk

TABLE 11

DAILY FACILITY AND CONTROL ACCIDENT RATES

(Concurrent Flow HOV Lane on Freeway)

PROJECT \ VARIABLE	TIME PERIOD	HOV FACILITY Inbound Direction Number of Accidents	HOV FACILITY Inbound Direction Accident Rate[a] (acc/mvm)	HOV FACILITY Outbound Direction Number of Accidents	HOV FACILITY Outbound Direction Accident Rate[a] (acc/mvm)	HOV FACILITY Total Accident Rate[a] (acc/mvm)	Control Accident Rate[a,c] (acc/mvm)
Moanalua Freeway							
• Before	—	b	—	b	—	—	—
• Bus/Carpool	1975-76	134	1.4	231	2.4	1.9	1.7
Santa Monica Freeway							
• Before	na - 3/76	1,046	1.4	1,156	1.4	1.4	0.9
• Bus/Carpool	3/76 - 7/76	472	3.5 **	447	3.7 **	3.6 **	0.9 ns
• After termination	8/76 - 12/76	250	1.7 **	242	1.6 *	1.6 **	0.9 ns
Route 101							
• Before	na - 12/74	321	1.7	462	2.3	2.0	1.4
• Bus-Only	12/74 - 3/76	103	1.2 **	243	2.7 ns	2.0 ns	1.1 **
• Bus/Carpool	6/76 - 12/76	49	1.3 ns	135	3.4 *	2.4 *	1.1 **
Interstate 95							
• Before	5/74 - 8/74	189	3.2	232	4.1	3.6	7.9
• Bus/Carpool (3 ppv)	3/76 - 1/77	359	2.3 **	336	2.0 **	2.1 **	6.4 **
• Bus/Carpool (2 ppv)	1/77 - 5/77	163	2.0 **	149	1.8 **	1.9 **	5.9 **

a. Statistical significance of accident rates compared to the before condition:
ns indicates difference is not significant
* indicates a 95 percent level of significance
** indicates a 99 percent level of significance
b. No data available.
c. Control Facilities: Moanalua - a three mile (4.8 km) section of the H-1 Freeway.
Santa Monica - all freeways in Caltrans, District 7.
Route 101 - all freeways in Caltrans, District 4.
Interstate 95 - all streets and highways in Dade County, Florida.

Metric Conversion

1 mile = 1.61 kilometers
1 acc/mvm = 0.62 acc/mvk

the daily accident rates were compared to the accident rates for a control facility or facilities. The results are summarized in Table 11 and specific conclusions are given below.

- The 24-hour accident rate ranges from a low of 1.2 accidents/MVM (0.8 accidents/MVK) on Route 101 under bus-only HOV operation to a high of 3.7 accidents/MVM (2.3 accidents/MVK) on the Santa Monica Freeway.

- Only the I-95 project experienced decreasing trends in the accident rates from the before condition. The other projects experienced increasing trends in the accident rates.

- The accident rate during 1975 on the Moanalua Freeway was not significantly different from the accident rate on the control facility. The accident rate on the Moanalua increased in 1976, but it is not known if the same trend prevailed on the control facility.

- On the Santa Monica Freeway, the daily accident rates during the HOV operations are greater with statistical significance than the accident rates on the facility during the before or after operating conditions. These accident rates on the Santa Monica Freeway are higher than the control accident rates, which remained virtually unchanged during the three operational stages.

- On Route 101, the daily accident rate in the inbound direction decreased with the operation of the HOV lane over the before condition. This decrease was statistically significant only for the bus-only HOV operation. However, the daily accident rate in the outbound direction increased with the operation of the HOV lane over the before condition. This increase was statistically significant for the bus/carpool HOV operation, the daily accident rate increased on Route 101 with the HOV operation. The accident rates on the control facilities decreased during these time periods.

- On I-95, the opening of the HOV lanes to buses and three person carpools were associated with a statistically significant decrease in the daily accident rates. The reduction in the minimum carpool eligibility from 3 persons to two persons was also associated with a further 10 percent decrease in the accident rate. There was also a decrease in accident rate on the control facility during the same periods but the percentage decrease was much lower than on I-95.

Accident Characteristics

HOV priority treatments can affect the severity of accidents due to such factors as the high speed differential between the HOV lane and the general lanes and the elimination of median refuge areas. Table 12 presents the injury-producing accident rates for each project. From this table, the following inferences can be made:

- The injury accident rate ranges from a low of 0.1 accidents/MVM (0.1 accidents/MVK) on the Moanalua Freeway to a high of 2.4 accidents/MVM (1.5 accidents/MVK) on the Route 101 during bus/carpool operation.

- The Santa Monica Freeway experienced statistically significant increases in injury accident rates during the peak periods and on a daily basis. Following termination of HOV operations, the injury rates decreased to levels comparable to the before condition.

- On Route 101 there was a statistically significant increase in the peak period injury accident rate when the HOV system was implemented, but the daily accident rate did not increase significantly. When carpools were admitted to the HOV lane, the injury accident

TABLE 12

INJURY ACCIDENT RATES

(Concurrent Flow HOV Lane on Freeway)

PROJECT \ VARIABLE	TIME PERIOD	COMBINED PEAK PERIODS: Number of Accidents	COMBINED PEAK PERIODS: Accident Rate[a] (acc/mvm)	24-HOUR PERIOD: Number of Accidents	24-HOUR PERIOD: Accident Rate[a] (acc/mvm)
Moanalua Freeway					
• Before	—	b	—	b	—
• Bus/Carpool	1975-76	b	—	15	0.1
Santa Monica Freeway					
• Before	na - 3/76	189	0.8	751	0.5
• Bus/Carpool	3/76 - 7/76	68	1.8 **	241	0.9 **
• After termination	8/76 - 12/76	36	0.8 ns	164	0.5 ns
Route 101					
• Before	na - 12/74	57	0.8	211	0.5
• Bus-Only	12/74 - 3/76	50	1.7 **	110	0.6 ns
• Bus/Carpool	6/76 - 12/76	29	2.4 **	58	0.8 *
Interstate 95					
• Before	5/74 - 8/74	28	2.1	153	1.3
• Bus/Carpool (3 ppv)	3/76 - 1/77	54	1.4 ns	268	0.8 **
• Bus/Carpool (2 ppv)	1/77 - 5/77	23	1.0 *	138	0.8 **

a. Statistical significance of accident rates compared to the before condition:
ns indicates difference is not significant
* indicates a 95 percent level of significance
** indicates a 99 percent level of significance
b. No data available.

Metric Conversion
1 mile = 1.61 kilometers
1 acc/mvm = 0.62 acc/mvk

TABLE 13

ACCIDENT CHARACTERISTICS BY PERCENTAGE (COMBINED PEAK PERIODS)

(Concurrent HOV Lane on Freeway)

CHARACTERISTIC \ FACILITY	Santa Monica Freeway: Before	Santa Monica Freeway: Bus/Carpool	Santa Monica Freeway: After	Route 101: Before	Route 101: Bus-Only	Route 101: Bus/Carpool	Interstate 95: Before	Interstate 95: Bus/Carpool 3 ppv	Interstate 95: Bus/Carpool 2 ppv
Vehicle Type									
• Auto	91	90	91	86	94	90	85	82	82
• Truck	7	8	6	11	5	7	12	10	15
• Bus	0	0	0	1	1	0	0	1	0
• Other	2	2	2	2	1	3	3	7	3
Location									
• Left[a]	33	44	23	55	36	33	—	13	11
• Interior lane	27	41	30	24	46	54	—	—	—
• Right lane	32	10	39	16	15	6	—	—	—
• Other	7	4	8	4	4	8	—	—	—
• Non-left lane	—	—	—	—	—	—	—	87	89
Pre-Collision Events									
• Stopped	28	31	23	30	36	28	51	43	45
• Going straight	32	23	28	37	28	14	49	51	52
• Changing lanes	7	7	9	4	3	5	—	—	—
• Slowing stopping	27	35	32	25	32	51	—	—	—
• Other	7	4	8	4	1	2	—	6	3
Collision Type									
• Side-swipe	10	7	9	11	6	4	9	21	16
• Rear-end	77	86	79	82	89	88	86	73	78
• Broad-side	4	1	5	1	2	2	0	0	0
• Hit object	7	5	8	4	3	5	0	3	1
• Other	2	1	0	1	1	2	5	3	5

a. This is HOV lane during HOV operations rates further increased.

- I-95 experienced a statistically significant decline in the injury accident rates for the 24-hour period. During the peak periods, the rate also declined but not significantly due to a small sample size. Several fatal accidents occurred in the off-peak periods due in part to the revised geometrics and lack of a median refuge area.

Table 13 presents for the combined peak periods the percentage breakdown of the accidents as to 1) vehicle type, 2) location, 3) pre-collision events and 4) accident types. A lack of data of this type precludes an analysis of the Moanalua Freeway.

There were no substantial changes in the distribution of vehicle types involved in accidents on any of the projects. None of the projects experienced a significant change in the percentage of bus accidents and the data sample was insufficient in order to compute and compare bus accident rates.

The location of the accidents laterally on the freeway is an indication of how the HOV lanes shifted the accident zones.[2] Under HOV operation, there is now one more "interior" lane than before. On the Santa Monica Freeway, the percentage of accidents in the left lanes and in the interior lanes increased when the left lanes were designated as HOV lanes.[3] On Route 101, the percentage of left-lane accidents decreased when the HOV lane was added, but the percentage of interior lane accidents increased. Comparing this trend with the Santa Monica Freeway, it appears that merging with the HOV lane was less serious on Route 101, probably due to a lower relative speed on this facility. On I-95 it did not appear that a disproportionate number of accidents occurred in the HOV lanes. However, there was a minor problem associated with the dropping of the southbound HOV lane at its output terminal. The accident rate in this vicinity doubled after the lane was in operation, although the rate was still very low in this section.

Pre-collision events and accident types are closely related characteristics. Exact project comparisons are difficult to make in this area because of coding differences. On the Santa Monica Freeway, the percentage of stopped and slowing/stopping accidents increased in both peak periods. This suggests the increased shock wave-related accidents, such as rearend accidents. The same percentage trend was observed on Route 101 despite the fact that congestion was relieved through increased capacity and reduced vehicular demand decreased. The only apparent explanation for this occurrence is that weaving to and from the HOV lane produced shock waves which led to rearend accidents.

A different trend occurred on I-95 as the relative frequency of accidents involving stopped traffic declined. In addition, the relative frequency of sideswipe accidents increased while the percentage of rear-end accidents declined. This combination suggests there was less of a problem with accidents related to the actual weaving. Thus, the I-95 HOV lane appears to have had a higher relative frequency of accidents related to gaining access to or egress from the HOV lane by weaving across the general lanes than the other projects in which relative speed or congestion-related problems predominated.

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2. Data on accident location were limited. In the case of the California projects "left lane" is a codeable item in the accident report. However, many officers were confused as to whether the HOV lane or left general lane should be designated as the "left lane;" thus the data are not totally reliable.

3. A manual analysis of accident records on the Santa Monica Freeway performed by the California Department of Transportation indicated that 60 percent of all interior lane accidents occurred in the left lane previously. After the HOV operation was terminated, only 6 percent of the accidents occurred in this lane. This appears to be a result of high speed vehicles of the HOV lane merging into the adjacent low speed general lane creating shock waves leading to rearend accidents.

SAFETY CHARACTERISTICS

Causative Factors Influencing Safety

Clearly the most evident causative factor is the establishment of the HOV lane by either adding a lane or "taking" a lane away from general traffic. The added HOV lanes on I-95 provided additional capacity and greatly decreased the peak period congestion and the associated accidents. When the HOV lanes were taken from general use on the Santa Monica Freeway, peak period congestion increased substantially and the accident rate increased accordingly. The short duration of this project made it impossible to evaluate the longer term, steady state conditions, but the accident rate was declining toward the end of the project. Some improvements in traffic flow were due to decreasing the input rates at metered ramps on the freeway.

The Route 101 project where the HOV lanes were added to the facility did not experience improved accident rates. The Route 101 project was unique in that the AM peak experienced no significant change in accident rate, while the PM peak accident rate increased substantially. In comparison with the other "added HOV lane" projects, overall traffic operations were generally superior on Route 101 with average speeds of 48 mph (77 kph) in the general lanes, compared to 42 mph (68 kph) on I-95 and only 14 mph (22 kph) on the Moanalua Freeway. This seems to contradict the relationship between the accident rate and level of service. Detailed investigation of this situation by the California Department of Transportation[4] also failed to determine any conclusive reasons for the increased accident rate, but they suggested that the reasons were most likely: 1) changes in congestion patterns related only indirectly to the HOV lane; and 2) HOV lane-related shock waves in the general traffic stream caused by weaving of vehicles entering and exiting the HOV lane. A more detailed investigation of the inter-relationships of the accident characteristics tends to support the second observation. The frequency of accidents involving rearends of slowing/stopping vehicles shifted substantially from the left lane to the interior lanes.

The initial accident rates on all projects except the Moanalua Freeway were higher than the steady state condition. Confusion over the new system and an aggressive desire to use the lane are the probable reasons for this. Interim operations of partial HOV lanes with temporary closures, such as barrels used on I-95 to close the lane downstream can produce bottlenecks and accidents.

Although the overall operation and accident rates improved significantly on I-95, the elimination of median refuge areas and resulting small distances to the concrete barrier wall were factors in several severe accidents. These generally did not occur during HOV operations, but are related to the manner of implementation of the HOV lane. Motorists, out of necessity or by error, used the median lane for pulling over and stopping on the facility. A motorist traveling in the median lane or left interior lanes may not be able when his vehicle becomes disabled to pull off the facility because of the congestion or other circumstances. Some motorists who stopped in the left lane during off-peak hours claimed they thought the median lane was a shoulder. A number of factors contributed to this illusion including: 1) a solid white line separating the HOV lane from the general lanes, 2) no signing designating the off-peak use of the median lane, 3) differences in the concrete's color and texture between the HOV lane and the general lanes, and 4) underutilization of the median lane by motorists. Several months after the opening of the

4. "Evaluation Report of the Peak Period High Occupancy Vehicle Lanes on Route 101 Between the Richardson Bay Bridge and Greenbrae in Marin County," California Department of Transportation, District 4, March, 1977.

HOV lane, the Florida Department of Transportation changed the solid line to a broken line of double width and placed on median sign supports signs reading "NO STOPPING THIS LANE" with an arrow directed at the left lane. The use of skipped lines and supplemental signing can alleviate this problem.

The only other geometric design factor having a direct relation to HOV lanes and safety was the HOV lane drop on I-95 and a general lane drop (to enable HOV and general traffic to merge into one lane) on the Moanalua Freeway. Neither of these lane drops were extremely serious problems.

High differential speeds between continuously accessible HOV lanes and adjacent general lanes, coupled with merging into and out of the HOV lane appeared to be the most significant cause of accidents in general. Weaving across several general lanes to gain access to or leave the HOV lane was a secondary factor. Incidents blocking any lane, but particularly the HOV lane, were a significant cause of accidents, although it was not possible to quantify the degree of this problem.

The major effect of HOV enforcement on safety is through the shock-waves associated with escorting violators across the general lanes to the right shoulder and with the gawking effect occurring as the citation is issued. Again, it was not possible to quantify this aspect but all project personnel contacted expressed this concern.

Difficult Maneuvers and Potential Safety Problems

An HOV priority treatment might be expected to generate potential safety problems on a transportation facility. Project personnel for the concurrent flow HOV facility projects identified several possible difficult maneuvers and safety problems that could be associated with this type of treatment. Such safety problems include:

- Continuous access/egress to a restricted median lane could be expected to increase weaving on the freeway as HOVs cross the freeway to enter and exit the HOV lane.
- Where no median refuge area exists, it may be extremely difficult for disabled vehicles to get off the roadway, if they are in the left lanes. While this is true in general, implementation of HOV lanes where a left shoulder once existed can create this problem. Additionally, the close proximity of the median wall can lead to multiple vehicle accidents if a car strikes the wall and is deflected back into the traffic lanes. Conversely, a disabled vehicle in an interior lane would have to weave across a high speed HOV lane to access a median refuge area.
- Where HOV lanes are terminated by dropping either the HOV lane or a general lane, a forced merging condition is created. This is a hazardous condition, particularly at locations having high speed differential between the HOV lane and general travel lanes.
- A large speed differential between the HOV lane and adjacent general lanes cause slower vehicles to merge into a high speed HOV lane or faster vehicles in the HOV lane having to decelerate rapidly to merge into the general lane. Either action could result in side-swipe or rearend accidents.
- Where the HOV lane is created by the taking of a general lane, large displacement of general traffic occurs from that lane to the remaining lanes. This can create a dispropor-

tionate imbalance in lane distribution and can create extensive congestion with stop and go conditions in the remaining general traffic lanes.

- Enforcement can adversely affect safety if violators have to be escorted to the right shoulder, thus creating shock waves as they weave. Also, the officer's presence (either monitoring or issuing a ticket) can cause gawking which creates a bottleneck and reduces traffic flow.

- Some motorists may be confused about the proper use of the median lane in the off-peak periods. If a motorist incorrectly believes it to be a refuge area, a safety problem occurs if he stops his vehicle in the lane which is being used by general traffic. This problem occurs only where there is no median refuge area.

RECOMMENDATIONS

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. General recommendations on safety of HOV priority treatments are presented on page 7. Specific recommendations that may improve the safety of a concurrent-flow HOV lane on a freeway include the following:

- It is strongly urged that concurrent HOV lanes be added to the facility rather than "taken" from existing general use, particularly on heavily congested urban freeways. Indeed, considering the right-of-way requirements and factors such as the resulting lack of adequate emergency refuge areas, it may be preferable to use other HOV priority techniques.

- The general recommendation on provision of median shoulders is emphatically reiterated for this priority treatment. If right-of-way constraints require compromising some geometric design standards, the provision of emergency refuge areas in the median should take precedence over such factors as lane width. However, lane width should not be reduced less than 11 feet (3.3 m).

- If the HOV lane is a continuously accessible lane, the lane demarcation between the HOV lane and general lane should be a conspicuous white line. The MUTCD presently allows a solid line for this purpose. However, this can be interpreted as an edge line, and its use for the HOV lane is not recommended except in areas where weaving is discouraged for other reasons and possibly for bus-only lanes or 24-hour HOV lane operations. Where solid lines are used, there should be a left shoulder and/or clear indication that the HOV lane is a traveled lane and no stopping is allowed. On the other hand, some special treatment of the HOV lane line is appropriate and may be accomplished by using wider skipped lines or by using delineators.

- The ideal input treatment to a concurrent HOV lane is an added lane on the left. This avoids merging problems as HOVs simply shift into the new lane. If it is necessary to take an existing lane, the transition point should be at a low volume location to minimize merging problems. If a general lane is to be dropped entirely to create the HOV lane, a right-hand lane should be dropped, preferrably at a normally high exit demand location, and shift general traffic to the right by one lane.

- The ideal exit terminal treatment is a continous lane, and/or, if demand is sufficient, a left-hand exit ramp. If any lane must be dropped at the end of the HOV lane section, it is preferable to drop a right lane at a high exit demand location and shift all lanes to the right. The HOV lane would then assume general-use status. If the only option is to drop the HOV lane, an adequate shoulder should be provided for vehicles having difficulty merging to use as a recovery area.

- Signalization is generally not necessary on concurrent lane treatments. In locations where sight distances are limited, consideration should be given to using either lane control signals (arrows and "X's") or warning beacons. These could be centrally operated by police officers or by an automated traffic surveillance and control system. These devices would warn motorists of stalled traffic ahead in the HOV lane or other lanes.

- The speed differential between the HOV lane and general-use lanes should be controlled if necessary and possible. This may be accomplished by metering general lane traffic at on-ramps, using variable speed control signing on the HOV lane, or a combination of both. Until additional research can be conducted to quantify an optimum speed differential, it is recommended that a 15 mph (25 kph) maximum speed differential not be exceeded. On each of the concurrent flow projects studied, the average speed differential did not exceed 15 mph (25 kph).

- If conventional enforcement techniques are used, the officers should make every effort to minimize disruption to traffic. On-freeway (stationary) monitoring is effective in reducing violations but it can also slow traffic. Weaving across the freeway to the right shoulder is particularly disruptive and, if possible, should be avoided. Ideally, citations should be issued out of the motorists' sight to eliminate "rubber-necking." The visibility of issuing citations on the right shoulder has minimal effect since passersbys cannot relate the specific violation to the enforcement activity.

CHAPTER FOUR

CONTRAFLOW HOV LANE ON FREEWAY

DETAILED DESCRIPTION

The common application of contraflow HOV lanes is to assign the inside (median) lane in the opposing (off-peak) direction to a special class of vehicles. The contraflow lane is separated from the other travel lanes by insertable plastic posts. If sufficient capacity remains in the off-peak direction, an additional lane can be taken for use as a buffer lane. The vehicles qualified to use the contraflow lane are usually buses, although one project (the Long Island Expressway in New York City) also allows taxis with passengers to use the contraflow lane. Thus, the contraflow lane treatment makes use of surplus capacity in the off-peak direction, thereby increasing the vehicle and person moving capacity in the peak direction by allowing the buses to bypass congested locations.

In practice, most contraflow lane projects operate only during one peak period, because there is either an upstream bottleneck (e.g. tunnel) in the one peak or because other special conditions prevail. Following the peak period, the safety posts are removed, any special traffic control devices are returned to "normal" and the lane is available for general use in the normal direction.

Typically, the contraflow lane section begins or ends upstream of a major bottleneck location such as a bridge, tunnel or toll facility. Buses (and other vehicles if permitted[1]) enter the lane via a median cross-over or by a special ramp and proceed in the peak direction against the flow of off-peak direction general traffic, thereby bypassing congested traffic in the peak direction. The output terminal depends on the site and may be a cross-over merging with the general freeway or it may terminate at a bridge, tunnel or toll facility (where the buses can use special lanes or toll booths to gain an additional time advantage). Contraflow lanes have been combined with concurrent flow carpool lanes as on Route 101 in Marin County, California.

Most contraflow lane projects in existence have been implemented on existing freeways and the lane(s) involved were existing. Thus, only cross-over's and/or special terminal treatments have been constructed. In Houston, more extensive construction is being planned for a new contraflow lane project which will be the first to have an intermediate access/egress point and which will operate during both peak periods.

Three contraflow bus lane projects were investigated in detail as part of this research. Project descriptions are given below and in Figures 9 to 11.

- <u>I-495, Hudson County, New Jersey (Figure 9).</u>
  This is a six lane urban freeway which serves as the approach to the Lincoln Tunnel into Manhattan, NYC. In December, 1970, the left lane of the outbound (WB) roadway was designated as a contraflow bus lane during the AM peak period. The 2.5 mile (4 km)

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1. Hereinafter, reference will be made only to buses in the contraflow lane although in some cases other classes of vehicles (primarily chaffeur-licensed and operated) are also permitted to use the contraflow lanes.

contraflow lane is fed by a special ramp in the New Jersey Turnpike Interchange and terminates in the tunnel toll plaza, where buses use separate toll booths. The priority operating period is 7:30 - 9:30 AM, weekdays. Safety posts are installed along the mainline and overhead lane-use control signs indicate the proper lane use.

- Long Island Expressway, New York City, New York (Figure 10)
  The physical description of the I-495 project applies similarly to this project. This HOV project was opened in October, 1971, but in September, 1977, taxies with passengers were also allowed to use the contraflow lane. There were no data available to fully evaluate this change in operating strategy, however. The operating hours are 7 - 9:45 AM, weekdays. Buses enter the contraflow lane via a median crossover and exit two miles (3.2 km) downstream at the Queens-Midtown Tunnel toll plaza.

- Route 101, Marin County, California (Figure 11)
  This is an eight lane, inter-regional freeway connecting San Francisco with suburban residential areas in southern Marin County. The priority section begins at the north end of the Golden Gate Bridge and extends for four miles (6.4 km). In September, 1972, the two left lanes of the inbound (SB) roadway were designated as a contraflow lane and buffer lane for exclusive use by buses in the outbound direction (NB). The operating time period is 4 - 7 PM weekdays, and the priority treatment project operates only in the PM peak. Safety posts as well as two-way traffic signs are installed in the buffer lane. The input is at the Golden Gate Bridge and the output feeds into a concurrent HOV lane for buses and carpools via a median crossover. (See Chapter 3)

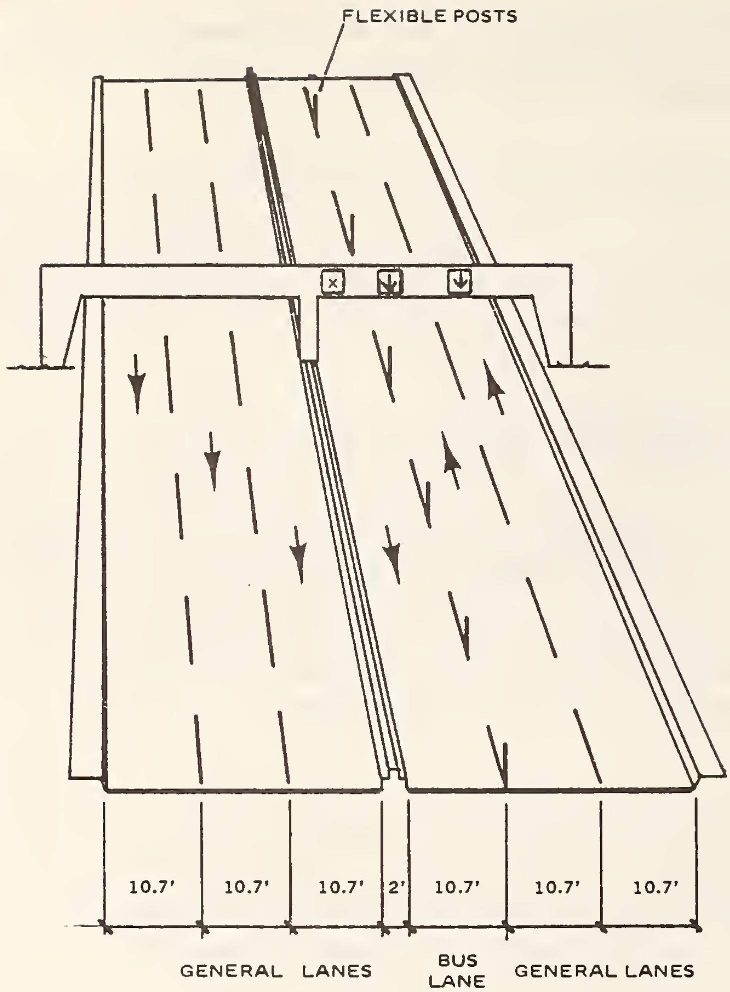
Tables 2 and 3 present the national standards applicable to HOV priority treatments on freeways. Since contraflow lanes are in effect reversible lanes, design and traffic control standards for reversible lanes are also applicable.[2] None of these projects is in conformance with MUTCD signing requirements for HOV lanes, and the project managers believe that these requirements should not be specified for contraflow HOV lanes. Nevertheless, the discussions below are relative to current MUTCD standards.

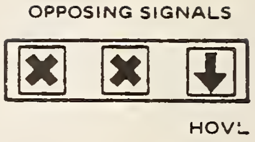
On the Route 101 project, the major geometric deficiencies are the lack of right shoulders in certain locations and the median refuge area not being accessible to traffic in both directions. These deficiencies to a great extent, are due to the mountainous terrain which restricts additional widening. The restricted lane signs and HOV lane delineation are non-standard and the diamond symbol is not used. Route 101 does not have lane-use control signals, but the buffer lane provides a place to station removable "TWO-WAY TRAFFIC" and "ONCOMING TRAFFIC" signs.

The I-495 project is deficient in almost every design category because the freeway is over 30 years old. Upgrading would be prohibitively expensive since much of the section passes through a cut in solid granite. To compensate for the deficiencies, speed limits have been reduced to 35 mph (56 kph) in the contraflow and opposing direction lanes. The project uses lane-use control signals, but the HOV lane delineation is non-standard. The restricted lane diamond symbol is not used.

The Long Island Expressway is also an older facility, but the design is superior to the I-495 project. Still there are no left shoulders or median refuge areas and there are no right shoulders on half of the section which is on a viaduct. The speed limit has also been reduced. The project uses lane-use

2. AASHTO, op. cit.





METRIC CONVERSION
1 in = 2.54 cm
1 ft = 0.3 m
1 m = 1.61 km

AASHTO DESIGN FACTORS

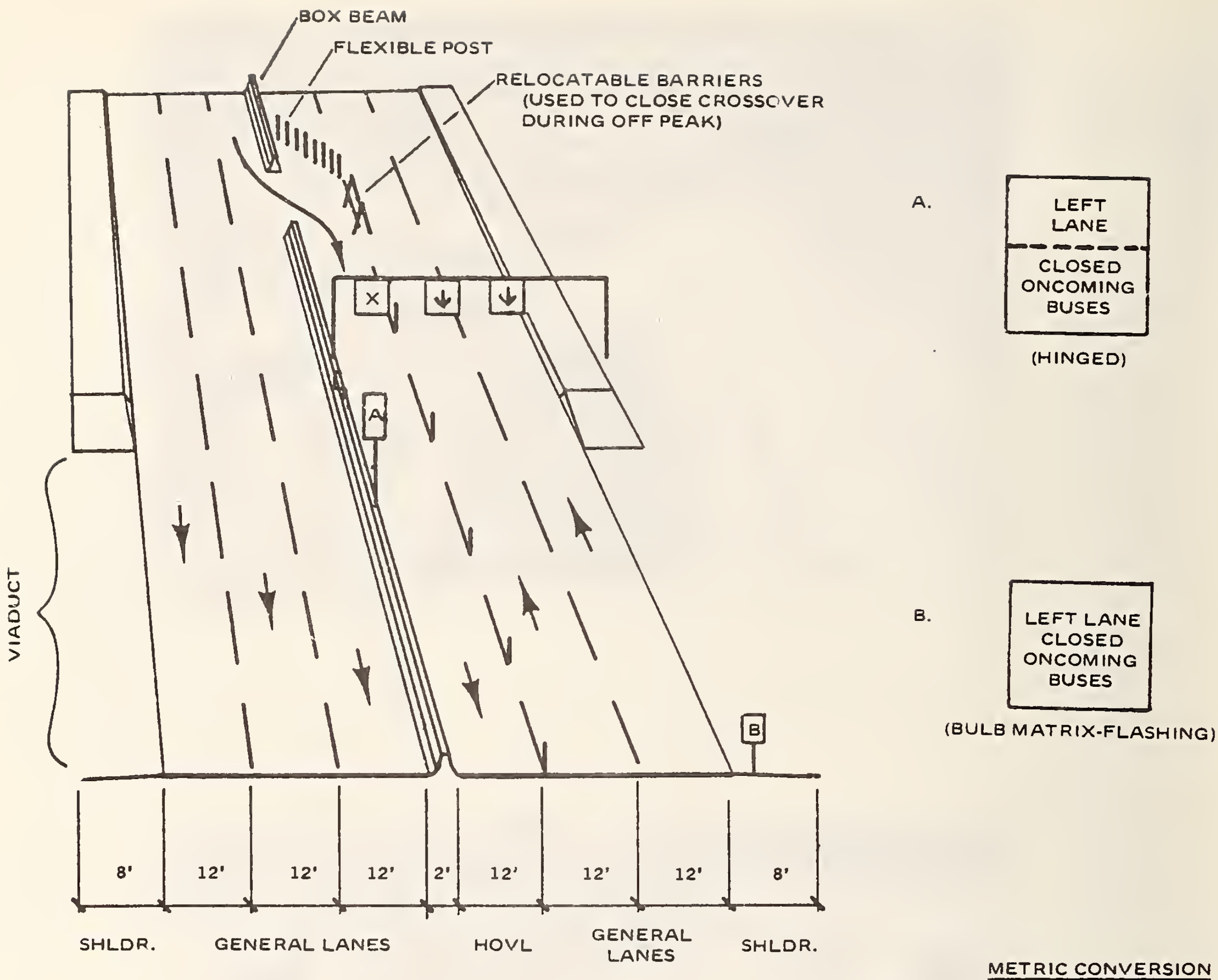
ALIGNMENT: linear except for spiral at toll plaza
VERTICAL SIGHT DISTANCE: limited by low overpasses
POSTED SPEED: 55 mph/inbound; 35 mph HOVL and outbound
ROADSIDE HAZARDS: limited lateral clearance
OTHER HAZARDS: lack of shoulders and median refuge area

MUTCD DESIGN FACTORS

LANE-USE CONTROL SIGNALS: red x and green arrow
ADVANCED WARNING SIGNS: non-standard
RESTRICTED LANE SIGNS: none
END OF HOVL SIGNS: none
DIAMOND SYMBOL: none
HOVL DELINEATION: 4" white skip line with flexible posts (40')

INTERSTATE 495, HUDSON COUNTY, NEW JERSEY
FIGURE 9

INTERSTATE 495, HUDSON COUNTY, NEW JERSEY
FIGURE 9 (CONT.)



METRIC CONVERSION
1 in = 2.54 cm
1 ft = 0.3 m
1 m = 1.61 km

AASHTO DESIGN FACTORS

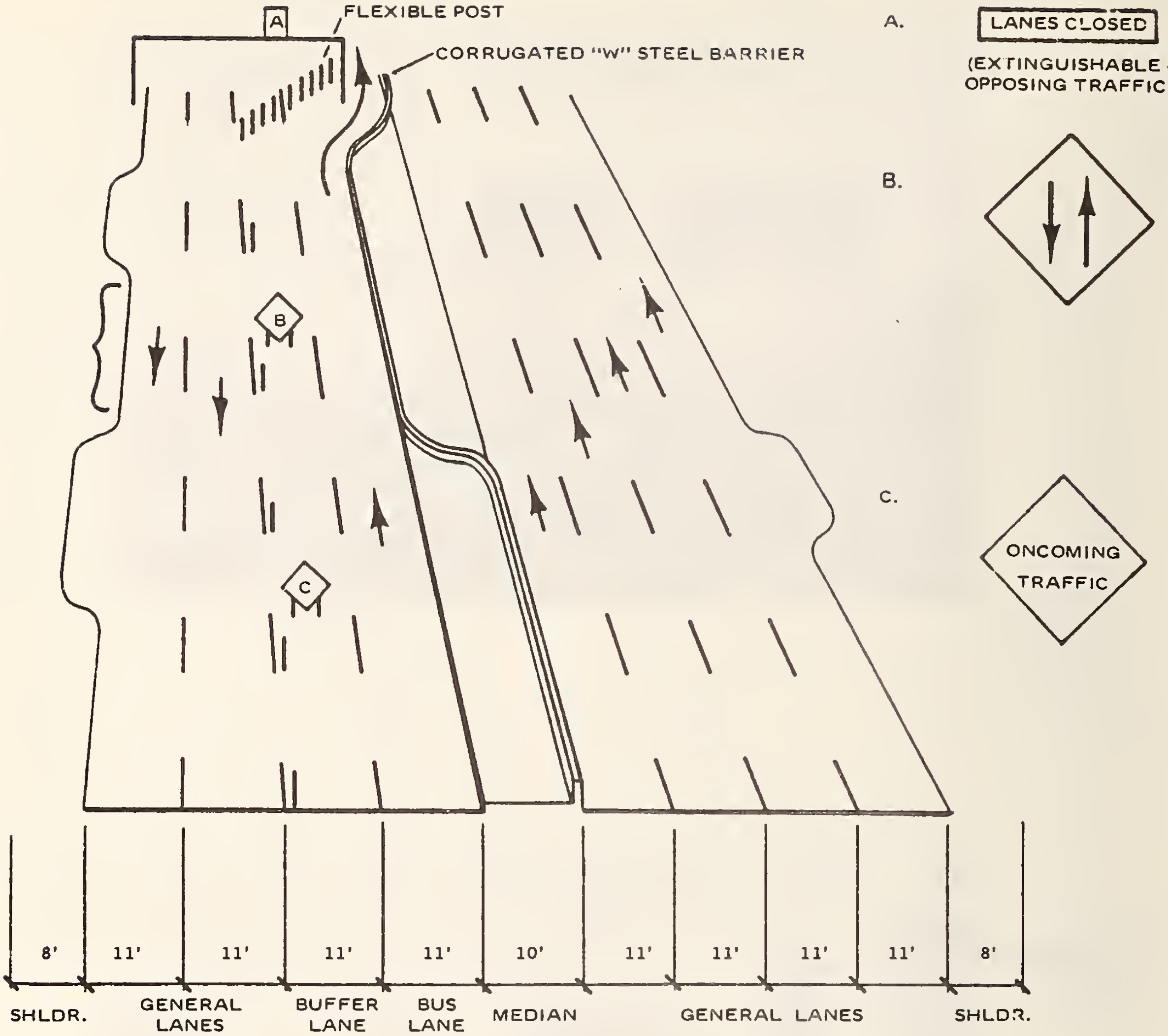
ALIGNMENT: linear
VERTICAL SIGHT DISTANCE: good
POSTED SPEED: 40-50 mph inbound; 35 mph HOVL and outbound
ROADSIDE HAZARDS: none
OTHER HAZARDS: no shoulder over viaduct

MUTCD DESIGN FACTORS

LANE-USE CONTROL SIGNALS: red 'x' and green arrows
ADVANCED WARNING SIGNS: non-standard
RESTRICTED LANE SIGNS: non-standard
END OF HOVL SIGNS: none
DIAMOND SYMBOL: none
HOVL DELINEATION: double 4" yellow line and flexible posts (40' intervals)

LONG ISLAND EXPRESSWAY, NEW YORK CITY, NEW YORK
FIGURE 10

LONG ISLAND EXPRESSWAY, NEW YORK CITY, NEW YORK
FIGURE 10 (CONT.)



METRIC CONVERSION
1 in = 2.54 cm
1 ft = 0.3 m
1 m = 1.61 km

AASHTO DESIGN FACTORS

ALIGNMENT: hilly topography
VERTICAL SIGHT DISTANCE: minor deficiencies, tunnel
POSTED SPEED: 55 mph general, 40 mph HOVL
ROADSIDE HAZARDS: hillsides
OTHER HAZARDS: limited shoulders

MUTCD DESIGN FACTORS

LANE-USE CONTROL SIGNALS: blank-out "lane(s) closed"
ADVANCED WARNING SIGNS: non-standard
RESTRICTED LANE SIGNS: non-standard
END OF HOVL SIGNS: none
DIAMOND SYMBOL: none
HOVL DELINEATION: 4" white skip line, flexible posts in buffer lane

ROUTE 101 (CONTRAFLOW LANE), MARIN COUNTY, CALIFORNIA
FIGURE 11

ROUTE 101 (CONTRAFLOW LANE), MARIN COUNTY, CALIFORNIA
FIGURE 11 (CONT.)

control signals, and the HOV lane delineation is standard having been installed in July, 1977. The restricted lane sign is non-standard and the diamond symbol is not used.

All projects employ "bus lane rules" to further enhance safety. Speed limits for buses have been reduced and bus drivers are required to maintain minimum headways of 200 feet (61 m), and use four-way flashers and headlights to alert oncoming traffic. The use of yellow plastic safety posts on Route 101 and I-495 is technically in violation of a recent change in the MUTCD.[3]

The contraflow lane on each project is established manually. As the crew progresses along the freeway in the direction of the prevailing traffic, poles are placed in pre-drilled holes and signs and signals are changed to the appropriate display. Removing the contraflow lane is accomplished in a similar manner, but in the opposite direction so the contraflow lane reverts to normal use behind the crew.

Enforcement of contraflow lanes is relatively simple since they are largely self enforcing. Police officers are often stationed at one of the terminals of the contraflow section, and violators can be waved off (at the input) or apprehended (at the output). Even when this capability is not present, autos are so conspicuous that there remains a high probability of detection through a standard enforcement patrol.

OPERATING CHARACTERISTICS

The extent of the safety impact for an HOV project is dependent, in part, on the operational effectiveness of the project. The major impact of an HOV priority treatment occurs during peak periods when congestion is high and most of the traffic stream is composed of daily commuters. The operational results of each project are displayed in Table 14. Only one peak period is presented—that which experienced the most serious safety problem, or for the period which had the most data. From Table 14, several of the more significant results are:

- Vehicular volumes increased on both projects for which there were "before" data, indicating that the buses removed from the peak direction roadway were replaced by autos to some extent. At the same time the contraflow operation opened on Route 101, a major improvement was implemented in the general lanes which produced additional operational improvements for general traffic. The reduction in capacity in the off-peak directions had minimal operational effects on the three facilities except on accidents.

- The volume of buses using the contraflow lanes is naturally a function of transit demand. The number of buses varied from 125 on Route 101 to 818 on I-495 in New Jersey. These do not represent large increases over previously existing bus volumes, so the contraflow lanes did not generate large modal shifts; however, the levels of service were increased on all projects.

- The HOV lane utilization illustrates the efficiency of the operation. On Route 101, the HOV lane carries 19 percent of the persons in the peak direction in one percent of the vehicles. On I-495, the HOV lane carries 65 percent of the persons in 6 percent of the vehicles. On the Long Island Expressway, the HOV lane carries 47 percent of the persons in 3 percent of the vehicles. Total passenger throughput (all lanes) increased on the two projects which had before data.

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3. FHWA, "Official Rulings on Requests for Interpretations, Changes and Experimentations," MUTCD Volume VIII, December, 1977, M-43 (c).

TABLE 14

OPERATING CHARACTERISTICS

(Contraflow HOV Lane on Freeway)

		PROJECT/CONDITION				
		I-495		Long Island Expressway[a]	Route 101	
VARIABLE	UNIT	Before	Bus-Only	Bus-Only	Before	Bus-Only
Critical Peak Period	—	7:30 - 9:30 AM	7:30 - 9:30 AM	7 - 9:45 AM	4 - 7 PM	4 - 7 PM
Length of HOV Lane	Miles	—	2.5	2.0	—	4.0
Total Peak Directional Lanes	Lanes	3	4	4	4	5
Number of HOV Lanes	Lanes	—	1	1	—	1
Volume - All Lanes	Vehicles	12,792	12,843	9,607	15,392	16,608[b]
Volume - HOV Lanes	Vehicles	—	818	307	—	125
Volume - HOV Lanes (bus only)	Vehicles	763[c]	818	300	120[c]	125
HOV Lanes/Total Volume	%	—	6.4	3.2	—	0.8
Auto Occupancy - All Lanes	PPV	1.60	1.54	1.35	1.28	1.30
Auto Occupancy - HOV Lanes	PPV	—	—	—	—	—
Person Throughput - All Lanes	Persons	51,296	52,875	23,662	24,348	26,428
Person Throughput - HOV Lanes	Persons	—	34,356	11,107	—	5,000
HOV Lanes/Total Throughput	%	—	65.0	46.9	—	18.9
Speed - General Lanes	MPH	10.0	17.2	6.7	24.0	40.0
Speed - HOV Lanes	MPH	—	22.4	34.3	—	36.9[d]
Travel Time - General Lanes	Minutes	14.7	8.7	17.9	10.0	6.0
Travel Time - HOV Lanes	Minutes	—	6.7	3.5	—	6.5
Violation Rate	%	—	0.0	2.3	—	0.0

Metric Conversion

1 mile = 1.61 kilometers

a. No before data available.

b. Freeway improvements resulted in increased auto volumes in the after condition. These data exclude the effects of the concurrent HOV lane project added in the north end later.

c. Buses in general lanes in before period.

d. Lower contraflow lane speed due to uphill grade and improvements in general lanes.

- The travel speeds in the HOV lane on the projects ranged between 22 mph (35 kph) on I-495 to 37 mph (59 kph) on Route 101. These speeds, while relatively low for a freeway HOV lane, represent an improvement over the before travel speeds. The differential in travel speeds between the HOV lane and general travel lanes favored the HOV lane by 5 mph (8 kph) on I-495 and 28 mph (45 kph) on the Long Island Expressway. The differential in travel speeds favored the general lanes by 3 mph (5 kph) on Route 101, as a result of operational improvements in the general lanes and the removal of the buses from the traffic stream.

- Because of the higher travel speeds in the HOV lane, persons traveling in the HOV lane experience travel time savings over general lane travel. For the I-495 project, the travel time savings is two minutes over the 2.5 miles (4 km). For the Long Island Expressway project, the travel time savings is 14.4 minutes over the 2.0 miles (3.2 km). On the Route 101 project, because of the slightly higher travel speeds in the general lanes, the travel time loss in the HOV lane travel is only 0.5 minute over the 4.0 miles (6.4 km).

- On each project, the violation rate (percentage of HOV lane volume that did not qualify) approaches zero percent.

ACCIDENT ANALYSIS

The accident data on the three contraflow HOV projects that were studied in detail, is analyzed by 1) peak period accident rates, 2) daily accident rates, and 3) accident characteristics. It is also pertinent to compare the 24-hour accident rates on the HOV facilities with some control base for which data are generally available. Accident rates were computed in terms of accidents per million vehicle-miles (MVM) and million person-miles (MPM) of travel. These rates automatically take into consideration the effects of differing stage lengths and demand levels. Accident rates were tested with the "t" statistic to determine the statistical significance of any apparent change.

For the purposes of this report, the "after" condition on all projects are considered as bus-only contraflow operations. In September, 1977, taxis were allowed to use the contraflow lane on the Long Island Expressway; however, there are no data available to evaluate this change.

The accident rate analyses on both New York area projects cannot be reported with great confidence. On I-495 the data were obtained from computerized records of the New Jersey Department of Transportation. Since this facility is under the jurisdiction of three separate agencies, it is possible that all accidents are not included. On the Long Island Expressway, MVM computations were based on limited volume data, and may not be totally reliable.

Peak Period Accident Rates

The contraflow HOV lane priority treatment clearly has its primary influence during the peak periods when traffic congestion is the greatest. The peak period accident rates are presented in Table 15 for the peak direction and off-peak direction. The results are summarized for accident rates based on both MVM and MPM. From the available data, the following general conclusions can be developed:

- The peak period accident rates in the peak direction ranged from a low of 2.2 accidents/MVM (1.3 accidents/MVK) on the Long Island Expressway to a high of 3.1 accidents/MVM (1.9 accidents/MVK) on I-495.

- The peak period accident rates in the off-peak direction ranged from a low of 3.6 accidents/MVM (2.2 accidents/MVK) on I-495 to a high of 5.4 accidents/MVM (3.3 accidents/MVK) on the Long Island Expressway.

- On all three projects during HOV operations, the accident rates were higher in the off-peak direction than in the peak direction. These differences were statistically significant except on I-495. On all projects, the off-peak direction "peak period" was approximately two hours longer than the time period analyzed for the peak direction. This was done to include the times the contraflow lanes were being set up and returned to general use.

- Only Route 101 had before data enabling an analysis of the impact on accident rates by the contraflow lane. On this project the accident rates did not change significantly in the peak direction (including contraflow lane traffic) from the before to the after condition. In the off-peak direction where capacity was reduced by 50 percent (from four lanes to two), the MVM accident rate increased 35 percent, which was statistically significant. The combined accident rate for the peak period operation in both directions increased from 2.5 to 2.9 accidents/MVM (1.5 to 1.8 accidents/MVK), but this was not statistically significant.

- By converting the accident rates from vehicle-miles to person-miles, the rates were lower; however, the relationships stated above did not change.

The Route 101 data in Table 15 covered the entire period of contraflow operations from September, 1972 through December, 1976 (the latest data available). This time period overlaps the period of operation (beginning December, 1974) of a concurrent HOV lane project immediately north of the contraflow lane section (See Chapter 3). A separate analysis was performed for the period of contraflow operation prior to the inception of the concurrent lane project. The results yielded somewhat different accident rates (per MVM) as shown in Table 16. The results of this table indicate that the peak period accident rates under contraflow lane operation were significantly higher for the initial period (September, 1972 to December, 1974) than in the latter period (December, 1974 to December, 1976). In fact, the peak period accident rates for the peak period direction and combined directions were lower, but not significantly, in the December, 1974 to December, 1976 period than in the before period.

Information on contraflow lane accidents (i.e. bus accidents) was obtained from project personnel. The results are presented in Table 17. The bus accident rates ranged from a low of 1.6 accidents/MVM (1.0 accidents/MVK) on Route 101 to a high of 8.6 accidents/MVM (5.3 accidents/MVK) on I-495, where geometric characteristics are very much inferior to the other projects. These differences were not statistically significant because of the low number of bus-miles.

Daily Accident Rates

Accident rates for the total 24-hour, seven days a week in both directions, are given in Table 18 Additionally for each project, the daily accident rates were compared to the accident rates for a control facility or facilities. From the available data, the following general conclusins can be developed:

- The daily accident rate ranges from a low of 2.1 accidents/MVM (1.3 accidents/MVK) on Route 101 to a high of 3.9 accidents/MVM (2.4 accidents/MVK) on the Long Island

TABLE 15

PEAK PERIOD FACILITY ACCIDENT RATES
(Contraflow HOV Lane on Freeway)

PROJECT \ VARIABLE	TIME PERIOD	PEAK PERIOD DIRECTION			OFF-PEAK PERIOD DIRECTION[b]	
		Number of Accidents	Accident Rate[a] (acc/mvm)	Accident Rate[a] (acc/mpm)	Number of Accidents	Accident Rate[a] (acc/mvm)
Interstate 495[c]						
• Bus-Only	1975/76	51	3.1	0.8	32	3.6
Long Island Expressway[c]						
• Bus-Only	1972-75	42	2.1	0.9	57	5.4
Route 101						
• Before	1/71 - 9/72	58	2.2	1.4	56	2.9
• Bus-Only	10/72 - 12/76	148	2.2 ns	1.2 ns	194	3.8 *

a. Statistical significance of accident rates compared to the before condition:
ns indicates difference is not significant.
* indicates a 95 percent level of significance.
**indicates a 99 percent level of significance.
b. Contraflow lane bus accidents are included in the off-peak direction accident rates.
c. No before data available.

Metric Conversion

1 mile = 1.61 kilometers
1 acc/mvm = 0.62 acc/mvk

TABLE 16

PEAK PERIOD FACILITY ACCIDENT RATES ON ROUTE 101

CONDITION \ VARIABLE	TIME PERIOD	PEAK PERIOD DIRECTION		OFF-PEAK PERIOD DIRECTION		Combined Accident Rate[a]
		Number of Accidents	Accident Rate[a] (acc/mvm)	Number of Accidents	Accident Rate[a] (acc/mvm)	(acc/mvm)
Before condition	1/71 - 9/72	58	2.2	56	2.8	2.5
After Condition (without concurrent flow HOV lane)	10/72 - 12/74	98	2.7 ns	121	4.5 **	3.5 **
After Condition (with concurrent flow HOV lane)	12/74 - 12/76	50	1.61ns	73	3.1 ns	2.3 ns

a. Statistical significance of accident rates compared to the before condition:
ns indicates difference is not significant
* indicates a 95 percent level of significance
**indicates a 99 percent level of significance

Metric Conversion

1 mile = 1.61 kilometers
1 acc/mvm = 0.62 acc/ mvk

TABLE 17

PEAK PERIOD BUS ACCIDENT RATES
(Contraflow HOV Lane on Freeway)

PROJECT \ VARIABLE	TIME PERIOD	PEAK PERIOD	NUMBER OF ACCIDENTS	ACCIDENT RATE (acc/mvm)
Interstate 495	1975-77	AM	12	8.6
Long Island Expressway	1971-75	AM	3	4.9
Route 101	1972-76	PM	1	1.7

Metric Conversion

1 acc/mvm = 0.62 acc/mvk

TABLE 18

DAILY FACILITY AND CONTROL ACCIDENT RATES
(Contraflow HOV Lane on Freeway)

VARIABLE / PROJECT	TIME PERIOD	HOV FACILITY					
		Inbound Direction		Outbound Direction		Total	Control Accident Rate[a,c] (acc/mvm)
		Number of Accidents	Accident Rate[a] (acc/mvm)	Number of Accidents	Accident Rate[a] (acc/mvm)	Accident Rate[a] (acc/mvm)	
Interstate 495[b]							
• Bus-Only	75/76	276	2.8	298	3.0	2.9	2.0
Long Island Expressway[b]							
• Bus-Only	72-75	437	3.7	400	4.0	3.9	2.0
Route 101							
• Before	1/71 - 9/72	180	1.8	151	1.5	1.7	1.8
• Bus-Only	10/72 - 12/76	657	2.4 **	464	1.7 ns	2.1 **	1.3 **

a. Statistical significance of accident rates compared to the before condition:
ns indicates difference is not significant.
* indicates a 95 percent level of significance.
** indicates a 99 percent level of significance.
b. No before data available.
c. Control Facilities: Interstate 495 and Long Island Expressway - total NYC accidents (1975-1976).
Route 101 - all freeways in Caltrans District 4.

Metric Conversion

1 mile = 1.61 kilometers
1 acc/mvm = 0.62 acc/mvk

TABLE 19

INJURY ACCIDENT RATES (PEAK PERIOD)
(Contraflow HOV Lane on Freeway)

VARIABLE / PROJECT	TIME PERIOD	PEAK PERIOD DIRECTION		OFF-PEAK PERIOD DIRECTION	
		Number of Accidents	Accident Rate[a] (acc/mvm)	Number of Accidents	Accident Rate[a] (acc/mvm)
Interstate 495[b]					
• Bus-Only	75-76	23	1.5	11	1.1
Long Island Expressway[b]					
• Bus-Only	72-75	11	0.6	19	1.7
Route 101					
• Before	1/71 - 9/72	17	0.6	12	0.7
• Bus-Only	10/72 - 12/76	36	1.1 *	55	0.5 ns

a. Statistical significance of accident rates compared to the before condition:
ns indicates difference is not significant.
* indicates a 95 percent level of significance.
** indicates a 99 percent level of significance.
b. No before data available.

Metric Conversion

1 mile = 1.61 kilometers
1 acc/mvm = 0.62 acc/mvk

Expressway.

- Only Route 101 had before data enabling an analysis of the impact on the accident rate by the contraflow lane. On this project, the daily accident rate experienced a statistically significant increase with the introduction of the contraflow lane. The "before" accident rate was 1.7 accidents/MVM (1.1 accidents/MVK) and the "after" accident rate was 2.1 accidents/MVM (1.3 accidents/MVK).
- On Route 101, the control accident rate (all freeways in California Department of Transportation District 4) experienced a decreasing trend, whereas the Route 101 accident rate increased.

Accident Characteristics

An obvious concern with the contraflow treatment is the potential for serious accidents involving head-on or side-swipe collisions. Table 19 presents the injury-producing accident rates for each project. From this table, the following general conclusions can be developed:

- The peak-period injury accident rate for the off-peak direction (against the contraflow lane direction) ranged from a low of 0.5 accidents/MVM (0.3 accidents/MVK) on Route 101 to a high of 1.7 accidents/MVM (1.1 accidents/MVK) on the Long Island Expressway.
- The peak-period injury accident rate for the peak direction ranged from a low of 0.6 accidents/MVM (0.4 accidents/MVK) on the Long Island Expressway to a high of 1.5 accidents/MVM (0.9 accidents/MVK) on I-495.
- On Route 101, from the before to the after conditions with the contraflow lane, the peak-period injury accident rate experienced a statistically significant increase for the peak-directional traffic but a non-statistically significant decrease for the off-peak directional traffic.

On the I-495 project, three serious accidents involving contraflow buses have occurred during time periods not covered by the available data. Two of the accidents were fatalities involving pedestrians who failed to look in the opposite direction for oncoming buses while illegally crossing the freeway. The third accident involved a truck traveling out of control in the off-peak direction and striking an oncoming bus. This incident then created a massive chain reaction accident whereby 25 persons were injured, two seriously.

Table 20 presents for the peak period the percentage breakdown of the accidents as to 1) vehicle type, 2) location, 3) pre-collision events, and 4) accident types. Only the data available for the Route 101 project permitted a before and after comparison.

On Route 101, there was no substantial change in the distribution of vehicle types involved in accidents. The percentage of accidents occurring in the left or interior lanes (as opposed to the right lane) for the peak period direction increased from 60 to 75 percent after the establishment of the contraflow lane. This suggests that improved geometrics and removing buses from the traffic stream probably resulted in higher speeds in the inside lanes and accidents were more likely to occur in these inside lanes. The head-on accident type accounted for zero to one percent of the total peak period accidents on Route 101.

TABLE 20

ACCIDENT CHARACTERISTICS BY PERCENTAGE (PEAK PERIOD)

(Contraflow HOV Lane on Freeway)

FACILITY / CHARACTERISTIC	Peak Period Direction				Off-Peak Period Direction[a]			
	I-495	L. I. Expwy.	Route 101		I-495	L. I. Expwy.	Route 101	
	Bus-Only	Bus-Only	Before	Bus-Only	Bus-Only	Bus-Only	Before	Bus-Only
Vehicle Type								
• Auto	63	—	90	85	62	—	90	87
• Truck	25	—	6	9	22	—	5	9
• Bus	7	—	2	1	14	—	1	0
• Other	4	—	2	5	2	—	5	4
Location								
• Left Lane	—	—	25	35	25	7	11	—
• Interior Lanes	—	—	35	40	—	—	—	—
• Right Lane	—	—	34	14	—	—	—	—
• Other	—	—	6	11	75	93	89	—
Pre-Collision Events								
• Stopped	—	13	14	25	—	14	6	20
• Going Straight	45	73	45	43	42	71	36	35
• Changing Lanes	16	1	13	9	5	2	12	5
• Slowing/Stopping	35	5	18	15	40	8	31	30
• Other	4	9	10	9	14	5	15	10
Collision Type								
• Side-swipe	—	—	35	24	—	—	18	11
• Rear-end	—	—	50	56	—	—	48	69
• Broadside	—	—	3	4	—	—	2	4
• Head-on	—	—	0	1	—	—	0	0
• Hit Object	—	—	10	13	—	—	30	11
• Other	—	—	2	3	—	—	2	5

a. Includes contraflow lane.

TABLE 21

NUMBER OF ACCIDENTS IN OFF-PEAK DIRECTION

(Contraflow HOV Lane on Freeway)

PROJECT	AVERAGE NO. OF ACCIDENTS/HOUR/YEAR		
	1 Hour Before HOV Operations	Average Hour During HOV Operations	1 Hour After HOV Operations
Interstate 495	3.0	6.0	4.0
Long Island Expressway	1.2	3.0	4.5
Route 101			
• Before Condition	1.8	11.5	4.8
• After Condition	8.5	11.3	3.2

The contraflow HOV priority treatment requires the closing of the contraflow lane prior to HOV operations and then restoration to normal conditions following HOV operations. This could be expected to change the accident pattern in the off-peak direction. Table 21 presents by project the average number of accidents per year occurring in the off-peak direction for 1) the hour before HOV operations, 2) the average hour during HOV operations, and 3) the hour after HOV operations. On Route 101, the yearly number of accidents occurring in the hour before HOV operations increased from 1.8 accidents to 8.5 accidents with the introduction of the contraflow lane. Contrary to Route 101, the New York City area projects experienced a higher accident rate during the hour following HOV operations than the hour preceeding HOV operations. This is possibly due to the fact that the New York City projects operate in the morning when there is more latent congestion following the main peak period. Route 101, on the other hand, is an evening operation and demand would be expected to subside following the peak period.

SAFETY CHARACTERISTICS

Causative Factors Influencing Safety

The most apparent causative factor related to contraflow HOV lane operations is the capacity reduction in the off-peak direction. This factor is evidenced by the higher accident rate on each project in the off-peak direction as compared with the peak direction.

The projects on facilities with superior geometric features generally had fewer and less severe safety problems overall. Presumably because of better alignments and fewer geometric constraints, the accident rates on the Long Island Expressway and Route 101 were about equal and lower than the comparable accident rate on I-495. Head-on conflicts between the contraflow lane and opposing traffic occurred only on I-495 with its tight geometrics. In general, geometric features combined with other traffic operational aspects can affect accident rates. A buffer lane, as on Route 101, separating the contraflow lane and opposing traffic lane is highly desirable particularly where running speeds are high.

There were two similar fatal accidents involving the contraflow lane on I-495. The accident type involved a contraflow lane bus striking a pedestrian, who was illegally attempting to cross the freeway. This accident type does point out an inherent problem with contraflow operations—pedestrians (or motorists) forgetting that buses are traveling in the opposite direction. While pedestrians crossing the freeway is not a common problem, drivers of disabled vehicles often need to cross the freeway. If glare fencing is added atop the median wall, this safety problem can be greatly reduced.

Difficult Maneuvers and Potential Safety Problems

An HOV priority treatment might be expected to generate potential safety problems on a transportation facility. Project personnel for the contraflow HOV lane projects identified several difficult maneuvers and safety problems that could be associated with this type of treatment. Such safety problems include:

- Clearly, the most obvious safety problem on contraflow HOV lane projects is the potential for conflict between opposing traffic. The danger of a vehicle losing control and penetrating the safety delineators into on-coming contraflow vehicles is always present. Reduction in capacity in the off-peak direction can lead to congestion in the remaining lanes and potentially increases accidents in this direction. An accident situation may cause an erratic maneuver resulting in a vehicle traveling the "wrong way" in the contraflow lane.

- The limited access to the contraflow lane minimizes problems such as weaving and merging into and out of the lane. However, if access is provided by a median crossover, contraflow vehicles may have to slow down in the left lane, forcing following traffic to brake or weave out of this lane.

- Incident removal from contraflow lanes is extremely hazardous especially if no buffer lane exists. Stalled vehicles must either be pushed to the end of the lane or removed by tow truck. If towing is required, the tow vehicle must generally approach the disabled vehicle from the opposing direction and turn around. This necessitates stopping the off-peak general traffic, which is always a hazardous condition on a freeway. Additionally, emergency aid vehicles may have to use this maneuver to reach vehicles in the contraflow lane.

- Although the chances of occurrence are small, the potential also exists that a vehicle in the off-peak direction will make a U-turn to use the contraflow lane, particularly in an emergency situation. This is clearly a hazardous maneuver and, indeed, such a maneuver resulted in one of the few accidents in the contraflow lane on the Route 101 project.

- Since setting up and removing safety posts is presently a manual operation, the crews are always exposed to injury. This is particularly true in inclement weather, or periods of darkness.

- Generally, access to the contraflow lane is effectively blocked during non-operating periods but on several occasions on Route 101, buses did improperly gain access to the contraflow lane during the off-peak. No accidents resulted from this maneuver as the buses were stopped immediately.

RECOMMENDATIONS

General recommendations on safety of HOV priority treatments are presented on page 7. Specific recommendations that may improve the safety of a contraflow HOV lane on a freeway include the following:

- Contraflow lanes are generally implemented on existing freeways without substantial modification of the freeway mainline geometrics. If possible, contraflow lanes should be implemented on freeways with a high design standard. Every effort should be made to maximize the quality of the geometrics including median walls, left and right shoulders, ramps, and buffer lanes.

- The ideal terminals to and from the contraflow lane are exclusive ramps or toll booth lanes if the output is to a toll plaza. Where median crossovers are required at the input, a short access lane allowing for deceleration should be provided upstream of the crossover. If surplus capacity exists, the existing median lane can be designated an HOV access lane so general traffic will be required to exit the lane in advance of the median crossover. Terminals should be positively closed during non-HOV operating periods.

- Where no buffer lane can be provided between the contraflow lane and the general-use lanes, the proper lane use should be designated by overhead lane use control signals. In the peak and off-peak freeway directions, lane use designation should be displayed over the contraflow lane and the adjacent general use lane.

- Where a buffer lane can be provided between the contraflow lane and the general use lanes, overhead lane use control signals are not necessary to designate proper lane use if sufficient physical separation and signing is provided. This may seem to contradict the MUTCD requirement for overhead lane use control signals over any reversible lane, but it is felt that the physical separation and other movable signing, if properly used, represent a different situation than that which led to the MUTCD requirement.

- Signing in the off-peak direction approaching the contraflow section should consist of both advanced warning and restricted lane signing along the mainline. Messages such as "CAUTION—ON-COMING TRAFFIC AHEAD—X FEET (Y KM)" and "LEFT LANE CLOSED—ON-COMING TRAFFIC" with flashers and merge-right arrows, as appropriate, are more positive than the standard MUTCD restricted lane signing. Blank-out message signs are preferable to specified time periods due to the flexibility in operating hours.

- Signing in the off-peak direction at the end of the contraflow section should be the standard MUTCD end-of-HOV-lane sign. A lane control signal should be placed downstream with all green arrows permanently displayed over each off-peak directional lane.

- Signing in the peak direction would depend on the type of terminal treatment. Standard MUTCD signing should be used with emphasis on which vehicles may use the contraflow lane.

- The contraflow lane demarcation should be a double yellow skip line indicating a reversible lane. Yellow flexible tubular delineators should be placed along the lane line. They should be reflectorized and spaced at a maximum distance of 40 foot (12 meter) intervals. The use of the diamond symbol on the contraflow lane is discouraged, as this implies vehicle classification and not direction.

- Use of the contraflow lane should be restricted to experienced and trained operators. In addition to transit operators, operators of other vehicles (charter buses, mini-buses, vanpools, taxis and carpools) could be permitted use of the contraflow lane if special licensing requirements are met. All motorists using the contraflow lane should be required to use flashers with the vehicle.

- It may be desirable to impose additional restrictions on both contraflow lane and/or opposing lane traffic. Reduction of the speed limit and spatial headways are the most common restrictions.

- Quick-reaction incident detection and removal systems should be incorporated into the project. If possible, median cuts should be provided if there is no buffer lane so emergency vehicles can approach in the proper direction; however, these should not be penetrable by general traffic nor present a collision hazard themselves. Care must also be taken to minimize pedestrian use of these crossings. Incident management can be greatly enhanced by the provision of freeway surveillance (electronic sensors or television) and warning beacons should be considered as well, to alert on-coming traffic of downstream incidents.

- Enforcement of contraflow lane use should be directed at the terminals because activity along the mainline can be extremely disruptive, if not impossible. Monitoring should be active throughout the project area, especially for violations of the special restrictions suggested above.

CHAPTER FIVE

TOLL PLAZA HOV LANE

DETAILED DESCRIPTION

A toll plaza is inherently a bottleneck on a freeway. In such instances, the capacity of the toll plaza is generally equal to or less than the upstream demand, resulting in extensive queuing in peak periods. Exclusive lanes for HOVs enable these vehicles to bypass the queue and gain access to the toll facility with less delay.

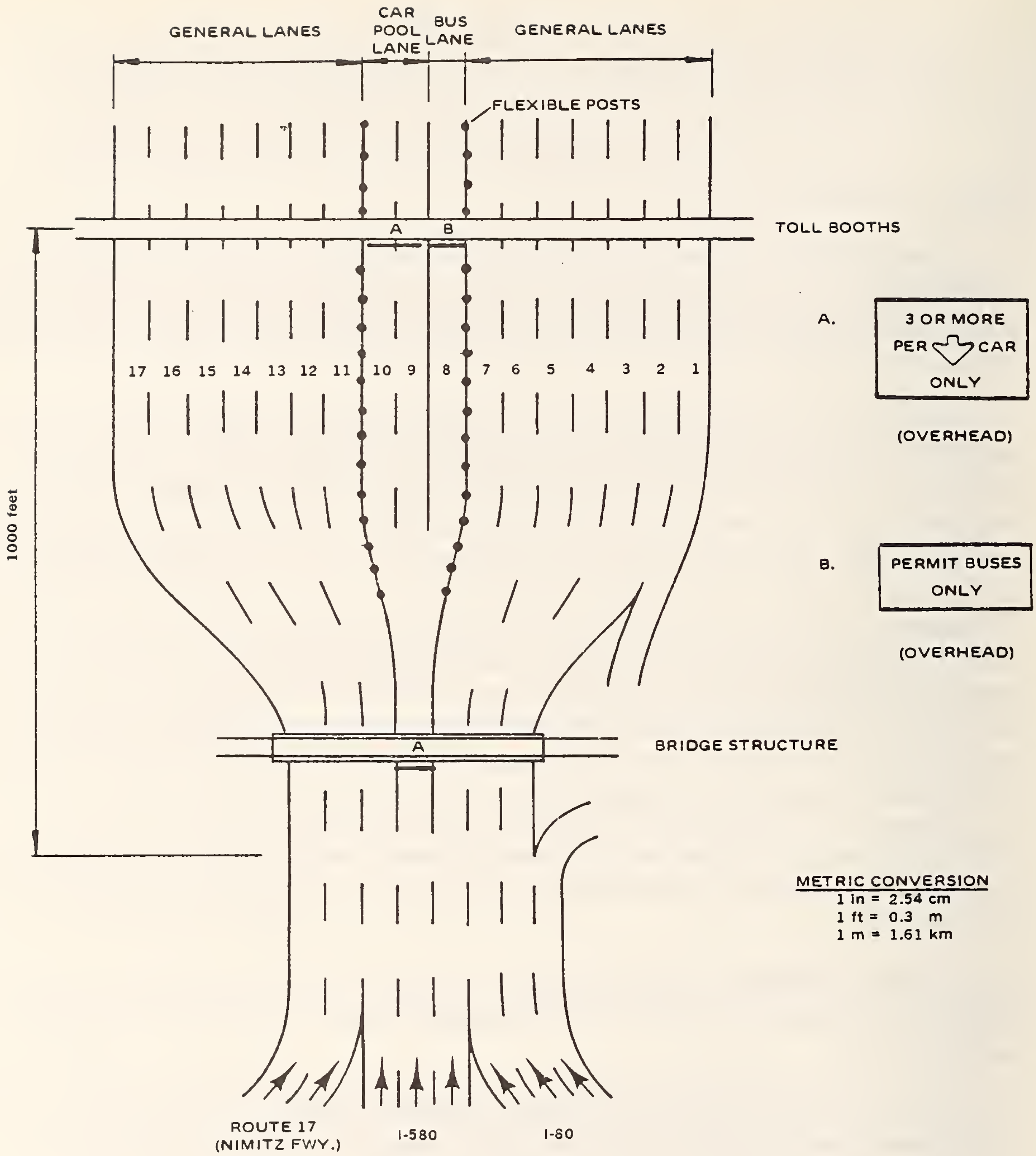
This HOV priority treatment is relatively simple to implement if lanes and/or toll booths are re-designated from general traffic use to exclusive use by HOVs. Since toll plaza configurations vary greatly, there is no "typical" manner of implementing restricted lanes or booths for HOVs. On the Evergreen Point Bridge approach in Seattle, the right shoulder is used as a bus/carpool lane to enable these HOVs to bypass the queue; however, there is no reserved toll booth so HOVs must merge with the right general lane to use a toll booth. In two projects in the New York City area (I-495 approaches to the Lincoln and Queens-Midtown Tunnels), buses approach the toll plaza in contraflow lanes and proceed through the toll station using restricted toll booths. In the San Francisco-Oakland Bay Bridge (SFOBB) toll plaza, three lanes of the 17 approach lanes are reserved for buses and carpools. The HOV lanes continue through the toll station where HOVs are not required to stop, as carpools pay no toll and bus companies are billed based on scheduled crossings. In addition, a freeway metering station has been installed to improve flow on the bridge and HOVs are processed through this metering station without stopping.

Thus, exclusive toll plaza lanes serve several purposes. They allow HOVs to 1) bypass queues on the approach, 2) move through the toll station with minimal delay, and 3) gain preferential access to the toll facility itself.

Toll plaza HOV lanes are generally "taken" from general lanes, as opposed to being newly constructed. This is because the capacity of the toll facility is fixed and adding capacity is generally not a feasible alternative.

Only the San Francisco-Oakland Bay Bridge (SFOBB) toll plaza HOV lanes project was investigated in detail. The project description is given below and is illustrated in Figure 12.

- <u>San Francisco-Oakland Bay Bridge, California (Figure 12)</u>
  The San Francisco-Oakland Bay Bridge spans five miles (8 km) connecting these two major cities. It is a toll bridge with 17 toll booths operating in the inbound direction (to San Francisco). After the toll booths, the freeway narrows down from the 17 lanes to 5 lanes on the bridge in a distance of just 3,800 feet (1,158 m). To alleviate merging problems and control the volume of traffic on the bridge, a freeway metering system was installed 1,000 feet (303 m) downstream of the toll booths. Beginning in April, 1970, the center lane of the 17 inbound lanes was designated as a bus-only lane. In December, 1971, the HOV operating strategy was modified whereby two additional center lanes were designated for carpools of three or more persons. The ramp metering system became operational on March, 1974. The vehicles in the HOV lanes pay no toll and are not delayed by the ramp metering system. This HOV operating strategy is only in effect in the inbound direction from 6:00 AM to 6:00 PM, but the main period of interest is the AM peak period (7-9 AM).



METRIC CONVERSION
1 in = 2.54 cm
1 ft = 0.3 m
1 m = 1.61 km

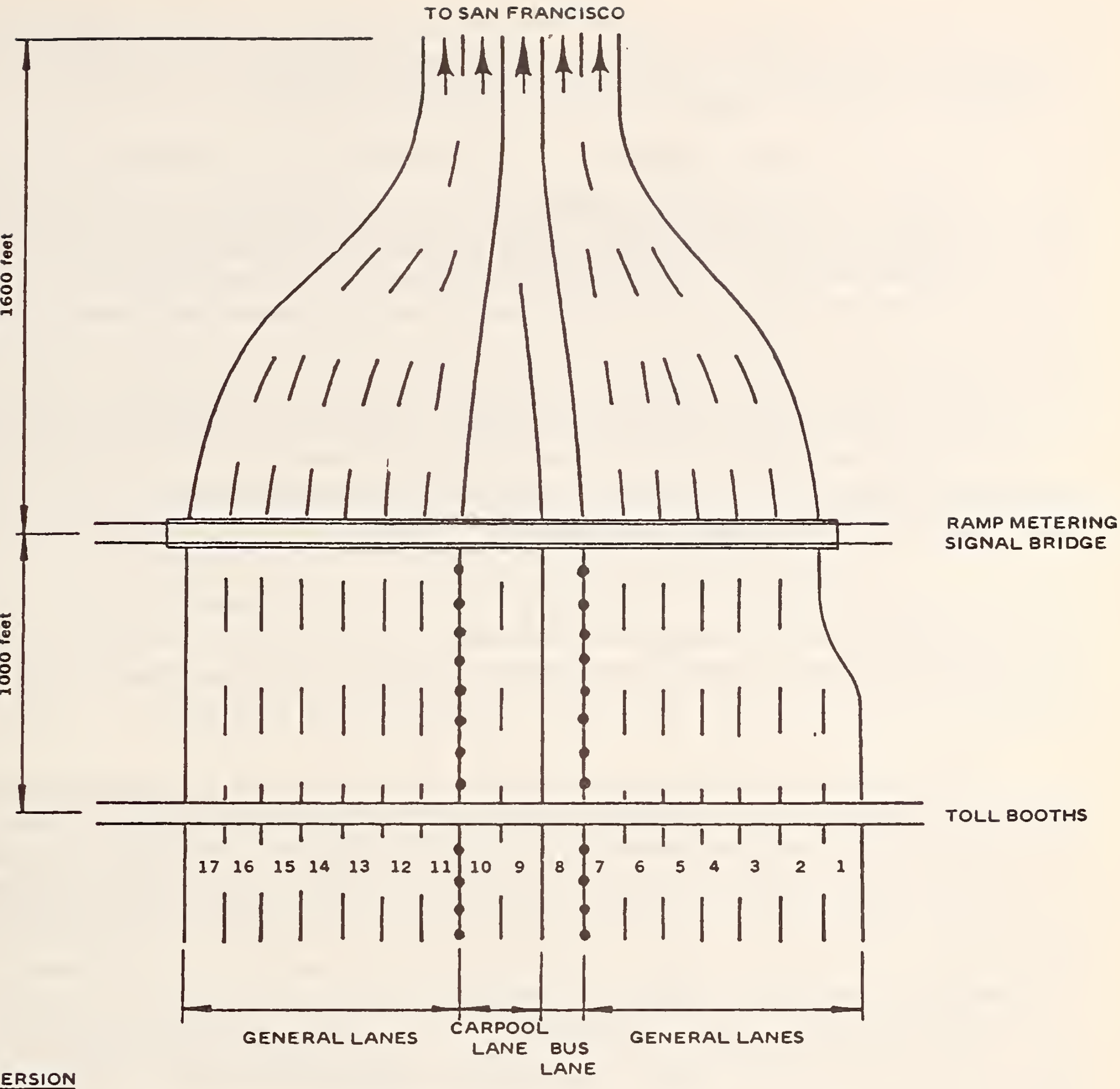
AASHTO DESIGN FACTORS

ALIGNMENT: s-curve through toll plaza
VERTICAL SIGHT DISTANCE: good
POSTED SPEED: 35 mph
ROADSIDE HAZARDS: none
OTHER HAZARDS: lane expansion (7 to 17) and reduction (17 to 5)

MUTCD DESIGN FACTORS

LANE-USE CONTROL SIGNALS: ramp metering of general lanes
ADVANCED WARNING SIGNS: non-standard
RESTRICTED LANE SIGNS: non-standard
END OF HOVL SIGNS: none
DIAMOND SYMBOL: none
HOVL DELINEATION: solid white line with flexible posts

SAN FRANCISCO-OAKLAND BAY BRIDGE TOLL PLAZA, OAKLAND, CALIFORNIA
FIGURE 12



METRIC CONVERSION
1 In = 2.54 cm
1 ft = 0.3 m
1 m = 1.61 km

SAN FRANCISCO-OAKLAND BAY BRIDGE TOLL PLAZA, OAKLAND, CALIFORNIA
FIGURE 12 (CONT.)

Tables 2 and 3 present the national standards applicable to HOV priority treatments on freeways. Toll facilities are not covered explicitly by AASHTO standards, but the guidelines shown are deemed to be applicable to the extent possible in such a special section of freeway.

There are no significant design deficiencies on the SFOBB project other than the necessary expansion of seven to 17 lanes and subsequent convergence or taper to five lanes. The HOV project predates MUTCD standards on traffic control devices for restricted lanes and has not yet been upgraded. The major deficiencies are in non-standard signing and the absence of the restricted lane diamond symbol. The absence of the diamond is due to the reluctance of the California Department of Transportation to use this symbol following the adverse publicity the symbol received on the Santa Monica "Diamond Lane" project in Los Angeles. Originally the advanced warning signs read "CARPOOL LANE AHEAD" followed by "THREE OR MORE PER CAR AHEAD." The word "ahead" was ambiguous and this word was later replaced by "BEGINS 1,500 FT " and "1,000 FT ," respectively. There are no signs within the restricted area except over the toll booths. During the off-peak periods, some of the upstream safety posts are removed and the hinged carpool lane signs are folded so as to appear blank.

As carpools are not required to pay tolls, they are free to pass through the toll booths without stopping. The slots are narrow and there is always the possibility of conflicts downstream so the speed limit in the carpool lanes is reduced to 15 mph (24 kph) through the booths. There is no speed limit imposed on the buses, but the bus operators are instructed to restrict their speed.

Enforcement of the SFOBB lanes is relatively simple. As the violation rate begins to exceed 10 percent of the vehicles using the HOV lanes, a special enforcement scheme is employed. Either one of the carpool lanes or the adjacent general lane is closed downstream of the toll booths. Officers then flag violators passing through the toll booths into this "shunt" lane, where they are subsequently cited or warned for the infraction. One specific operating problem has resulted from the implementation of the HOV lanes on the SFOBB toll plaza. Trucks entering this freeway from the left (Nimitz Freeway) must weave across the lanes to the right-hand toll booths. However, the HOVs, which are primarily buses, tend to queue far upstream of the toll booths, forming a physical barrier to these trucks. As a result, the weaving area for the trucks is considerably shortened and some trucks may have to weave across the HOV lanes themselves, which is technically a violation.

OPERATING CHARACTERISTICS

The extent of the safety impact for an HOV project is dependent in part on the operational effectiveness of the project. The operational results of the SFOBB project are given in Table 22. There were actually four operating conditions, or stages, of interest. These are:

1) Before Stage—general operations prior to any HOV priority treatment,

2) Bus-Only Stage—one lane (No. 8) was reserved for buses,

3) Bus/Carpool Stage—in addition to the bus lane, two carpool lanes (Nos. 9 & 10) were reserved for carpools of three or more persons, and

4) Bus/Carpool and Metering Stage—the HOV lanes are allowed non-stop passage through the metering station, which was installed to control the volume and merging as the

facility narrows from 17 to five lanes.

Data on the before condition was limited due to the age of the project. The HOV lanes operate inbound from 6 AM to 6 PM, but the primary area of interest is the 7-9 AM peak period. From Table 22, several of the more significant results are:

- The total peak period volumes did not vary substantially from stage to stage. In the bus/carpool and metering stage, the average hourly volume per general lane is 679 vehicles and the average hourly volume per carpool lane is 733 vehicles. The general lane rate is primarily a function of capacity, while the carpool lane rate is primarily a function of demand.

- Passenger utilization of the HOV lanes is excellent on the SFOBB project. Although no data were available to compare total throughput with the before condition, 41 percent of the passengers were moved in only 3 percent of the vehicles during the bus-only condition. After carpools were allowed to use HOV lanes these percentages increased to 53 percent and 13 percent, respectively. Total passenger throughput increased by 4 percent. When metering was added, the total persons throughput declined by 8 percent, but this was primarily the result of the opening of the Bay Area Rapid Transit (BART) System.

- Travel speeds in the HOV lanes for the different stages ranged from 32 to 38 mph (52 to 62 kph). The differential in travel speeds between the HOV lanes and general travel lanes varied from 16 mph (26 kph) in the bus-only stage to 12 mph (19 kph) in the bus/carpool stage.

- Because of these higher travel speeds, persons traveling in the HOV lane experienced travel time savings over general lane travel. In the bus-only stage, the travel time savings was 8.1 minutes over the 3.8 miles (6.1 km). For the bus/carpool stage, the travel time savings was 2.1 minutes. As previously stated, it is believed that metering has resulted in additional savings especially for HOVs, although no studies have been conducted to confirm this suspicion.

- Violation rates varied from stage to stage but the actual number of violators remained constant at about 75 during the peak hour. The violation rate (ratio of violators to HOV lane volume) during the bus/carpool stage is 6 percent. During the bus-only stage, this rate was higher at 29 percent reflecting the smaller HOV volume.

ACCIDENT ANALYSIS

The accident data on the San Francisco-Oakland Bay Bridge (SFOBB) project is analyzed by 1) peak period accident rates, 2) daily accident rates, and 3) accident characteristics. It is also pertinent to compare the 24-hour accident rates on the HOV facility with some control base for which data are generally available. Accident rates were computed in terms of accidents per million vehicle-miles (MVM) and million person-miles (MPM) of travel. These rates automatically take into consideration the effects of differing stage lengths and demand levels. Accident rates were tested with the "t" statistic to determine the statistical significance.

The SFOBB project represents HOV operations in several specific conditions, as outlined in the previous section, and it is useful to discuss each operating condition individually, provided sufficient data were available. The "before" period data collection covered only 78 operating days, raising the possibility that interpretations drawn from these data may be inconclusive due to the small sample size.

TABLE 22

OPERATING CHARACTERISTICS

(SFOBB Toll Plaza HOV Lane)

VARIABLE	UNIT	PROJECT/CONDITION			
		SFOBB Toll Plaza Lanes			
		Before	Bus-Only[a]	Bus/3 ppv Carpool[a]	Bus/3 ppv Carpool[b]
Critical Peak Period	—	6 - 9 AM	6 - 9 AM	6 - 9 AM	6 - 9 AM
Length of HOV Lane	Miles	—	1.1	1.1	1.1
Total Peak Directional Lanes	Lanes	17	17	17	17
Number of HOV Lanes	Lanes	—	1	3	3
Volume - All Lanes	Vehicles	22,820	23,001	22,694	22,346
Volume - HOV Lanes	Vehicles	—	767	2,827	3,338
Volume - HOV Lanes (bus only)	Vehicles	—	542	509	406
HOV Lanes/Total Volume	%	—	3.3	12.5	14.9
Auto Occupancy - All Lanes	PPV	na	1.31	1.42	1.50
Auto Occupancy - HOV Lanes	PPV	—	1.31[c]	3.23	3.29
Person Throughput - All Lanes	Persons	na	49,069	50,914	46,908
Person Throughput - HOV Lanes	Persons	—	19,942	26,875	23,718
HOV Lanes/Total Throughput	%	—	40.6	52.8	50.6
Speed - General Lanes[d]	MPH	na	15.1	28.6	na
Speed - HOV Lanes[d]	MPH	—	31.5	38.2	na
Travel Time - General Lanes[d]	Minutes	na	15.5	8.2	na
Travel Time - HOV Lanes[d]	Minutes	—	7.4	6.1	na
Violation Rate	%	—	29.3	7.1	5.6

Metric Conversion

1 mile = 1.61 kilometers

a. HOV priority at toll plaza.
b. HOV priority at toll plaza and metering station.
c. These are violators.
d. Speed and travel time based on 3.9 mile (6.3 km) section from junction of I-80 and I-580.

Peak Period Accident Rates

Table 23 presents the peak-period accident rates for the AM (inbound) peak period based on MVM and MPM. The study area of the SFOBB project covered a total of 2.8 miles (4.5 km) beginning at the intersection of the Nimitz Freeway and I-80, through the toll plaza, and onto the bridge. This length covers three distinct sections (see Figure 12): 1) upstream of the toll booths (0.8 mile or 1.3 km), 2) downstream of the toll booths to the bridge deck, including the metering station (0.7 mile or 1.1 km), and 3) the bridge deck (1.3 mile or 2.0 km). The peak period accidents are presented by each section in Table 23.

The MVM accident rate for the entire 2.8 mile (4.5 km) section increased with each subsequent stage until metering was introduced. The increase in the accident rate from the bus-only condition to the bus/carpool condition was statistically significant. Also, the reduction in the accident rate when metering was added to the bus/carpool condition was statistically significant when compared to the bus/carpool condition without metering.

Fairly large algebraic changes occurred in the accident rates in each distinct section; however, the segregated samples were too small to yield statistically significant differences in most cases. In the upstream section, the conversion of existing lanes to HOV lanes for buses and carpools produced an increase in the accident rate, probably due to increased congestion. In the downstream section, the accident rate decreased significantly when metering was added, indicating that metering had a positive effect in reducing the problems associated with merging 17 lanes down to 5. In the bridge section, the accident rate increased significantly in the bus-only and bus/carpool conditions, and then decreased to the before level when metering was added.

Because of the large volume of buses crossing the SFOBB and using the HOV priority lanes, it is of interest to examine the effect of the HOV treatment on the bus accident rates, which are presented in Table 24. The highest number of accidents in any one condition was five; however, there is no statistical basis to compare such limited historical accident records. The only possible conclusion is that the bus accident rates, which ranged between 3.7 to 7.6 accidents/MVM (2.3 to 4.7 accidents/MVK), were not drastically different between operating conditions. The bus accident rates do compare very favorably with other HOV priority projects.

Daily Accident Rates

Total accident rates in the inbound direction for the project section for 24 hours, seven days a week, are shown in Table 25. These accident rates are compared to the accident rates on the control base to identify the effects of extraneous variables.

The daily accident rates for SFOBB during HOV operating conditions ranged from 3.4 to 5.0 accidents/MVM (2.1 to 3.1 accidents/MVK) and were significantly higher than the accident rates of the control base. This would be expected because of the complexity of the SFOBB toll area. The daily accident rate on the SFOBB followed a trend that was completely opposite of the control base. The accident rate on the SFOBB steadily increased until the metering stage. This suggests again that the metering had a significantly beneficial effect on total operations.

TABLE 23

PEAK PERIOD FACILITY ACCIDENT RATES

(SFOBB Toll Plaza HOV Lane)

VARIABLE / SECTION	TIME PERIOD	AM PEAK PERIOD		
		Number of Accidents	Accident Rate[a] (acc/mvm)	Accident Rate[a] (acc/mpm)
Total Length				
• Before	1/70 - 4/70	9	1.8	0.9
• Bus-Only	5/70 - 12/71	74	2.7 ns	1.3 ns
• Bus/Carpool	1/72 - 2/74	146	4.0 **	1.8 **
• Bus/Carpool with Metering	3/74 - 12/76	83	2.3 ns	1.1 ns
Upstream of Toll Plaza				
• Before		5	3.5	1.7
• Bus-Only	Same	26	3.3 ns	1.6 ns
• Bus/Carpool		53	5.1 ns	2.3 ns
• Bus/Carpool with Metering		49	4.7 ns	2.3 ns
Downstream of Toll Plaza				
• Before		3	2.3	1.1
• Bus-Only	Same	19	2.7 ns	1.3 ns
• Bus/Carpool		41	4.3 ns	1.9 ns
• Bus/Carpool with Metering		20	2.1 ns	1.0 ns
Bridge Section				
• Before		1	0.4	0.2
• Bus-Only	Same	29	2.4 **	1.1 **
• Bus/Carpool		52	3.2 **	1.4 **
• Bus/Carpool with Metering		14	0.9 ns	0.4 ns

a. Statistical significance of accident rates compared to the before condition:
ns indicates difference is not significant
* indicates a 95 percent level of significance
**indicates a 99 percent level of significance

Metric Conversion

1 mile = 1.61 kilometers
1 acc/mvm = 0.62 acc/mvk

TABLE 24

PEAK PERIOD BUS ACCIDENT RATES

(SFOBB Toll Plaza HOV Lane)

VARIABLE / CONDITION	TIME PERIOD	NUMBER OF OPERATING DAYS	NUMBER OF BUS ACCIDENTS	BUS ACCIDENT RATE (acc/mvm)
Before	1/70 - 4/70	78	0	0.0
Bus-Only	5/70 - 12/71	423	4	6.2
Bus/Carpool	1/72 - 2/74	573	3	3.7
Bus/Carpool with Metering	3/74 - 12/76	578	5	7.6

Metric Conversion

1 mile = 1.61 kilometers
1 acc/mvm = 0.62 acc/mvk

TABLE 25

DAILY FACILITY AND CONTROL ACCIDENT RATES

(SFOBB Toll Plaza HOV Lane)

VARIABLE / CONDITION	TIME PERIOD	HOV FACILITY Inbound Direction		Control Accident Rate[b]
		Number of Accidents	Accident Rate[a] (acc/mvm)	(acc/mvm)
Before	1/70 - 4/70	91	3.4	—
Bus-Only	5/70 - 12/71	536	3.5 ns	1.8
Bus/Carpool	1/72 - 2/74	998	5.0 **	1.1
Bus/Carpool with Metering	3/74 - 12/76	699	3.4 ns	1.3

a. Statistical significance of accident rates compared to the before condition:
ns indicates difference is not significant
* indicates a 95 percent level of significance
**indicates a 99 percent level of significance
b. Control base is all freeway accidents in Caltrans, District 4.

Metric Conversion

1 mile = 1.61 kilometers
1 acc/mvm = 0.62 acc/mvk

Accident Characteristics

The injury accident rates were quite small and the only statistically significant change was a decrease in both peak period and 24-hour injury accident rates after metering was added. The low injury accident rates were due mainly to the low vehicle speeds through the toll plaza area.

Because of small sample sizes and the varied geometric and operational characteristics of the three distinct sections comprising the SFOBB toll area, it is impossible to draw firm conclusions regarding a classification of accidents as to vehicle type, pre-collision events and accident type.

SAFETY CHARACTERISTICS

Causative Factors Influencing Safety

Implementation of HOV lanes in the SFOBB toll facility appeared to adversely affect safety on the facility, although this was largely alleviated by the metering system.

The most obvious factor affecting safety in the SFOBB toll plaza area was the congestion pattern resulting from the implementation of the HOV lanes. This project had the effect of splitting what was formerly a homogeneous stop-and-move queue which extended some distance upstream, into two sections separated by HOV lanes in the middle. This resulted in: 1) extending the queuing area further upstream in the two "halves" of the general roadway lanes, and 2) introducing a speed differential in the center of the facility.

The geometry of the SFOBB was not designed to accommodate the HOV toll priority treatment. The facility had several problems in this respect: 1) trucks entering the facility from the left (Nimitz Freeway) must weave across the lanes to gain access to the right hand toll plaza lanes that accommodate trucks; 2) the HOV lanes are in the center of a 17 lane toll plaza requiring a large amount of weaving; 3) there is a penetrable barrier between the HOV lanes and the general lanes; and 4) there is a rapid narrowing from 17 to 5 lanes in the toll plaza output section. These problems are not all resulting from the HOV priority treatment, but the HOV strategy has compounded the potential hazards to some extent.

Difficult Manuevers and Potential Safety Problems

An HOV priority treatment might be expected to generate potential safety problems on a transportation facility. Project personnel for the SFOBB toll plaza project identified several possible difficult maneuvers and safety problems that could be associated with this type of treatment. Such safety problems include:

- The location of the HOV lanes at the toll plaza, being the center lanes of 17 lanes, requires a major amount of weaving (up to 4 lanes) by some HOVs to gain access to the priority lanes through the narrow portion (8 lanes) of the approach strip. Once the HOV has reached the widened portion (17 lanes) of the plaza area, the queue makes it nearly impossible to merge into the priority lanes.

- A potential safety problem is created by the reduction in the number of lanes from 17 to 5 after the toll booths. This reduction, occurring within a distance of 3,960 feet (1,200 m), is a source of merging problems for both general and HOV traffic. The HOV lanes aggrevated the situation by introducing a speed differential of 12 to 16 mph (19 to 26 kph) with the general lanes. If vehicles remain in the appropriate lane, this differential does not pose a problem and the metering system has been successful in reducing the hazard.

- In accessing the HOV lanes, vehicles merge late from the slower traveling general lanes to overcome the speed differential created by the HOV lanes. To minimize this safety problem, plastic tubular posts are used to discourage entering the HOV lanes beginning at 900 feet (273 m) in front of the toll booths.

- Violators cutting into the HOV lanes pose a safety problem. This violation problem was minimal upstream because the HOV toll booths are manned. However, it is a common occurrence for general lane users in lanes 7 or 11 to weave into the HOV lane after exiting the toll booth.

- An unanticipated difficult maneuver occurred when the HOV lane was first opened. Trucks entering the toll plaza area from the left (Nimitz Freeway) must weave to the extreme right lanes, as trucks are required to use the right toll booths. When the HOV lanes were first opened to buses, the buses would queue behind the toll area creating a physical barrier to the weaving trucks. If a truck could not weave through the buses upstream of the queue, it would eventually have to weave across the HOV lanes. To minimize this problem, the input of the HOV lane was moved about 0.1 mile (0.16 km) closer to the toll booth.

RECOMMENDATIONS

The previous sections have shown that exclusive HOV toll plaza lanes can affect the safety of the facility. General recommendations on safety of HOV priority treatments are presented on page 7. Specific recommendations that may improve the safety of an HOV toll plaza lane include the following:

- Ideally, the HOV lanes and general lanes should be separated by a physical barrier or raised curb, so long as such a barrier does not pose a safety hazard itself. Where physical barriers are impossible to implement, some type of lane delineation should be incorporated. Any stanchions delineating the HOV lane should be placed close enough to prevent lane change movements.

- The weaving area to gain access to the priority lane should be of sufficient length to minimize conflict. This is especially true where multiple roadways access the toll facility.

- Similarly, adequate merging distance should be provided to the priority lanes where they rejoin the general traffic lanes after passing through the toll booths.

- HOVs given priority at the toll plaza should be allowed passage through the toll booths with a minimum amount of delay.

- When possible, special refuge areas or shoulders should be provided adjacent to the HOV lanes. Such areas aid both disabled HOVs and enforcement operations.

CHAPTER SIX

HOV RAMP TREATMENTS

DETAILED DESCRIPTION

Chapters 2 through 5 have discussed HOV priority treatment techniques commonly applied on freeway mainlines. Preferential treatment can also be provided at entry and exit ramps on freeways. There are commonly two types of HOV treatments on ramps: 1) HOV bypass of ramp metering at on-ramps and 2) exclusive on- or off-ramps for HOVs.

Ramp metering has been used for nearly two decades to improve general operations on freeways by limiting access onto the mainline of the freeway. This enables vehicles making longer trips to travel at a high level of service and requires motorists desiring to use the facility for shorter trips to pay a "time toll" for the privilege or to seek an alternative route. As an incentive to HOVs, bypass lanes have been constructed which allow these vehicles "free" access to the freeway without the delays encountered by low occupancy vehicles at the ramp signal. The ramp metering bypass (RMB) technique can be used at isolated ramps, or can be incorporated into a series of ramps which collectively form a RMB HOV priority system. RMB can only be functional when metering is active.

Ramp metering bypass lanes are generally constructed by widening existing ramps, or redesignating one lane of existing multi-lane ramps. Generally, the ramp metering has been in effect when the RMB is implemented, but they can be implemented simultaneously. General lane traffic is metered to release one vehicle at a time and excess demand queues up in the general lane. HOVs enter the ramp in the RMB lane and bypass the queue, proceeding directly to the freeway. RMB lanes can also be metered if the ramp poses a problem to freeway operations. This reduces the level of preferential treatment, but their metering rate can be higher than the general lane(s) and the smaller numbers of HOVs produce shorter queues. RMB lanes can be the right or left lane depending on the geometric configuration of the ramp. RMB lanes can also be physically separated from the general lanes. This eliminates the interaction between HOVs and general traffic, thereby enhancing safety and enforcement.

As part of this safety research, 21 ramps in the Los Angeles, California, area were investigated in detail as one project. The project description is given below and in Figure 13.

- <u>Santa Monica, Golden State and Harbor Freeways, Los Angeles, California (Figure 13)</u>
  Implementation of these 21 RMB ramps took place over a period ranging from September, 1974, to July, 1976. Each RMB ramp operates in the priority mode during only one peak period[1] on weekdays. For those operating in the AM peak, the times are 6-9 AM and for those operating in the PM peak, the times are 3-6:30 PM. All but one of these ramps were two-lane ramps with the HOV lane serving as one lane and most of these were widened from one lane. The other ramp was a two-lane ramp which was

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1. In exception to this statement, RMB ramps on the Santa Monica Freeway in Los Angeles operated during both peaks when the "Diamond Lane" experiment was underway.

widened to three lanes and both general lanes are metered. On all of these ramps, both buses and two-person per vehicle (ppv) carpools are authorized to use the HOV lanes. None of these RMB lanes is physically separated from the general metered lane(s).

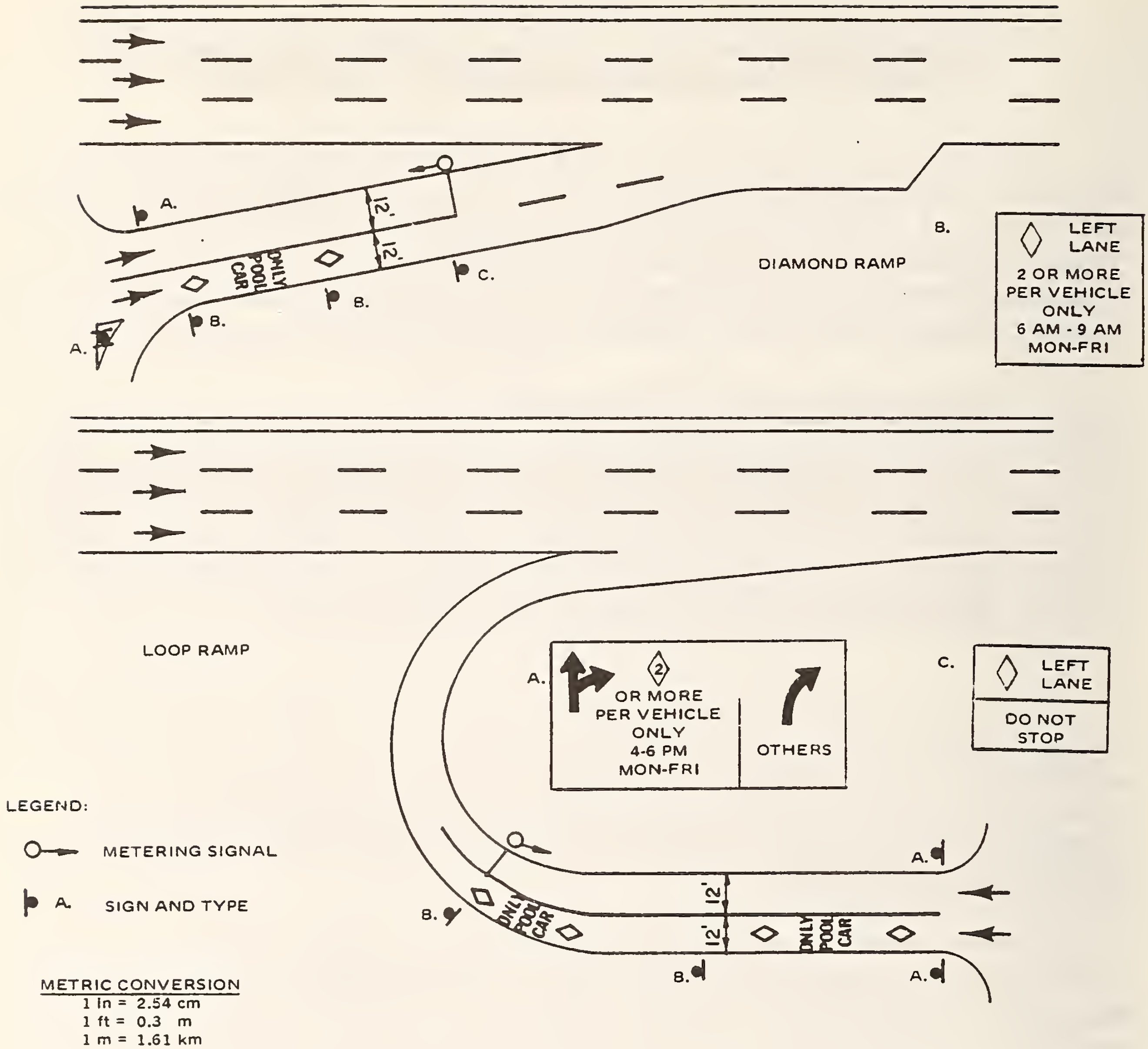
Exclusive HOV ramps are generally of two types. One type connects general-use lanes with HOV-specific facilities, such as bus terminals, in order to allow direct access to or from these restricted areas. This type is not a priority treatment per se, but it operates similarly. The second type is the "typical" HOV priority facility which is intended to give preferential service to HOVs by serving desirable origin-destination patterns of motorists. The I-5 exclusive ramp in Seattle, Washington, was investigated in detail for this research. The project description is given below and in Figure 14.

- <u>I-5 Exclusive Ramp, Seattle, Washington (Figure 14)</u>
  This reversible ramp was originally a general-use ramp connecting the reversible lanes of Interstate 5 with the Seattle CBD at Cherry and Columbia Streets. In September, 1970, the ramp was redesignated as a bus-only ramp. In March, 1977, carpools of three or more occupants were also permitted to use the ramp. Along with the latter change, a 1.1 mile (1.8 km) section of one lane on the reversible roadway, that channels into the ramp, was designated as a concurrent flow HOV lane in the AM peak period. The exclusive reversible ramp operates for 22 hours a day—5 AM to 12 noon in the inbound mode (exit ramp) and 1 PM to 4 AM in the outbound mode (entrance ramp).

Tables 2 and 3 present the national standards applicable to HOV priority treatments on freeways. The HOV standards established by the MUTCD are generally applicable except that advanced warning and lane-end signs would not necessarily be appropriate because of the short length of the ramp. Advanced warning signing would be appropriate on an exclusive ramp serving as an exit ramp. In regard to the HOV signing, it is more important to identify clearly which lane or ramp is restricted and the nature of the restriction.

On the Los Angeles Freeway projects, some of the ramps having RMB are deficient in one or more areas. Since most RMB lanes were constructed by paving over existing shoulders or widening single lane ramps, there are often no shoulders. Additionally, the curb radii at ramp entries are often too small for proper access onto the ramp and right-turning vehicles often have to turn wide and encroach into the other lane, which creates a safety hazard. Many of the ramps are simply too short to accommodate the queuing during peak hours and the backup interferes with surface street operation. Any ramps having substandard HOV signing (i.e. missing the diamond symbol) are being upgraded with fully standard signs. On non-separated ramps, solid white lane demarcations and the diamond symbol are used on the pavement. Pavement markings stating "CARPOOL LANE" are used to reinforce the restriction. Metering is generally standard with the exception that on some ramps only one signal head is provided for the metered lane.

The major geometric deficiency on the I-5 exclusive ramp is a curved section in the tunnel. The minimum sight distance in the tunnel is 144 feet (43 m) which provides for a maximum safe speed of 23 mph (37 kph) based on AASHTO guidelines. However, no speed limit is posted on the ramp although the transit company requires its bus drivers to maintain a speed of 10 mph (16 kph) in the tunnel.



AASHTO DESIGN FACTORS

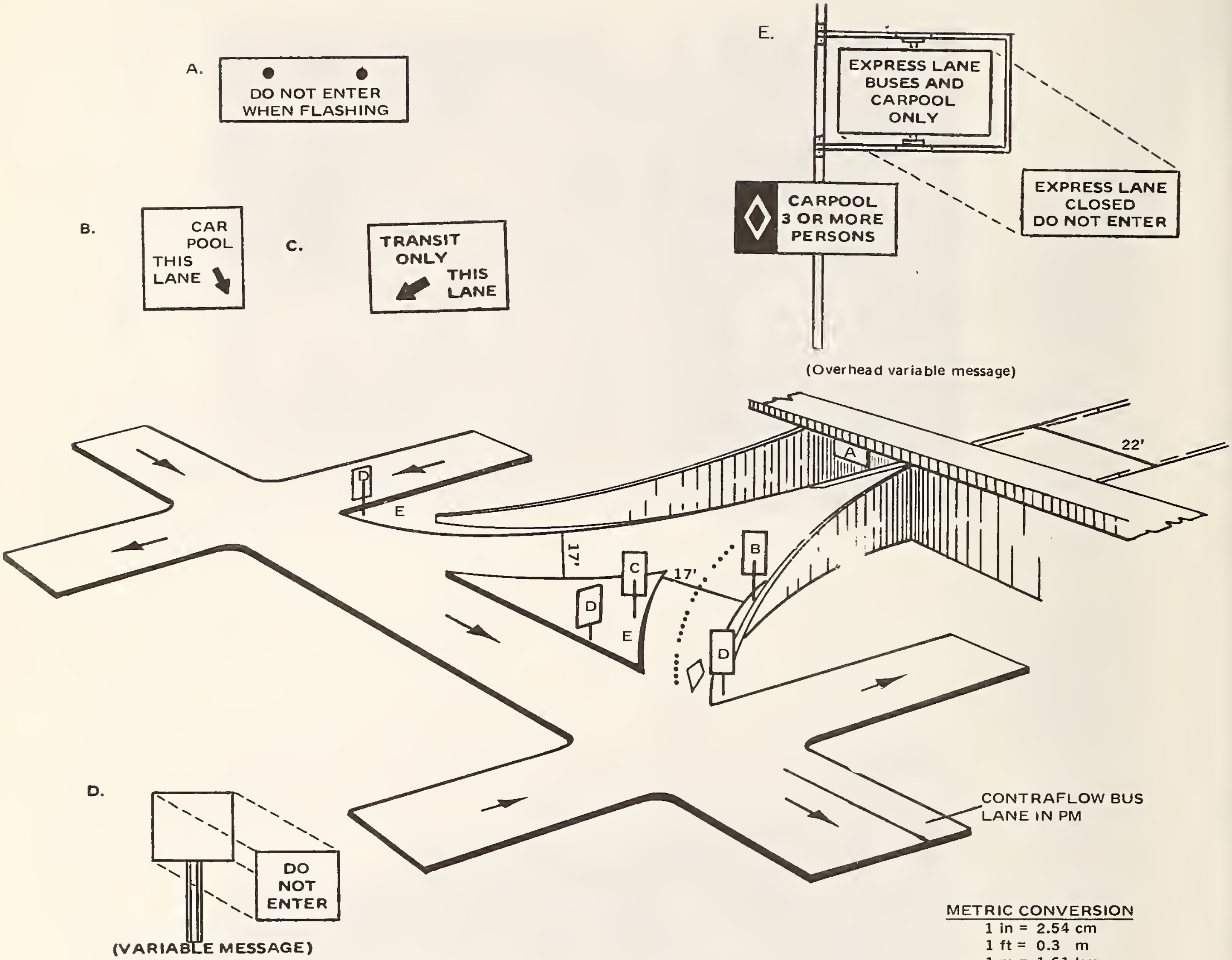
ALIGNMENT: varies
VERTICAL SIGHT DISTANCE: good
POSTED SPEED: none
ROADSIDE HAZARDS: none
OTHER HAZARDS: sharp curb radii and no shoulders

MUTCD DESIGN FACTORS

LANE-USE CONTROL SIGNALS: ramp meter
ADVANCED WARNING SIGNS: non-standard
RESTRICTED LANE SIGNS: standard
END OF HOVL SIGNS: none
DIAMOND SYMBOL: standard
HOVL DELINEATION: solid white line

RAMP METERING BYPASS RAMPS, LOS ANGELES, CALIFORNIA
FIGURE 13

RAMP METERING BYPASS RAMPS, LOS ANGELES, CALIFORNIA
FIGURE 13 (CONT.)



METRIC CONVERSION
1 in = 2.54 cm
1 ft = 0.3 m
1 m = 1.61 km

AASHTO DESIGN FACTORS

ALIGNMENT: curved
VERTICAL SIGHT DISTANCE: poor
POSTED SPEED: none
ROADSIDE HAZARDS: no shoulders
OTHER HAZARDS: tunnel

MUTCD DESIGN FACTORS

LANE-USE CONTROL SIGNALS: flashing signals and signs
ADVANCED WARNING SIGNS: none
RESTRICTED LANE SIGNS: non-standard
END OF HOVL SIGNS: none
DIAMOND SYMBOL: one symbol
HOVL DELINEATION: none

INTERSTATE 5 EXCLUSIVE RAMP, SEATTLE, WASHINGTON
FIGURE 14

INTERSTATE 5 EXCLUSIVE RAMP, SEATTLE, WASHINGTON
FIGURE 14 (CONT.)

The fact that the I-5 exclusive HOV ramp is reversible introduces a number of special traffic control requirements. Since this is a ramp, use of standard lane control signals would be inadequate. Three primary types of signing are used in the terminal area of the project (see Figure 14): 1) an overhead bulb matrix variable message sign, 2) a ground mounted illuminated flashing sign, and 3) an illuminated flashing sign mounted over the tunnel portal. All of these signs are non-standard, but the special conditions warrant their use.

Only an exclusive ramp, which is closed part-time or operates as a reversible ramp, requires traffic control operation. Otherwise, the restricted ramp operation can be adequately controlled by fixed message signing. On the I-5 reversible exclusive ramp, a highway department technician closes the ramp, changes the variable message signs and then opens the ramp in the reverse direction.

Overall, the Los Angeles RMB project and the I-5 exclusive ramp project receive little enforcement attention. Enforcement may be a critical item in the success of the HOV ramp treatments. Because such ramps tend to be isolated, a selective enforcement campaign has been instituted at these ramp projects.

OPERATING CHARACTERISTICS

The extent of the safety impact for an HOV project is dependent in part on the operational effectiveness of the project. The major impact of an HOV priority treatment occurs during peak periods when congestion is high and most of the traffic stream is composed of daily commuters. The operational results of each project are displayed in Table 26. From this table, several of the more significant results are:

Los Angeles RMB Project

- For the average of the 21 RMB ramps, the RMB lane carries 54 percent of the persons in 36 percent of the vehicles.
- Travel time savings to the RMB users compared to the metered lane users averaged slightly over two minutes. The maximum travel time savings averaged five minutes for the 21 RMB ramps.
- The violation rate, as measured as a percentage of all vehicles using the HOV lane, averaged 38 percent among the 21 RMB ramps and ranged from 7 to 59 percent on individual ramps.

I-5 Exclusive Ramp Project

- The peak-hour bus volume ranges from 6o to 70 vehicles. With the introduction of carpools to the ramp, the AM peak hour ramp volume increased to 106 vehicles even though the bus volume decreased by nine vehicles. When general traffic was removed from the ramp and only buses were permitted, vehicular volume drastically decreased; however, the total passenger-throughput increased by 58 percent.
- The violation rate for the AM peak hour was 7 percent during bus-only operations and 5 percent during bus/carpool operations. The number of violators using the exclusive HOV ramp remained the same between the two operating stages.

TABLE 26

OPERATING CHARACTERISTICS

(HOV Ramp Treatments)

		PROJECT/CONDITION				
		LA Freeways[a]	I-5 Exclusive Ramp			
VARIABLE	UNIT	Bus/2 ppv Carpool	Before	Bus-Only	Bus-Only	Bus/3 ppv Carpool[b]
Critical Peak Period	—	6 - 9 AM; 3 - 6:30 PM	24 hour	24 hour	7 - 8 AM	7 - 8 AM
Length of HOV Lane	Miles	—	0.22	0.22	0.22	0.22
Total Peak Directional Lanes	Lanes	2	1	1	1	1
Number of HOV Lanes	Lanes	1	1	1	1	1
Volume - All Lanes	Vehicles	1,409	4,650	—	—	—
Volume - HOV Lanes	Vehicles	509	—	396	70	106
Volume - HOV Lanes (bus only)	Vehicles	14	—	370	65	56
HOV Lanes/Total Volume	%	36.1	—	—	—	—
Auto Occupancy - All Lanes	PPV	1.43	—	—	—	—
Auto Occupancy - HOV Lanes	PPV	2.11	—	—	—	—
Person Throughput - All Lanes	Persons	2,821	7,250	—	—	—
Person Throughput - HOV Lanes	Persons	1,534	—	11,431	2,086	1,954
HOV Lanes/Total Throughput	%	54.4	—	—	—	—
Travel Time Savings (Average)	Minutes	2.1	—	—	—	—
Travel Time Savings (Maximum)	Minutes	5.3	—	—	—	—
Violation Rate	%	38.3	—	3.5	7.0	4.7

Metric Conversion

1 mile = 1.61 kilometers

a. Data are the average of 21 ramps on Santa Monica, Golden State and Harbor Freeways.

b. Data was compiled one month after inclusion of carpools to the HOV strategy.

Besides affecting the ramp operation, a ramp metering and bypass project should favorably affect traffic flow and operations on the freeway mainline. Data was not available to accurately portray such effects on the LA RMB project.

ACCIDENT ANALYSIS

The accident data on the two HOV ramp projects is analyzed by 1) peak period accident rates, 2) daily accident rates and 3) accident characteristics. The absence of either accident or operational data make it impossible to conduct as thorough accident analyses for this treatment as has been done for other HOV treatments.

Peak Period Accident Rates

Table 27 presents the peak period accident rate analysis for the isolated RMB ramps for the Los Angeles RMB project. There were no before period volume counts on the individual ramps making comparative analyses impossible. However, accident rates are summarized by 1) per year basis for both before and after operating periods and 2) per million vehicles for only the after operating period. From this table, the following general conclusions can be developed:

- The total number of accidents per year increased after the RMB lanes were implemented. The average number of accidents on all 21 ramps increased from two accidents/year to 17 accidents/year. The numbers of accidents on individual ramps were too small to be statistically significant, but taken collectively, the increase was statistically significant based on the sign statistical test.

- There was no significant difference in the relative distribution of AM/PM peak period accidents from the before to the after operating conditions.

RMB was implemented on the eastbound Santa Monica Freeway in Los Angeles under a schedule that makes possible some comparative accident analyses of the freeway mainline effects. The following freeway operating conditions were analyzed and compared: 1) before implementation of RMB lanes, 2) after implementation of RMB lanes and before implementation of the "Diamond Lane" concurrent flow HOV project, and 3) after implementation and termination of the "Diamond Lane" project.[2] Table 28 presents the freeway mainline accident rates, based on million vehicle-miles and million person-miles, for these operating conditions.

As can be seen in Table 28, the accident rates (both per MVM and MPM) did not change significantly between the before condition and the period during which the eight RMB ramps were being implemented, although there were slight numerical increases. After the "Diamond Lane" project was terminated and the number of carpools had increased, there were slight numerical declines in the accident rates, but these declines were not statistically significant. Thus, it is concluded that the RMB lane treatment, as a system on the eastbound Santa Monica Freeway, had no significant effect on safety on the freeway mainline.

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2. For detailed information on the "Diamond Lane" concurrent flow HOV project on the Santa Monica Freeway, please see Chapter 3.

TABLE 27

PEAK PERIOD FACILITY ACCIDENT RATES

(Los Angeles HOV Bypass of Ramp Metering)

FREEWAY	RAMP	PEAK PERIOD	BEFORE RMB		AFTER RMB			
			Acc.	Acc./ Year	Acc.	Acc./ Year	Vehicles (million)	Acc. Rate/ Million Vehicles
Santa Monica Freeway	Hoover St.	PM	1	1	3	1.7	.59	5.1
	Vermont Ave.	PM	0	0	0	0	.71	0
	Western Ave.	PM	2	2	5	2.8	.49	10.2
	Grenshaw Blvd.	PM	0	0	2	0.6	.52	3.8
	Fairfax Ave.	PM	0	0	1	0.6	.45	2.2
	Vermont Ave.	AM	0	0	0	0	.35	0
	Western Ave.	AM	0	0	1	0.9	.43	2.3
	Grenshaw Blvd.	AM	1	0.5	0	0	.29	0
	Venice Blvd.	AM	0	0	2	1.8	.25	8
	National Robertson	AM	0	0	0	0	.25	0
	Manning Ave.	AM	0	0	0	0	.49	0
	Bundy Dr.	AM	0	0	2	1.1	1.03	1.9
	Cloverfield Blvd.	AM	0	0	0	0	.20	0
Harbor Freeway	Vernon Ave.	AM	0	0	0	0	.12	0
	Florence Ave.	AM	0	0	0	0	.14	0
	EB Manchester	AM	0	0	1	2.4	.09	11.1
	WB Artesia	AM	0	0	0	0	.18	0
	EB Artesia	AM	0	0	0	0	.07	0
Golden State Freeway	Statium Way	PM	0	0	0	0	.24	0
	EB Los Feliz	PM	0	0	1	0.7	.91	1.1
	EB Western Ave.	AM	0	0	1	0.7	.27	3.7
Total	All Ramps		4	2.0	19	17.3	8.07	0.38

TABLE 28

PEAK PERIOD FACILITY ACCIDENT RATES ON SANTA MONICA FREEWAY MAINLINE

VARIABLE / CONDITION	TIME PERIOD	AM PEAK PERIOD		
		Number of Accidents	Accident Rate[a] (acc/mvm)	Accident Rate[a] (acc/mpm)
Metering only	3/74 - 4/75	151	2.4	2.1
RMB (prior to mainline treatment)[b]	5/75 - 2/76	115	3.0 ns	2.5 ns
Metering only (after main-line treatment)[b]	8/76 - 12/76	55	2.8 ns	2.3 ns

a. Statistical significance of accident rates compared to the before condition: ns indicates difference is not significant.
* indicates a 95 percent level of significance.
**indicates a 99 percent level of significance.

b. The mainline treatment refers to the "Diamond Lane" HOV experiment; see Chapter 3.

Metric Conversion

1 mile = 1.61 kilometers
1 acc/mvm = 0.62 acc/mvk

The accident history for the I-5 exclusive ramp project is discussed in the following section.

Daily Accident Rates

The RMB treatment should not have a major impact on the ramp operation during non-operating hours. For the Los Angeles RMB projects, an analysis by accidents/MVM is not possible due to a lack of 24-hour ramp volumes, but an analysis on the basis of accidents per year is presented in Table 29. From the before to the after operating conditions, the accident rate on all 21 ramps increased by 66 percent from 33 to 55 accidents per year. This increase was statistically significant. If the peak period accidents are removed from the analysis, the total off-peak accident rate for all ramps increased by 19 percent from 31 to 37 accidents per year from the before to the after condition. Most of the increase in the daily accident rate was then due to the changes in the peak period.

On the I-5 exclusive HOV ramp, only five accident have occurred over six years of bus-only operations resulting in a bus accident rate of 35 accidents/MVM (56 accidents/MVK). This accident rate compared favorably to the Seattle system-wide bus accident rate of 62 accidents/MVM (100 accidents/MVK). None of these accidents were directly caused by the HOV operation, but rather by the reversible operation and other site-specific characteristics of the ramp.

During the first 15 months of bus/carpool operations on the I-5 exclusive HOV ramp, there were no reported accidents of any kind. Officials attributed this performance in part to the low volume of carpools.

Accident Characteristics

There were very few injury accidents on any of the ramps studied. On the Los Angeles RMB ramps, there was a trend in the off-peak period toward a higher percentage of accidents producing injury from 30 percent in the before condition to 46 percent in the after condition. The sample sizes were too small to test statistically. On the I-5 exclusive ramp, only one of the five accidents resulted in a slight injury. The low speeds on the ramps help to contribute to a low injury rate.

As summarized for the Los Angeles RMB project, Table 30 presents the peak period percentage breakdown of the accidents as to 1) vehicle type, 2) location of accidents and 3) pre-collision events and 4) accident type. The sample sizes for this table are small, so any conclusions developed from this data should be viewed with caution. From this table, several of the more significant results are:

- No buses were involved in any accidents.
- There was a greater tendency for accidents to occur at or near the ramp entry. (This is further discussed in the next section.)
- The distribution of pre-collision events did not change substantially. There were several lane change accidents in the after condition, which could not have occurred in the before condition except on the one two-lane ramp.

TABLE 29

DAILY FACILITY ACCIDENT RATES

(Los Angeles HOV Bypass of Ramp Metering)

		BEFORE CONDITION		AFTER CONDITION	
FREEWAY	RAMP	Accidents	Accidents/Year	Accidents	Accidents/Year
Santa Monica Freeway	Hoover St.	5	2.5	4	2.2
	Vermont Ave., WB	5	2.5	3	1.7
	Vermont Ave., EB	0	0	0	0
	Western Ave., WB	3	1.5	9	5.0
	Western Ave., EB	6	3.0	3	2.7
	Grenshaw Blvd., WB	15	7.5	9	5.0
	Grenshaw Blvd., EB	6	3.0	6	16.2
	Fairfax Ave.	2	1.0	2	1.3
	Venice Blvd.	1	0.5	3	2.7
	National Robertson	0	0	1	1.3
	Manning Ave.	2	1.0	1	0.9
	Bundy Dr.	2	1.0	4	2.2
	Cloverfield Blvd.	7	3.5	0	0
Harbor Freeway	Vernon Ave.	0	0	0	0
	Florence Ave.	4	2.0	1	2.4
	EB Manchester	0	0	4	9.6
	WB Artesia	2	1.0	2	4.8
	EB Artesia	1	0.5	1	2.4
Golden State Freeway	Statium Way	0	0	1	0.7
	EB Los Feliz	3	1.5	5	3.3
	EB Western Ave.	1	0.5	1	0.7
Total	All Ramps	65	32.9	60	54.6

TABLE 30

ACCIDENT CHARACTERISTICS BY PERCENTAGE (PEAK PERIOD)

(Los Angeles HOV Bypass of Ramp Metering)

CHARACTERISTIC	BEFORE RMB	AFTER RMB
Vehicle Type		
• Auto	100	100
• Other	0	0
Location		
• Ramp Exit	0	2
• Ramp	0	0
• Ramp Entry	78	45
• Ramp Area - Intersect Street	22	50
• In Intersection	0	3
Pre-Collision Events		
• Stopped	37	29
• Going Straight	25	29
• Ran Off Roadway	38	32
• Changing Lanes	0	8
• Other	0	3
Collision Type		
• Sideswipe	0	26
• Rear-End	50	63
• Other	50	10

- There was a distinct increase in the percentage of side-swipe accidents and a slight increase in the percentage of rear-end accidents.

SAFETY CHARACTERISTICS

Causative Factors Influencing Safety

The exclusive HOV ramp project in Seattle did not exhibit any accident characteristics which could be directly assigned to the HOV treatment. Indeed, the exclusive use of the ramp probably enhanced the safety of the particular ramp, although comparative data were not available to test this suggestion.

On the LA RMB project, an accident trend was observed which does seem to be directly related to HOV operations. The shifts in accident characteristics reported earlier point to a recurring conflict between vehicles entering the ramp from several surface street approaches and having to split into the two lanes. Often, some weaving can be expected in these maneuvers and accidents can result from the somewhat unpredictable movements by entering vehicles.

Difficult Maneuvers and Potential Safety Problems

An HOV priority treatment might be expected to generate potential safety problems on a transportation facility. Project personnel for the HOV ramp treatment projects identified several possible difficult maneuvers and safety problems that could be associated with this type of treatment. Such safety problems include:

- On RMB ramps, the HOVs move through the metering signal station without stopping, while vehicles in the metered lane must stop and queue up. The potential exists that a violator (or HOV finding itself in the wrong lane) may attempt to change lanes into the faster HOV lane.

- Where the RMB lane and the metered lane converge after the metering signal station, there is the potential for merging related accidents to occur. This condition is not unique to an HOV treatment.

- As discussed in the previous section, the conflicts at the ramp entry are the most significant safety problems with the HOV ramp treatment. Commonly, vehicles may enter the ramps from several surface street approaches and have to split into two lanes. This safety problem is further compounded if the metered queue extends back onto the surface street. In this event, HOVs "trapped" in the queue on the surface street may attempt erratic maneuvers to bypass this temporary delay, and move directly onto the ramp in the HOV lane.

RECOMMENDATIONS

The previous sections have shown that the RMB treatment can adversely impact safety. On the other hand, the exclusive HOV ramp has not been shown to have general safety problems unless they are site-specific. General recommendations on safety of HOV priority treatments are presented on page 7. Specific recommendations that may improve the safety of an HOV ramp treatment include the following:

Ramp Metering Bypass Lanes

- Ideally, the HOV lane should be physically separated from the metered lane(s), either by being constructed separately (thus having many characteristics of exclusive ramps) or by barriers. This is particularly important at the ramp entry. Shoulders should be provided to enable unintentional violators to pull-off the travelled lane.

- When separation is not possible and if the ramp is long and has sufficient storage capacity, begin the HOV lane after the entrance point so there is a single entry lane. This may at times delay HOVs but would largely eliminate the entry conflicts.

- Sufficient merging distance should be provided on the body of the ramp so that HOVs and general traffic can merge together and assume the same speeds prior to merging on the freeway.

- The selection of right or left lanes as the HOV lane is important particularly on non-separated RMB ramps. Consideration should be given to access to the ramp, position of signals vis. a vis. the stopped queue and how the two lanes will merge. It is impossible to give specific guidelines in this regard because of the diversity of site specific parameters; however, the most important items to consider are summarized below:

  1) Generally, the preferred configuration is to have the HOV lane on the left as this configuration allows the slower metered traffic to merge with HOV traffic on the left. This technique provides general traffic with a customary merging situation and eliminates the problem of general lane drivers being wary of traffic on both sides.

  2) If metering signals are pole mounted, the preferred lane for metering is the left, so that drivers have a better view of the signal. If the right lane is the metered lane, consideration should be given to providing a narrow median with a signal installed both in the median and on the right. Adequate lighting, reflectorization, channelization and MUTCD policies are needed to prevent collisions with the median or signal standard during hours of darkness.

  3) On curved ramps, the HOV lane should generally be on the outside of the general lane (i.e. the lane having the larger radius). This gives the non-stop HOVs a lower degree of curvature, but more importantly, metered lane traffic has a clearer rear view of the HOV lane, thus reducing the hazard of their changing lanes.

- Metering rates, queue lengths and HOV operations should be reviewed on a continual basis to optimize the operation of the ramp and minimize traffic problems.

Exclusive HOV Ramp

- Implementation of exclusive HOV ramps can be accomplished through either new construction or conversion of existing ramps. Adding ramps generally have minimal effect as they do not result in substantially changed traffic problems. Thus, new exclusive HOV ramps should be planned in locations having a special need for access or in locations which allow the provision of preferential service for HOVs to encourage their use.

- Converted ramps can displace a significant amount of traffic since not all former users can or will shift to HOVs. This displacement places a burden on the mainline freeway and/or ramps at other interchanges. Thus, HOV ramp locations should be carefully selected and consideration should be given not only to the access needs of the HOVs, but also to the resulting adverse impacts.

- The intersection with surface streets is of particular concern for HOV ramps. This is especially true if the ramp is reversible. Hazardous maneuvers or conflicts with surface traffic should be minimized by proper geometric design and/or traffic controls.

- Exclusive HOV ramps generally require restrictive traffic control devices only at the input terminals to identify the authorized users, times, etc. At outputs it may be necessary to post "do not enter" signs. Reversible HOV ramps are more complex, particularly at the surface street intersection. Wrong-way entry can possibly be a problem on these ramps, and traffic controls must be absolutely positive in displaying the proper usage. Changeable message signs and traffic-actuated stop signs may effectively supplement time-control static signs.

CHAPTER SEVEN

SEPARATE HOV FACILITY ON ARTERIAL STREET

DETAILED DESCRIPTION

Separate facilities on an arterial street system are commonly referred to as "transitways" because the only type of vehicle that is generally permitted to travel on such a facility is the transit coach. There are two types of transitways, each serving a different objective:

(1) A separate facility serving as a major transit collection/distribution route. These facilities tend to be located in the central business districts in order to provide a high level of transit accessibility to heavily concentrated retail and business districts. Commonly associated with this transitway is some type of pedestrian mall and other aesthetic features. The benefits with this type of transitway are transit accessibility and separation of different classes of vehicles.

(2) A separate facility serving the line-haul portion of transit service. Because of this function, these facilities tend to connect the CBD with outlying areas. The benefits associated with this type of transitway would be the more traditional HOV objectives of travel time savings and increased total person through-put.

This chapter will examine the separate facility serving as a major transit collection/distribution route, because this is the predominant type of separate facility on an arterial street. The transitway can range in length anywhere from several blocks up to one mile. Such transitways exist in Minneapolis, Minnesota (Nicollet Mall), Portland, Oregon (Portland Mall), Chicago, Illinois (Halsted and 63rd Streets), and Philadelphia, Pennsylvania (Chestnut Street). Preliminary discussions with project personnel for several of these transitway projects indicate safety of the facility is not a problem. There was no separate facility HOV project studied in detail because of the lack of a safety problem. The remainder of this chapter then examines transitways from a general standpoint.

A separate facility generally consists of a two lane, undivided arterial street. For the transitway that has an elaborate pedestrian mall associated with it, the arterial street may have been a four-lane facility that has been modified to a two-lane facility. This extra width then allows for the inclusion of more elaborate and wider pedestrian sidewalks as well as a curved roadway if desired for aesthetic purposes.

Access and egress to the separate facility most often occurs only through the facility's terminal points even though the facility will most likely traverse at-grade intersections with cross streets. The access and egress is controlled at the cross-street intersections through both traffic restrictions and possibly supportive geometrics such as a low curvature radius not allowing for AASHTO's 24 feet (7.2 m) minimum turning path for a passenger car. By controlling the access and egress of the facility, the safety and enforcement aspects of the facility can be enhanced. Terminal treatments for a separate facility can vary considerably because the treatments are site-specific. Generally, the separate facility is established by restricting, for the desired length, an arterial street that previously handled through traffic. For this treatment, the approaching general traffic on the arterial can be channeled and guided from the transitway much in the manner of a non-through leg of a T-intersection.

Traffic control devices applied to the separate facility treatment restrictions are most needed in the vicinity of the terminal areas and cross streets. This is the location where the general traffic and separate facility need to be effectively and safety segregated. A variety of localized regulatory signs and markings are necessary to 1) inform motorists of the separate facility's restrictions, and 2) channel the different classes of traffic into or away from the separate facility.

As previously mentioned, a separate facility is often associated with a pedestrian mall. In order to make the mall and transitway more aesthetically pleasing, the proper use of traffic control devices has been compromised on several projects. This compromise includes such matters as the placement of non-standard signs in inconspicuous places and elimination of pavement markings and crosswalk markings. Police may believe that the use of inconspicuous, non-standard signs does not provide a legally acceptable basis for the issuance of citations. The elimination of pavement markings and cross lines may violate the MUTCD "advisory" standards as follows:

- "Stop lines should be used . . . where it is important to indicate the point, behind which vehicles are required to stop, in compliance with a STOP sign, traffic signal, officer's directions, or other legal requirement"
- "Crosswalks should be marked at all intersections where there is substantial conflict between vehicle and pedestrian movements"

The elimination of crosswalk markings may be especially important for safety regarding a pedestrian mall transitway because of the high pedestrian volume for such a separate facility.

The main function of a transitway associated with local bus service is to provide a high level of transit accessibility to heavily concentrated retail and business districts. Both local and express bus routes may feed into the transitway, but once on the transitway the bus service becomes local in nature. The transitway may operate with bus service up to 24 hours each day, or as long as the local bus service operates. The bus volume tends to be greatest during the peak-hours where over 60 buses per peak hour may be operating in one direction. Generally, there is not a significant directional split in bus volumes because the location of the facility tends to be in the central business districts. It is possible that the operation of a separate transitway may slightly increase the running time for transit over the bus operation in general traffic. However, this possible increase in running time is more than offset by the improved stature for transit through having its own facility to travel within a major pedestrian concentration. The average running speed is likely to range between 10 and 15 mph (16 to 24 kph).

SAFETY CHARACTERISTICS

The overall safety experience of separate facility transitways has been very good. Safety does not appear to pose even a minor concern to the officials associated with transitway projects. Buses simply travel the facility in a standard manner stopping periodically at bus stop locations and intersections.

A difficult maneuver could exist in the vicinity of the entry/exit locations to the transitway. Partly because of this potential, the only entry/exit locations generally occur at the terminals, thereby eliminating turning movements onto or off the transitway at intermediate locations. In the vicinity of the terminals, the following two coordinated movements need to occur:

1. The approaching bus and general traffic need to be separated—the bus traffic channeled into the transitway and the general traffic channeled away from the transitway.

2. The bus traffic on the transitway needs to be channeled off the transitway and merged with any general traffic that would be traveling away from the transitway.

Potential safety problems for a transitway might include 1) pedestrian conflicts, or 2) conflicts with cross street general traffic.

Pedestrian conflicts are likely to be the main safety concern because of large pedestrian volumes attracted by the pedestrian mall and the transit collection/distribution service. Pedestrian movements can be quite varied and are difficult to control. A pedestrian mall with its commercial, aesthetic and unique characteristics (exhibits, displays, public entertainment, etc.) provides visual distractions that could adversely affect pedestrian movement, such as unknowingly stepping into a traffic lane. The minimization of pedestrian conflicts on the transitway could become the sole responsibility of the transit agency as a result of traffic engineering and enforcement agencies abandoning efforts on pedestrian control on the transitway.

Conflicts with cross street general traffic can involve either pedestrian movements or bus movements. One objective of the transitway is to have it look unlike the common city street. If the project is indeed successful with this camouflage, there may be conflicts as a result of the cross street traffic not realizing the existence of the transitway. Because of a lack of familiarity, out-of-town motorists may have a greater propensity for being involved in these conflicts.

RECOMMENDATIONS

A separate facility transitway on an arterial street or highway can be a safe and effective HOV technique. General recommendations on safety of HOV priority treatments are presented on page 7. Specific recommendations that may improve the safety of a separate HOV facility operation include the following:

- Cross streets across the transitway should be eliminated whenever possible. When the elimination of cross streets is impossible, the turning movements between the transitway and the cross streets should be restricted. Traffic signals and signs should be standard and easily visible to the motorists. A one-way cross street is preferred to a two-way cross street because of the fewer potential conflicts and traffic operational requirements.

- Procedures regarding bus operations on the transitway should include 1) low bus speeds, and 2) increased driver awareness and courtesy. A low bus speed should not detract from the bus operations because the prime advantage of the transitway is its accessibility and that is not affected. Buses can be equipped with bells or chimes to indicate their presence.

- All appropriate pedestrian controls should be instituted. These include pedestrian crosswalks, pedestrian signals and strict enforcement of "jay-walking." The pedestrian crosswalks and signals may be located at intersection and mid-block locations.

CHAPTER EIGHT

CONCURRENT FLOW HOV LANE ON ARTERIAL STREET

DETAILED DESCRIPTION

Concurrent flow priority applications involve reservation of either the curbside lane or the median lane for HOVs. The different applications have differing operational objectives and requirements.

Curbside lanes have historically been installed to provide better transit circulation in the CBD and/or to improve downtown traffic flow through the segregation of buses and autos. A second objective may be to provide a travel time improvement (not advantage) for the HOV vehicle (i.e. bus). This type is commonly associated with local bus service making stops at assigned locations (bus stops) for passenger loading and unloading. The concurrent flow curb HOV lane can be either a 24-hour or peak-period operation over a project length that ranges from several city blocks to several miles. Taxi-cabs, other vehicles loading and unloading passengers, right-turning vehicles, motorcycles and bicycles may also be permitted to travel in the curb HOV lane.

Median lanes are generally intended to provide high-occupancy vehicles with travel time advantages by bypassing traffic congestion in the general traffic lanes. This type is commonly associated with express bus service operating in a "through" or "express" mode. The concurrent flow median lane operates generally during the peak period in the peak direction, over a project length of several miles. Carpools may also be permitted to travel in the concurrent flow median HOV lane.

This research examined four concurrent flow HOV lane projects. Project descriptions are given below and in Figures 15 to 18.

- <u>Washington, D.C. CBD, Washington, D.C. (Figure 15)</u>
  This project has 28 lane-miles (45 lane-kilometers) of curb lanes on 18 arterial streets or service roads. Some streets have a bus lane in each direction, while others have the priority treatment in only one direction. The length of the curb lane ranges from 0.1 mile (0.2 km) (one city block) to 3.6 miles (5.8 km). The curb bus lanes are generally in effect for both peak periods (7:00 - 9:00 AM and 4:00 - 6:00 PM) but there are exceptions to this including a 24-hour operation and several peak period/peak direction-only operations. Implementation of the curb bus lanes occurred over a period of 12 years beginning in 1962. The objective of the project is to provide for more efficient circulation of buses in the downtown area and also to reduce bus travel times on radial arterials. During the time of bus lane operation, taxi-cabs, other vehicles loading and unloading passengers, right-turning vehicles, motorcycles, and bicycles are also permitted to use the lane.

- <u>U.S. 1/South Dixie Highway, Miami, Florida (Figure 16)</u>
  This project includes a concurrent flow median carpool lane, a contraflow median bus lane and signalization improvements on a 5.5 mile (8.9 km) segment of South Dixie Highway (U.S. 1). A carpool is defined here as a vehicle carrying two or more persons. Left turns across the median HOV lane are prohibited. The HOV lanes operate in the peak direction during the peak periods of 7 - 9 AM and 4 - 6 PM. The project commenced in July, 1974. In April, 1976, express "Blue Dash" buses were transferred into the concurrent flow median carpool lane.

- Kalanianaole Highway, Honolulu, Hawaii (Figure 17)
  This 2.4 mile (3.9 km) HOV project includes a 1.9 mile (3.1 km) contraflow bus/carpool lane[1] connecting into a 0.5 mile (0.9 km) concurrent flow median bus/carpool lane. A carpool is defined as a vehicle carrying three or more persons. The project operates in the inbound direction only during the AM peak period (approximately 6 - 8 AM). It began as a bus-only HOV operation in August, 1973, but it was altered to a bus/carpool operation in September, 1975.

- N.W. 7th Avenue, Miami, Florida (Figure 18)
  This project included express "Orange Streaker" buses operating in a reserved bus lane for ten miles (16.1 km). For a section of 2.6 miles (4.2 km), the inbound median lane was reserved throughout the day for buses and vehicles weaving into left-turn bays. The buses in effect utilized this lane only from 6:00 - 9:00 AM. The remaining bus lane consisted of a reversible median bus lane.[2] Express buses operated in the concurrent flow median bus lane with 1) signal preemption,[3] 2) signal progression, and 3) a combination of the two. The N.W. 7th Avenue bus priority system commenced August, 1974, and operated until March, 1976. On this latter date, the project was terminated and the express bus operation was transferred to the nearby Interstate 95 concurrent flow HOV lanes.[4]

Tables 2 and 3 present the national standards regarding geometrics and traffic control devices applicable to HOV priority treatments. Figures 15-18 show how each project addresses these items.

The Washington, D.C. project is deficient on various streets in lane width and proximity of roadside hazards. The U.S. 1/South Dixie Highway project is deficient in lane widths, proximity of roadside hazards, and sight distance on occasion. The Kalanianaole project is deficient in lane width and proximity of roadside hazards. The N.W. 7th Avenue project is deficient in only the proximity of roadside hazards.

The deficiencies regarding lane width and proximity of roadside hazards are quite common for urban areas and especially for downtown areas where available right-of-way for streets and highways is a scarce commodity. These deficiencies more often would effect the operation of a curb bus lane than a median bus lane for the following reasons: 1) the curb bus lane is closer to roadside hazards off the curb; 2) the curb lane oftentimes slopes towards the gutter causing the bus to lean toward the roadside hazards; 3) the bus operations in a curb lane is commonly providing local service requiring the bus to stop as near the curb as possible for passenger loading and unloading; and 4) the bus volume in a curb lane tends to be higher. The existence of these deficiencies does not necessarily indicate that there is a safety problem, as safe operations can be achieved with lane widths of less than 12 feet (3.6 m) and roadside hazards within eight feet (2.4 m) of the roadway.

Only the Washington, D.C. project closely conforms to the MUTCD requirements regarding preferential lane signing and marking, having recently completed the changeover to the MUTCD standards. The other three projects have their own preferential lane signing while omitting use of the diamond pavement symbol. All four projects were implemented prior to the January 1, 1976, compliance date established for the MUTCD special markings and signing for preferential lane-use control.

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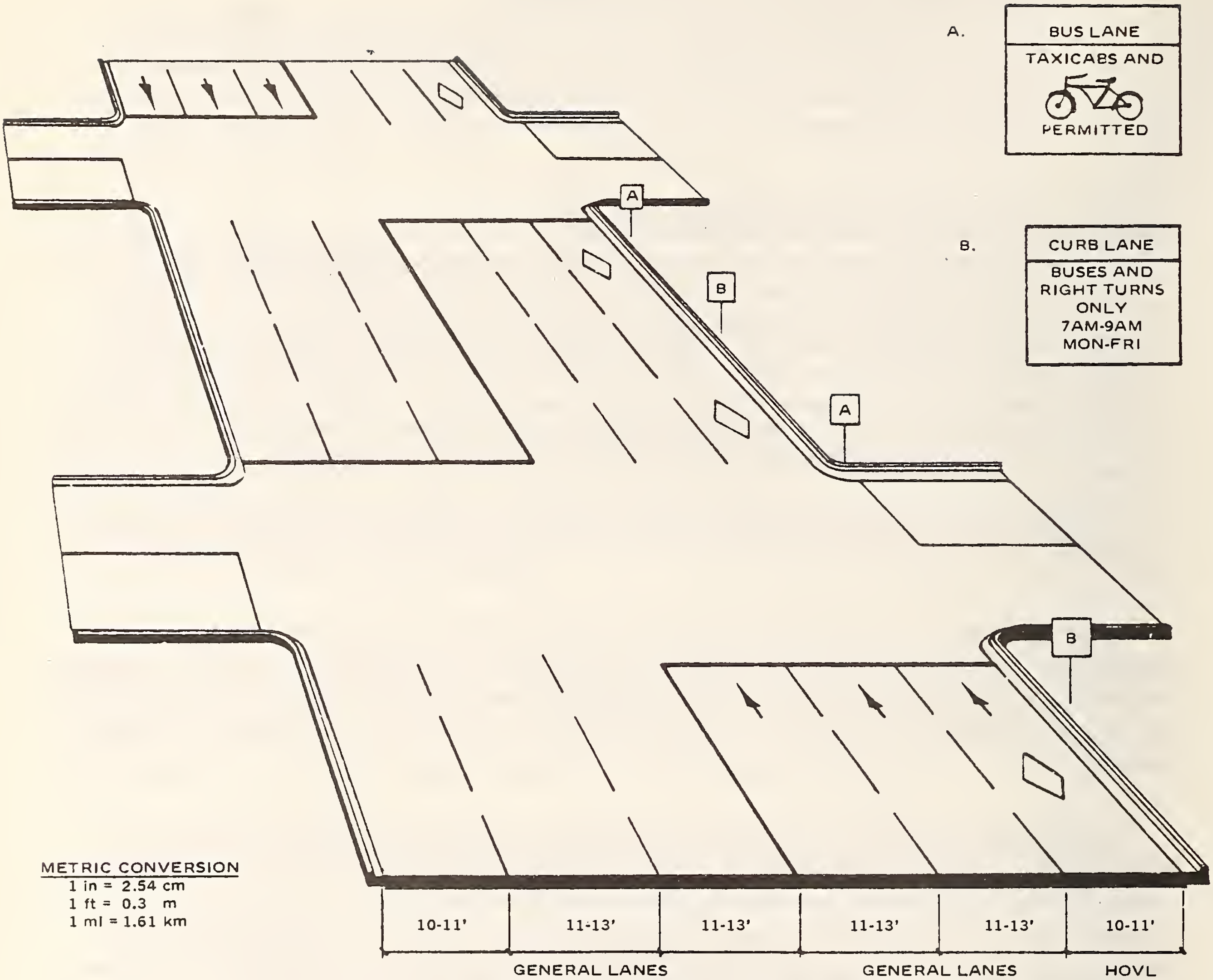
1. See Chapter Nine.
2. See Chapter Nine.
3. See Chapter Ten.
4. See Chapter Three.



AASHTO DESIGN FACTORS

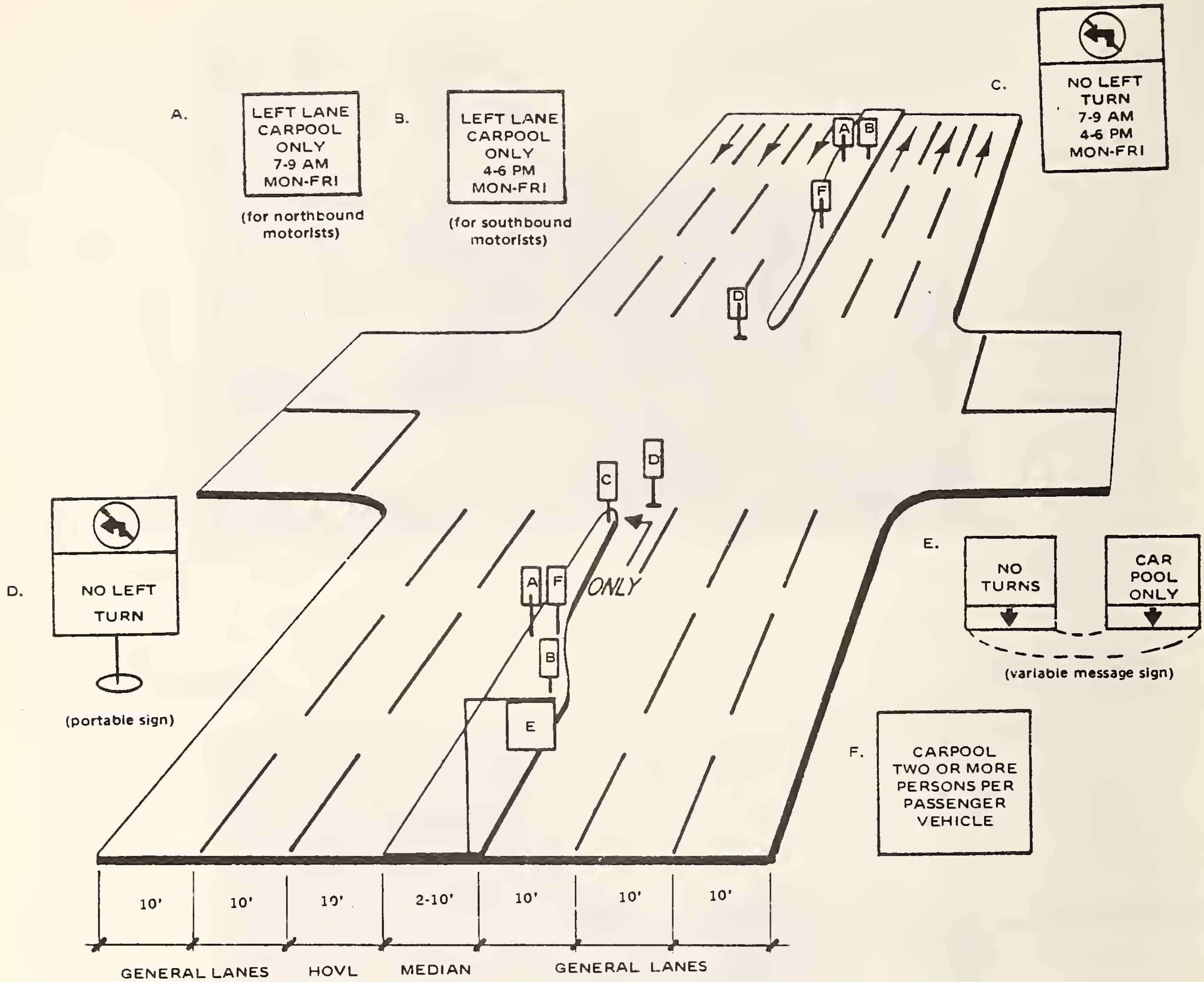
ALIGNMENT: varies
VERTICAL SIGHT DISTANCE: adequate to good
POSTED SPEED: varies
ROADSIDE HAZARDS: poles within several feet of roadway

MUTCD DESIGN FACTORS

LANE-USE CONTROL SIGNALS: none
ADVANCED WARNING SIGNS: standard
RESTRICTED LANE SIGNS: standard
END OF HOVL SIGNS: standard
DIAMOND SYMBOL: standard
HOVL DELINEATION: none

WASHINGTON, D.C. CBD STREETS
FIGURE 15

WASHINGTON, D.C. CBD STREETS
FIGURE 15 (CONT.)



METRIC CONVERSION
1 in = 2.54 cm
1 ft = 0.3 m
1 mi = 1.61 km

AASHTO DESIGN FACTORS

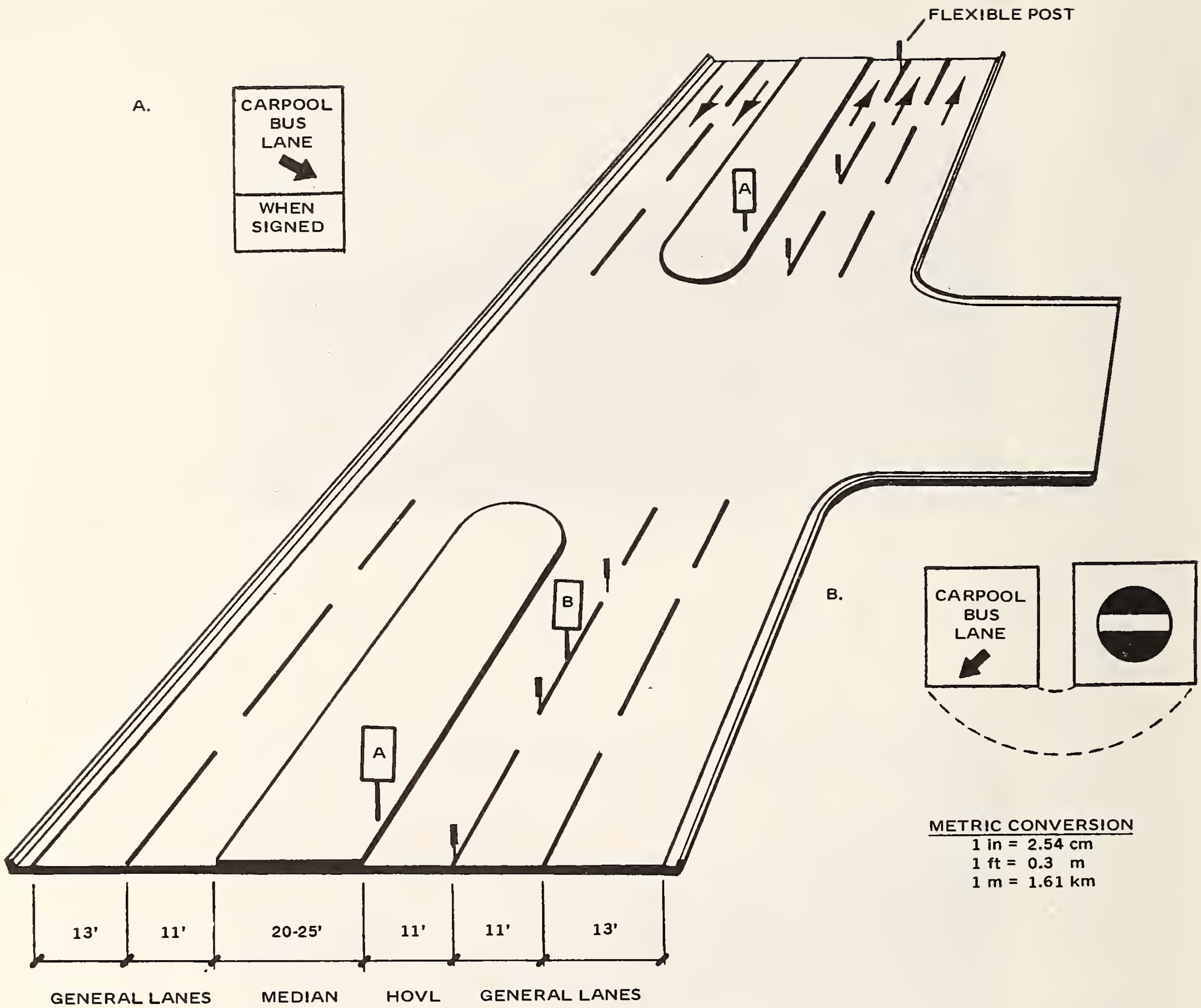
ALIGNMENT: linear
VERTICAL SIGHT DISTANCE: adequate to poor
POSTED SPEED: 35 mph
ROADSIDE HAZARDS: poles within several feet of roadway

MUTCD DESIGN FACTORS

LANE-USE CONTROL SIGNALS: none
ADVANCED WARNING SIGNS: non-standard
RESTRICTED LANE SIGNS: non-standard
END OF HOVL SIGNS: none
DIAMOND SYMBOL: none
HOVL DELINEATION: skip white marking

U.S. 1/SOUTH DIXIE HIGHWAY (CONCURRENT FLOW LANE), MIAMI, FLORIDA
FIGURE 16

U.S. 1/SOUTH DIXIE HIGHWAY (CONCURRENT FLOW LANE), MIAMI, FLORIDA
FIGURE 16 (CONT.)



AASHTO DESIGN FACTORS

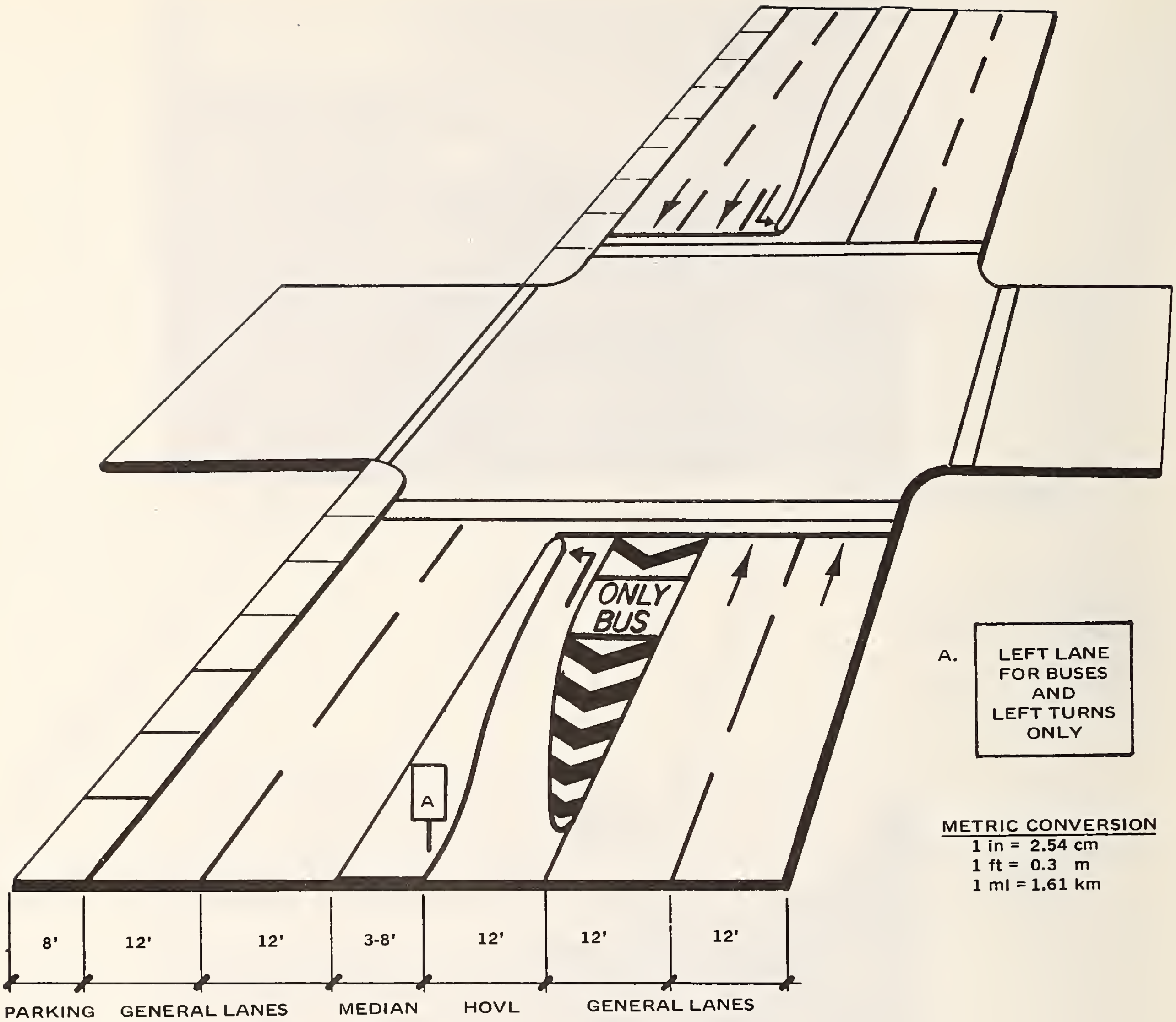
ALIGNMENT: linear
VERTICAL SIGHT DISTANCE: good
POSTED SPEED: 35 mph
ROADSIDE HAZARDS: poles within several feet of roadway

MUTCD DESIGN FACTORS

LANE-USE CONTROL SIGNALS: none
ADVANCED WARNING SIGNS: none
RESTRICTED LANE SIGNS: non-standard
END OF HOVL SIGNS: non-standard
DIAMOND SYMBOL: none
HOVL DELINEATION: skip white line with flexible posts

KALANIANAOLE HIGHWAY (CONCURRENT FLOW LANE), HONOLULU, HAWAII
FIGURE 17

KALANIANAOLE HIGHWAY (CONCURRENT FLOW LANE), HONOLULU, HAWAII
FIGURE 17 (CONT.)



METRIC CONVERSION
1 in = 2.54 cm
1 ft = 0.3 m
1 mi = 1.61 km

AASHTO DESIGN FACTORS

ALIGNMENT: linear
VERTICAL SIGHT DISTANCE: good
POSTED SPEED: 35 to 45 mph
ROADSIDE HAZARDS: poles within several feet of roadway

MUTCD DESIGN FACTORS

LANE-USE CONTROL SIGNALS: none
ADVANCED WARNING SIGNS: none
RESTRICTED LANE SIGNS: non-standard
END OF HOVL SIGNS: non-standard
DIAMOND SYMBOL: none
HOVL DELINEATION: solid white marking

N.W. 7th AVENUE (CONCURRENT FLOW LANE), MIAMI, FLORIDA
FIGURE 18

N.W. 7th AVENUE (CONCURRENT FLOW LANE), MIAMI, FLORIDA
FIGURE 18 (CONT.)

In addition to signing and pavement markings, some concurrent flow median HOV lanes incorporate delineators such as polyvinyl chloride (PVC) safety posts to delineate the HOV lane. The PVC safety posts have been utilized on the Kalanianaole Highway project at an average spacing of 250 feet (75 m) in order to increase driver awareness to the HOV lane and on the U.S. 1/South Dixie Highway project at an average spacing of 40 feet (12 m) (with longer gaps at intersections providing for crossing traffic and access to the HOV lane). Both projects also involved a contraflow lane which generated the main reason for placing safety posts. On the U.S. 1/South Dixie Highway project, the safety posts for the concurrent flow HOV lane turned out to be a potential safety hazard causing motorists 1) to weave improperly (bus not illegally) between the safety posts with 40 feet (12 m) spacing, 2) to take evasive maneuvers to avoid hitting the safety posts, and 3) to accomplish the merging into and out of the HOV lane at the designated gaps in the safety posts, regardless of what the traffic flow conditions might be in the general traffic lanes. The spacing between the safety posts on this project was increased to 80 feet (24 m) and later to 120 feet (36 m) with no apparent negative effects on safety and violations in the HOV lane. Because of this development, safety posts delineating the concurrent flow median HOV lane were removed altogether.

On a concurrent flow curb HOV lane, restrictions on right-turns and parking are desirable. The restriction against right-turns however is generally impractical; thus right-turning vehicles are generally permitted to use the curb lane in order to execute the turn. The problem then is where the right-turning vehicle should be permitted to enter the curb bus lane. The legal entrance to the curb bus lane by right-turning vehicles may be defined as 1) at a distance "as close as practical" prior to making the right turn,[5] 2) within one block of the right turn,[6] and 3) after the point where the sign states "buses and right-turns only."[7] In order for a curb HOV lane to operate properly, parking in the lane must be prohibited. For the Washington, D.C. curb bus lanes, wreckers remove illegally parked vehicles from certain key streets at the beginning of the restricted operations each day. On the other streets, steel "boots" are fixed to the wheels to prevent the owner from removing the vehicle until paying the parking fine. Buses then have to pass any parked vehicle which has not been removed.

On a concurrent flow median HOV lane, restrictions on left-turns may be desirable. The U.S. 1/South Dixie Highway project instituted a prohibition on left-turns, whereas the N.W. 7th Avenue project permitted left turns during the operation of the median HOV lane. The traffic lane configuration of each project had the left-turn bay to the left of the median HOV lane thereby requiring a left-turn vehicle to weave across the HOV lane in order to enter the left-turn bay. The N.W. 7th Avenue project attempted to control this weaving through pavement markings on the bus-only lane (see Figure 18). This weaving by left-turn vehicles across the HOV lane and into a left-turn bay did not pose a safety problem. One factor for the good safety record was the limited volume of traffic—less than 30 buses per three hour peak period—that travelled in the bus-only lane. On the other hand, the U.S. 1/South Dixie Highway project prohibited left-turns because of 1) safety concerns regarding left-turn movements with a contraflow bus lane located on the other side of the raised median (the contraflow bus lane operated simultaneously with concurrent flow HOV lane), and 2) traffic flow and capacity considerations

5. Dallas, Texas curb bus lanes.
6. Washington, D.C. curb bus lanes.
7. Denver, Colorado curb bus lanes.

associated with the concurrent flow median HOV lane. Even when the contraflow lane was abolished and the express bus operation was transferred to the concurrent flow HOV lane, left-turns continued to be prohibited because of the second factor. The concurrent flow HOV lane has a high volume of carpools and if additional traffic, such as vehicles maneuvering to make a left-turn used the HOV lane, the travel speed advantage of the HOV lane would be correspondingly lessened.

OPERATING CHARACTERISTICS

The extent of the safety impact for an HOV project is dependent, in part, on the operational effectiveness of the project. The major impact of this HOV priority treatment occurs during peak periods when congestion is high and most of the traffic stream is composed of daily commuters. The operational results of each project are displayed in Table 31. Only one peak period is presented—that which experienced the most serious safety problem, or for the period which had the most data. From Table 31, several of the more significant results are:

- For the Washington, D.C. CBD project, local bus service on the facility traveled at 10 mph (16 kph), whereas express bus service on the same facility traveled only slightly higher at 13 mph (21 kph). For the median HOV lane projects, the express bus services were able to travel at speeds ranging from 23 to 26mph (37 to 42 kph).

- The U.S. 1/South Dixie Highway project and the Kalanianaole Highway project both show a travel speed advantage of the median HOV lane over the congested general travel lanes. These projects respectively had a speed differential of 7 mph (11 kph) and 5 mph (8 kph) in favor of the HOV lane. For the N.W. 7th Avenue project, the express buses traveled essentially at the same speed as the automobile because there was no appreciable traffic congestion to slow the automobile in this section of N.W. 7th Avenue. The Washington CBD project had a travel speed advantage ranging from 11 to 14 mph (18 to 23 kph) for the general travel lanes over the curb bus lane.

- The projects, which permit carpools to travel in the HOV lane, achieve a high vehicle utilization of the HOV lane. The U.S. 1/South Dixie Highway project and the Kalanianaole Highway project respectively handle 24 and 21 percent of the directional traffic in the median HOV lane. For a bus lane operation, the Washington, D.C. project and the N.W. 7th Avenue project respectively handle three and one percent of the directional traffic in the bus-only lane.

- Where there is no travel time advantage by the HOV lane, as in the Washington CBD project and N.W. 7th Avenue project, there is nearly a zero violation rate by through-moving vehicles. Where the HOV lane has a travel time advantage, as in the U.S. 1/South Dixie Highway project and Kalanianaole Highway project, closer enforcement scrutiny of the HOV restrictions is necessary. The U.S. 1/South Dixie Highway project and the Kalanianaole Highway project also permitted carpools in the HOV lane whereas the other HOV projects did not. These projects respectively had a violation rate of 5 and 10 percent.

ACCIDENT ANALYSIS

The accident data on the four concurrent-flow HOV projects, that were studied in detail, is analyzed by 1) HOV lane accident rates, 2) total facility accident rates, and 3) accident characteristics. The accident rates are calculated for both million vehicle-miles (MVM) of travel and million person-

TABLE 31

OPERATING CHARACTERISTICS

(Concurrent Flow HOV Lane on Arterial Street)

		PROJECT/CONDITION					
		Washington D.C. Project[a]	US 1/South Dixie Highway[b]		Kalanianaole Highway	NW 7th Avenue	
VARIABLE	UNIT	Bus-Only	Before	Bus/2 ppv Carpool	Bus/3 ppv Carpool	Before	Bus-Only
Critical Peak Period	—	6:30-9:30AM	7-9AM; 4-6PM	7-9AM; 4-6PM	6 - 8 AM	7-9 AM	7-9 AM
Length of HOV Lane	Miles	3.6	—	5.5	0.5	—	2.7
Total Peak Directional Lanes	Lanes	4	3	3	3	2	3
Number of HOV Lanes	Lanes	1	—	1	1	—	1
Volume - All Lanes	Vehicles	4,352	10,664	11,709	5,538	1,389	1,610
Volume - HOV Lanes	Vehicles	141	—	2,834	1,138	—	23
Volume - HOV Lanes (bus only)	Vehicles	141	—	51	18	—	23
HOV Lanes/Total Volume	%	3.2	—	24.2	20.5	—	1.4
Auto Occupancy - All Lanes	PPV	1.59	1.25	1.22	1.71	1.24	1.28
Auto Occupancy - HOV Lanes	PPV	—	—	1.71	3.26	—	—
Person Throughput - All Lanes	Persons	13,121	13,330	16,232	10,390	1,722	2,698
Person Throughput-HOV Lanes	Persons	6,438	—	6,716	4,400	—	667
HOV Lanes/Total Throughput	%	49.1	—	41.4	42.3	—	24.7
Speed - General Lanes	MPH	24	19.4	18.5	17.4	24.4	26.9
Speed - HOV Lanes	MPH	10-13	—	25.7	22.9	—	25.7
Travel Time - General Lanes	Minutes	9	17.9	17.8	1.7	6.5	5.9
Travel Time - HOV Lane	Minutes	16-22	—	12.8	1.3	—	6.2
Violation Rate	%	—	—	5.0	10.0	—	—

a. Data represent Connecticut Avenue

b. Before data are for three hour peak periods (6-9 AM and 4-7 PM) that is reduced to two hour peak periods by assuming uniform hourly rates.

Metric Conversion

1 mile = 1.61 kilometers

miles (MPM) of travel. These rates automatically take into consideration the effects of differing stage lengths and demand levels. Both the bus accident rates and total facility accident rates are compared to a "control" accident rate. Accident rates were tested with the "t" statistic to determine the statistical significance.

HOV Lane Accident Rates

Table 32 presents the accident rates for each concurrent flow median HOV lane project. The results are summarized for accident rates based on both MVM and MPM and are compared to a control accident rate. Similar data was not available for the Washington, D.C. curb bus lanes' project. From the available data, the following general conclusions can be developed:

- There is a wide range of bus accident rates associated with this type of priority treatment. The bus accident rates range from a low of 9 accidents/MVM (6 accidents/MVK) on the U.S. 1/South Dixie Highway project to a high of 1,429 accidents/MVM (886 accidents/MVK) on the Kalanianaole Highway bus-only project. Because of the low sample size in terms of vehicle miles of travel, the difference in the two accident rates is not statistically significant.

- For the Kalanianaole Highway project, the bus accident rate of 1,429 accidents/MVM (886 accidents/MVK) during bus-only operation is five times greater than the bus accident rate of 385 accidents/MVM (239 accidents/MVK) during bus/carpool operation. Because of the low sample size in terms of vehicle miles of travel, the difference in accident rates is not statistically significant.

- For the N.W. 7th Avenue project, bus accident rates decreased with the establishment of the median bus lane. The "after" condition accident rate was 54 accidents/MVM (33 accidents/MVK) compared to the "before" condition accident rate of 91 accidents/MVM (56 accidents/MVK). This difference is not statistically significant. The bus accident rate in the "after" condition nearly equals the control accident rate.

- For the U.S. 1/South Dixie Highway project, the bus accident rate of 9 accidents/MVM (6 accidents/MVK) is much lower than the control accident rate of 50 accidents/MVM (31 accidents/MVK). This difference is significant at a 95 percent level of statistical significance.

- By converting the accident rates from vehicle-miles to person-miles, the projects are able to portray a very low accident rate in the HOV lane, such as 0.3 accidents/MPM (0.2 accidents/MPK) on the U.S. 1/South Dixie Highway project.

Both the U.S. 1/South Dixie Highway and the Kalanianaole Highway projects involve a bus/carpool lane. Only the Kalanianaole Highway project has data on both bus and carpool accidents in the HOV lane. Table 33 presents for this project, the accident rates summarized for buses and carpools. During the bus/carpool operation, the bus-only accident rate of 385 accidents/MVM (239 accidents/MVK) is nearly 50 times greater than the carpool-only accident rate of 8 accidents/MVM (5 accidents/MVK). Because of the low sample size in terms of vehicle-miles of travel, this difference is not statistically significant.

TABLE 32

PEAK PERIOD BUS AND CONTROL ACCIDENT RATES

(Concurrent Flow HOV Lane on Arterial Street)

PROJECT \ VARIABLE	HOV FACILITY				Control Accident Rate[a,c] (acc/mvm)
	Time Period	Number of Accidents	Accident Rate[a] (acc/mvm)	Accident Rate (acc/mpm)	
U.S. 1/South Dixie Highway[b]					
• Bus/Carpool	4/76 - 7/77	1	8.9	0.3	49.5
Kalanianaole Highway[b]					
• Bus-Only	8/73 - 9/75	3	1428.6	31.7	—
• Bus/Carpool	9/75 - 12/76	1	384.6	8.5	—
N.W. 7th Avenue					
• Before	8/74 - 1/75	5	90.9	—	51.4
• Bus-Only	1/75 - 3/76	3	53.6 ns	1.8	49.5 ns

Metric Conversion
1 mile = 1.61 kilometers
1 acc/mvm = 0.62 acc/mvk

a. Statistical significance of accident rates compared to the before condition:

ns indicates difference is not significant
* indicates a 95 percent level of significance
**indicates a 99 percent level of significance

b. No before data available.

c. Control base is Dade County Metropolitan Transit Agency.

TABLE 33

PEAK PERIOD HOV LANE ACCIDENT RATES ON KALANIANAOLE HIGHWAY UNDER BUS/CARPOOL HOV LANE OPERATION

TYPE \ VARIABLE	Time Period	Number of Accidents	Accident Rate (acc/mvm)	Accident Rate (acc/mpm)
Bus Accident	9/75 - 12/76	1	384.6	8.5
Carpool Accidents	9/75 - 12/76	5	7.8	2.4
Total Accidents	9/75 - 12/76	6	9.3	2.4

Facility Accident Rates

An analysis of the total facility accident rates provides insight into the effect of a concurrent lane operation on the safety of the total facility. Table 34 presents a "before" and "after" facility accident rate comparison by peak periods and 24-hour periods, as data is available on each project. The results are summarized for accident rates based on both MVM and MPM and are compared to a control accident rate.

As the U.S. 1/South Dixie Highway and the Kalanianaole Highway projects operate only in the peak periods with temporary traffic control measures, there would be no influence on the facility's accidents outside these peak periods. For the U.S. 1/South Dixie Highway project, the accident data incorporates a period when a contraflow bus lane was also operating with the concurrent-flow carpool lane. This operational strategy reduced the off-peak directional lanes from three to two in the peak period. In order to have a truer representation of the total facility effects of the concurrent-flow operation, the accidents involving the contraflow lane have been deleted from the analysis and table. For the N.W. 7th Avenue project, the establishment of the concurrent-flow bus lane occurred with a general upgrading of the facility and the establishment of coordinated signal strategies. The Washington CBD curb bus lanes project represents a composite total of six facilities. The facility accident rates for each of the Washington CBD facilities are presented in Table 35.

From Tables 34 and 35, the following general conclusions can be developed regarding the impact by the concurrent-flow HOV lane operation on the total facility accident rates:

- On median HOV lane projects, the accident rate in the AM peak period ranges from a low of 3.4 accidents/MVM (2.1 accidents/MVK) on the Kalanianaole Highway project (bus-only) to a high of 8.3 accidents/MVM (5.1 accidents/MVK) on the U.S. 1/South Dixie Highway project.

- On curb HOV lanes in the Washington CBD project, the accident rate in the AM peak period ranges from a low of a zero accident rate on 7th Street to a high of 13.6 accidents/MVM (8.2 accidents/MVK) on 14th Street NW.

- For each applicable median HOV lane project and each curb HOV lane in the Washington CBD project, the accident rate in the PM peak period is higher than the accident rate in the AM peak period.

- For the U.S. 1/South Dixie Highway and the Kalanianaole Highway projects, there was an increase in the accident rate from the "before" condition to the "after" condition. This is true for both the AM peak period and PM peak period. The increase for the U.S. 1/South Dixie Highway project is statistically significant.

- For the N.W. 7th Avenue project, there was a decrease in the accident rate from the "before" condition to the "after" condition. This is true for both the AM peak period and PM peak period. These differences are not statistically significant.

- The control accident rates for each median HOV lane project followed a decreasing trend. Only the N.W. 7th Avenue project also followed this decreasing trend.

- By converting the accident rates from vehicle-miles to person-miles, the rates were lower, however, the relationships stated above did not change.

TABLE 34

PEAK PERIOD FACILITY AND CONTROL ACCIDENT RATES

(Concurrent Flow HOV Lane on Arterial Street)

PROJECT \ VARIABLE	HOV FACILITY						Control Accident Rate[c] (acc/mvm)
		AM PEAK[a]			PM PEAK[a]		
	Time Period	Number of Accidents	Accident Rate[b] (acc/mvm)	Accident Rate[b] (acc/mpm)	Number of Accidents	Accident Rate[b] (acc/mvm)	
Washington, D.C. CBD[d]							
• bus-only	1976	36	2.8	1.0	99	12.7	—
U.S. 1/South Dixie Highway							
• before	7/73 - 6/74	70	5.2	3.7	123	9.2	8.0
• bus/carpool	4/76 - 3/77	110	8.3**	5.2*	166	12.7**	7.5
Kalanianaole Highway							
• before	1/72 - 7/73	12	2.8	—	—	—	2.8
• bus-only	8/73 - 8/74	20	3.4 ns	1.9	—	—	2.3
• bus/carpool	9/74 - 12/76	19	4.6 ns	2.5	—	—	2.2
N.W. 7th Avenue							
• before	1/74 - 8/74	8	11.6	9.4	8	8.5	8.0
• bus-only	1/75 - 3/76	7	4.5 ns	3.5 ns	9	5.1 ns	7.5

Metric Conversion
1 mile = 1.61 kilometers
1 acc/mvm = 0.62 acc/mvk

a. AM Peak: 7 to 9 AM for each project except for Kalanianaole Highway, which is 6 to 8 AM.
PM Peak: 4 to 6 PM for each project.

b. Statistical significance of accident rates compared to the before condition:

ns indicates difference is not significant
* indicates a 95 percent level of significance
**indicates a 99 percent level of significance

c. Control Base:

U.S. 1/South Dixie Highway - Dade County (Miami) Countywide Summary
N.W. 7th Avenue - Dade County (Miami) Countywide Summary
Kalanianaole Highway - FAP Route 60 in Honolulu

d. No before data available.

TABLE 35

FACILITY ACCIDENT RATES ON WASHINGTON CBD CURB HOV LANES

FACILITY \ VARIABLE	HOV Strategy[a]	Length (miles)	Number of Accidents	Accident Rate (acc/mvm)
AM PEAK PERIOD[b] (7 to 9 AM)				
• 7th Street	A	0.4	0	0
• 14th Street	C	2.1	11	13.6
• 16th Street NW	B	2.0	6	3.5
• Connecticut Avenue NW	B	7.0	14	2.3
• H Street NE	B	2.4	2	0.8
• Pennsylvania Avenue SE	B	3.0	3	1.6
• Total	—	16.9	36	2.8
PM PEAK PERIOD[b] (4 to 6 PM)				
• 7th Street	A	0.4	2	24.4
• 14th Street	C	2.1	40	70.4
• 16th Street NW	B	2.0	12	10.0
• Connecticut Avenue NW	B	7.0	40	9.0
• H Street NE	B	2.4	1	1.1
• Pennsylvania Avenue SE	B	3.0	4	6.6
• Total	—	16.9	99	12.7
ALL DAY[b] (6 AM to 8 PM)				
• 7th Street	A	0.4	2	3.8
• 14th Street	C	2.1	104	25.0
• 16th Street NW	B	2.0	47	5.6
• Connecticut Avenue NW	B	7.0	135	5.0
• H Street NE	B	2.4	7	1.0
• Pennsylvania Avenue SE	B	3.0	14	2.4
• Total	—	16.9	309	5.8

a. A indicates that both curb lanes operate as bus-only lanes during both AM and PM peak periods.
B indicates that one curb lane operates as bus-only lane-inbound in the AM peak and outbound in the PM peak.
C indicates that both curb lanes operate as bus-only lanes during PM peak only.
b. Weekdays only.

Metric Conversion

1 mile = 1.61 kilometers
1 acc/mvm = 0.62 acc/mvk

TABLE 36

ACCIDENT CHARACTERISTICS BY PERCENTAGE (COMBINED PEAK PERIODS)

(Concurrent Flow HOV Lane on Arterial Street)

VARIABLE \ PROJECT	Washington CBD		US 1/South Dixie Highway		Kalanianaole Highway		NW 7th Avenue	
	Before	Bus-Only	Before	Bus/Carpool	Before	Bus/Carpool	Before	Bus-Only
Accident Severity								
• Injury	—	30	34	32	59	39	19	6
• Property Damage Only	—	70	66	68	41	61	81	94
Accident Type								
• Rear-end	—	27	—	68	—	—	—	34
• Side-swipe	—	25	—	16	—	—	—	26
• Right-angle	—	25	—	6	—	—	—	41
• Fixed-object	—	2	—	3	—	—	—	0
• Parked vehicle	—	14	—	0	—	—	—	0
• Other	—	6	—	7	—	—	—	0

Accident Characteristics

Table 36 presents for the combined peak periods the percentage breakdown on total facility accidents as to 1) accident severity and 2) accident type.

The percentage of accidents resulting in injury has decreased on each project with the introduction of the HOV lane. This percentage ranges from a low of 6 percent on the N.W. 7th Avenue project to a high of 39 percent on the Kalanianaole Highway project.

The rear-end, side-swipe and right-angle accidents are the major accident types for the total facility accidents. However, the rear-end accident type occurs infrequently in the HOV lane accidents, perhaps due to a lack of congestion in the HOV lane. For the Washington, D.C. curb bus lane project, an accident with a parked vehicle is also a major accident type.

SAFETY CHARACTERISTICS

Causative Factors Influencing Safety

Of the three median HOV lane projects, only the N.W. 7th Avenue project experienced a decrease in the total facility accident rate with the introduction of the HOV lane. This project established the bus-only lane without altering the number of lanes available for general traffic. The other two median HOV lane projects—U.S. 1/South Dixie Highway and Kalanianaole Highway—established the HOV lane by taking a lane away from the general traffic. Instead of three peak-directional general traffic lanes, there are two lanes for general traffic with the third lane (median lane) reserved for HOVs. This reduction in the number of general traffic lanes has the potential of increasing the traffic congestion in the remaining lanes. As a result of this congestion, a rear-end accident becomes a major type of accident in the general traffic lanes, but not in the HOV lane. On U.S. 1/South Dixie Highway, even with signalization improvements on the facility, the average vehicle operating speed in the peak-directional general traffic lanes decreased from 19 to 18 mph (31 to 29 kph) with the reduction in the number of general traffic lanes. The vehicle operating speed in the uncongested HOV lane is 26 mph (42 kph). This decrease in operating speed is one sign of increased traffic congestion.

There is a wide variance in the bus accident rates associated with the median HOV lane projects. There are perhaps two contributing causes to this circumstance: 1) the vehicular volume travelling in the HOV lane, and 2) the restriction of crossing movements across the HOV lane. These reasons should be considered tentative because of the limited number of bus accidents occurring in the HOV lane.

There may be a direct relationship between the volume of traffic in the median HOV lane and safety of the vehicles traveling in the HOV lane. This relationship could result from the motorists being more keenly aware of the HOV lane due to a higher volume in the HOV lane. The U.S. 1/South Dixie Highway project has the highest average peak-hour volume in the HOV lane with 708 vehicles and the lowest bus accident rate of 9 accidents/MVM (6 accidents/MVK). On the other hand, the bus-only HOV lane operation of the Kalanianaole Highway project has the lowest average peak-hour volume in the HOV lane with nine vehicles and the highest bus accident rate of 1,429 accidents/MVM (886 accidents/MVK). With the introduction of the bus/carpool operation to the Kalanianaole Highway project, the average peak-hour volume in the HOV lane increased to 560 vehicles and the bus accident rate decreased to 385 accidents/MVM (239 accidents/MVK).

There also may be a direct relationship between the restriction of crossing movements and safety of the vehicles traveling in the HOV lane. The U.S. 1/South Dixie Highway project, which has the lowest bus accident rate, prohibited left-turns from the facility, even though a left-turn bay exists in numerous locations to the left of the median HOV lane. Additionally, this project only permits crossing movements from the side to occur at signalized intersections where such movements are easily controllable. On the N.W. 7th Avenue project, which has a bus accident rate six times greater than the U.S. 1/South Dixie Highway project, left-turns were permitted from left-turn bays located to the left of the median HOV lane. This required a left-turning vehicle to weave across the HOV lane in order to access the left-turn bay. Also, there are numerous non-signalized intersections whereby the vehicle from a side street may cross the HOV lane. The Kalanianaole Highway project experiences an almost non-existent demand for left-turns from the facility and this movement is prohibited. However, there is a major safety problem with the crossing movement by vehicles from a side street location (Nenue Street) that is non-signalized. One-half of the HOV lane bus accidents and 60 percent of the HOV lane carpool accidents occurred at this location involving a vehicle turning across the HOV lane from the side street.

Besides the common accident types (rear-end, side-swipe, and right-angle) for the total facility accidents on the median HOV lane projects, the Washington CBD curb bus lanes project experiences two additional accident types—an accident with a parked vehicle and an accident involving a pedestrian. The parked vehicle and pedestrian accidents respectively accounted for 14 and 2 percent of the total facility accidents.

Vehicles traveling in the curb bus lanes will come into direct conflict with vehicles illegally parked in the curb lane. This type of occurrence may be commonplace in busy downtown areas. Besides vehicles parked in a curb bus lane, there is the additional problem of other vehicles, including taxi-cabs, that stop temporarily in the curb lane in order to pick-up or drop-off passengers. A vehicle parked or stopped in the curb lane forces the following vehicles to weave into the adjacent general traffic lane. For the Washington, D.C. curb bus lanes, illegally parked vehicles are oftentimes not removed but have "steel boots" fixed to the wheels to prevent the owner from removing the vehicle until paying the parking fine.

Whereas an accident involving a pedestrian on the Washington CBD project accounts for only 2 percent of the total facility accidents, this type of accident can be a potentially serious one and create negative public reaction. A pedestrian accident may be associated with a curb HOV lane because these projects most often will be located in the downtown area where 1) pedestrian traffic is the highest, and 2) the local bus service that travels the curb lane creates additional pedestrian traffic, as well as being in close proximity to the pedestrians.

Difficult Maneuvers and Potential Safety Problems

An HOV priority treatment might be expected to generate potential safety problems on a transportation facility. Project personnel for the concurrent-flow HOV lane projects identified several possible difficult maneuvers and safety problems that could be associated with this type of treatment. Such safety problems include:

Curb HOV Lane

- A vehicle that is stopped in the curb lane forces any following vehicles to continue the travel by encroaching into the adjacent general traffic lane and going around the stopped vehicle. A bicyclist traveling in the curb lane may also force vehicles to encroach into the adjacent general traffic lane.

- Vehicles authorized to use the curb HOV lane (HOV vehicles, taxicabs, and right-turning vehicles) will be merging into and out of the curb lane throughout the project limits. The potential safety problem is with vehicles unduly merging ahead or weaving around a slower moving bus in the curb lane.

- For vehicles turning right onto a street with a curb HOV lane, this maneuver may cause the vehicle to be in the curb lane. Once realizing the existence of the HOV restrictions, this motorist may attempt to quickly merge out of the curb lane or perhaps be trapped in the curb lane by the existing traffic congestion in the general traffic lanes. In order not to violate the HOV restriction, the motorist may come to a stop in the curb lane.

- Where pedestrian movements crossing the curb HOV lane are common and somewhat unregulated, a safety problem may occur from a bus stopping suddenly in order to avoid a pedestrian conflict, as a bus does not stop as readily as an auto. If there are trailing vehicles, especially a bus, a rear-end accident situation may also develop due to the trailing vehicles being shielded from view of the pedestrian conflict and the need for stopping suddenly.

Median HOV Lane

- Left-turns off the facility with the HOV lane may create a safety problem by motorists 1) stopping in the "express" HOV lane to make the left turn or 2) weaving unexpectedly across the HOV lane into a left-turn bay. A decision must be made by the motorist making the weave as to when he should enter the lane. Being a non-HOV vehicle, he may wait until the very last moment and hurriedly make the weave in order to stay out of the HOV lane as long as possible.

- Motorists crossing the HOV lane from a side street may be unaware of the HOV lane presence. This unawareness would be due to the general traffic blocking the view of the HOV lane coupled with the low volume of traffic in the HOV lane.

- A large speed differential between the HOV lane and adjacent general lanes cause slower vehicles to merge into a high speed HOV lane or faster vehicles in the HOV lane having to decelerate rapidly to merge into the general lane. Either action could result in side-swipe or rear-end accidents.

- Where the HOV lane is created by the taking of a general lane, large displacement of general traffic occurs from that lane to the remaining lanes. This can create a disproportionate imbalance in lane distribution and can create extensive congestion with stop and go conditions in the remaining general traffic lanes.

RECOMMENDATIONS

The previous sections have shown that a concurrent-flow HOV lane on an arterial street can be operated safety, but there is the possibility of safety problems occurring. General recommendations on safety of HOV priority treatments are presented on page 7. Specific recommendations that may improve the safety of a concurrent-flow HOV lane on an arterial street include the following:

Curb HOV Lane

- Prohibit taxi-cabs and other vehicles from stopping in the curb lane to pick-up and drop-off passengers, or to make deliveries. This can be done through a posted "no stopping or standing" regulation and strict enforcement of it.

- Remove parked vehicles from the curb lane. The technique of putting locked "boots" on parked vehicles in order to insure the payment of the parking fine has the effect of keeping the parked vehicle in the lane longer.

- Address the potential pedestrian safety problem possibly by 1) strict enforcement of "jay-walking" ordinances, 2) special visual or audible warning devices installed on the buses, 3) a special yellow stripe one to two feet (0.3 to 0.6 m) with a warning message painted on the sidewalk adjacent to the curb, and 4) the application of foliage to keep the pedestrians away from the curb.

Median HOV Lane

- Prohibit left-turns at selected locations, if not at all locations. Closing off of non-signalized intersections by cones or other implements should be considered to reduce crossing movements across the HOV lane. The operational effect of this recommendation on the cross-street or "off-line" will vary by location.

- The speed differential between the HOV lane and general-use lanes should be controlled if necessary and possible. This may be accomplished by using variable speed control signing on the HOV lane. Until additional research can be conducted to quantify an optimum speed differential, it is recommended that a 10 mph (16 kph) maximum speed differential not be exceeded. On each of the concurrent flow projects studied, the average speed differential did not exceed 10 mph (16 kph).

- Volumes in the HOV lane should be high enough to portray the lane as an operational lane. The higher the HOV lane volume, then the more keenly aware are the motorists to the HOV lane. Increased volumes can be achieved by greater bus usage or permitting carpools to use the HOV lane.

CHAPTER NINE

CONTRAFLOW HOV LANE ON ARTERIAL STREET

DETAILED DESCRIPTION

A contraflow HOV lane on an arterial street is commonly a lane in the off-peak direction reserved for HOV vehicles traveling in the peak direction. A specialized type of contraflow lane is the reversible lane in which a lane's traffic flow may be reversed in order to provide a reserved lane in the peak direction without reducing the capacity in the off-peak direction. A contraflow HOV lane can incorporate the median lane or the curb lane of a highway facility. Because of its nature, a reversible lane is almost always a median lane.

A contraflow HOV lane operating in the median lane is commonly associated with express bus service operating in a through or line-haul trip. Carpools may also be permitted to travel in the contraflow HOV lane. The major objective of the contraflow median HOV lane is to provide travel-time advantages to the HOV vehicles by bypassing traffic congestion in the general traffic lanes and traffic queues at signalized intersections. Because of this objective, the contraflow median lane generally operates during the peak-period over a distance of several miles. During the off-peak periods, the reverse flow lane may function as a through lane, a left-turn lane or a median lane closed to any type of traffic.

A contraflow HOV lane operating in the curb lane occurs on a facility which otherwise serves one-way traffic. This type is commonly associated with local bus service making periodic stops for passenger loading and unloading. Carpools usually are not permitted to travel in the contraflow HOV lane, which is not unreasonable because of the stop-and-go bus movement occurring in the lane. The major objectives of the contraflow curb HOV lane is to 1) separate the different classes of vehicles—bus and auto—in order to improve traffic flow on the facility and traffic circulation in the CBD, and 2) provide a travel-time advantage for the HOV vehicles (i.e. local buses). The contraflow curb HOV lane can be either a 24-hour or peak-period operation over a distance ranging from several city blocks to several miles.

This research examined four contraflow HOV lane projects (two median contraflow lanes, one median reversible lane and one curb contraflow lane). Project descriptions are given below and in Figures 19 to 22.

- U.S. 1/South Dixie Highway, Miami, Florida (Figure 19)
  This project included a contraflow median bus lane, a concurrent flow median carpool lane,[1] and signalization improvements on a 5.5 mile (8.9 km) segment of South Dixie Highway (U.S. 1). The six lane divided highway operated with a median contraflow lane inbound (northbound) in the outbound lanes from 6-9 AM and with a median contraflow lane outbound (southbound) in the inbound lanes from 4-7 PM. The hours were later reduced to 7-9 AM and 4-6 PM. Left-turns across the median HOV lane were prohibited.

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1. See Chapter Eight.

The contraflow lanes were initiated on July 22, 1974, and terminated on April 5, 1976. The termination was due to safety and financial considerations associated with operation of the lane.

- Kalanianaole Highway, Honolulu, Hawaii (Figure 20)
  This 2.4 mile (3.9 km) HOV project includes a 1.9 mile (3.1 km) contraflow median bus/carpool lane connecting into a 0.5 mile (0.8 km) concurrent flow median bus/carpool lane.[2] The contraflow lane operates on a four lane undivided facility. A carpool is defined as a vehicle carrying three or more persons. The project operates in the inbound direction only during the AM peak period (approximately 6-8 AM). It began as a bus-only HOV operation on August 21, 1973, but it was altered to a bus/carpool operation on September 15, 1975.

- N.W. 7th Avenue, Miami, Florida (Figure 21)
  This project included express "Orange Streaker" buses operating in a reserved bus lane for 9.9 miles (15.9 km). For 7.3 miles (11.8 km) the reserved bus lane was a reversible lane while the other 2.6 miles (4.2 km) the bus lane consisted of a concurrent flow median lane.[2] The reversible bus lane operated inbound (southbound) from 6:00 - 9:30 AM and outbound (northbound) from 3:00 - 6:30 PM. During the other times of the day, the reversible lane operated as a dual left-turn lane. Express buses operated in the reversible bus lane with 1) signal preemption,[3] 2) signal progression, or 3) a combination of the two. The N.W. 7th Avenue bus priority system commenced August 19, 1974, but the reversible bus lane did not begin operating until January 20, 1975. It operated until March 12, 1976, at which time the project was terminated and the express bus operation was transferred to the nearby Interstate 95 concurrent flow HOV lanes.[4]

- Ponce de Leon/Fernandez Juncos Avenues, San Juan, Puerto Rico (Figure 22)
  Ponce de Leon and Fernandez Juncos Avenues comprise a one-way pair of arterials connecting two major sections of San Juan. The arterials are four to five lanes wide. The left curb lane serves as the contraflow bus lane in order for the passenger door to be curbside for collection/distribution of passengers. Parking in the contraflow lane is restricted but left turns across the contraflow lane are permitted. There are a total of 13.6 miles (21.9 km) of contraflow bus lanes with the first section being implemented in May, 1971.

Tables 2 and 3 present the national standards regarding geometrics and traffic control devices applicable to HOV priority treatments. Figures 19 to 22 show how each project addresses these items. All four projects predated the March, 1975 publication of the MUTCD standards for HOV facilities.

The U.S. 1/South Dixie Highway project was deficient in lane widths, proximity of roadside hazards and sight distance on occasion. The project utilized non-standard restricted lane signing located overhead as a changeable message sign and in the median as a static sign. The diamond pavement marking is not used. The project used polyvinyl chloride (PVC) safety posts at a 40-feet (12 m) spacing to differentiate between the contraflow lane and the general traffic lanes.

The Kalanianaole Highway project is deficient in lane width and proximity of roadside hazards. The project utilized non-standard restricted lane signing located along the road and attached to PVC posts. The diamond pavement marking is not used. The project used plastic cones and PVC posts at an average spacing of 70 feet (21 m) to differentiate between the contraflow lane and general traffic lane.

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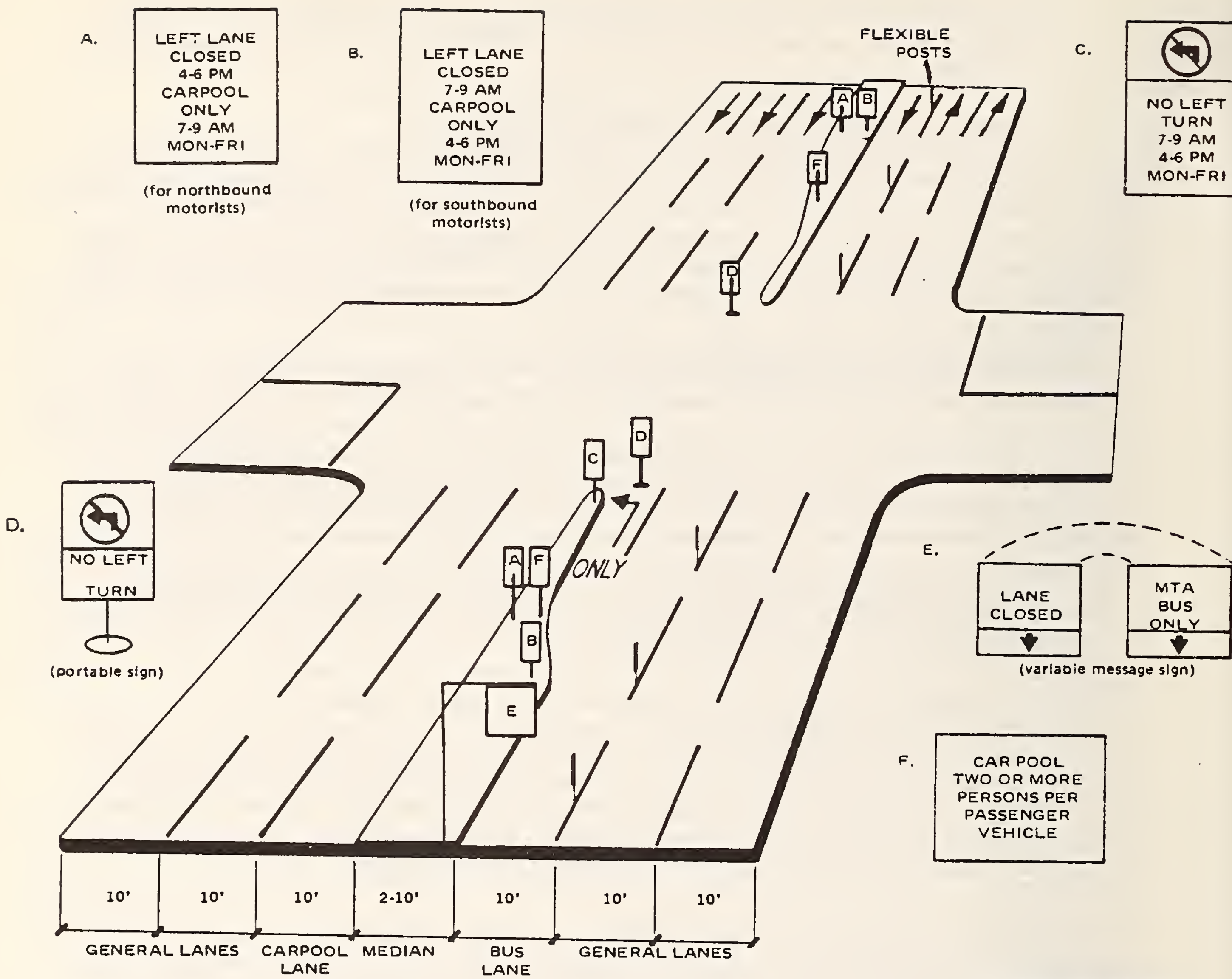
2. See Chapter Eight.
3. See Chapter Ten.
4. See Chapter Three.



METRIC CONVERSION
1 in = 2.54 cm
1 ft = 0.3 m
1 mi = 1.61 km

AASHTO DESIGN FACTORS

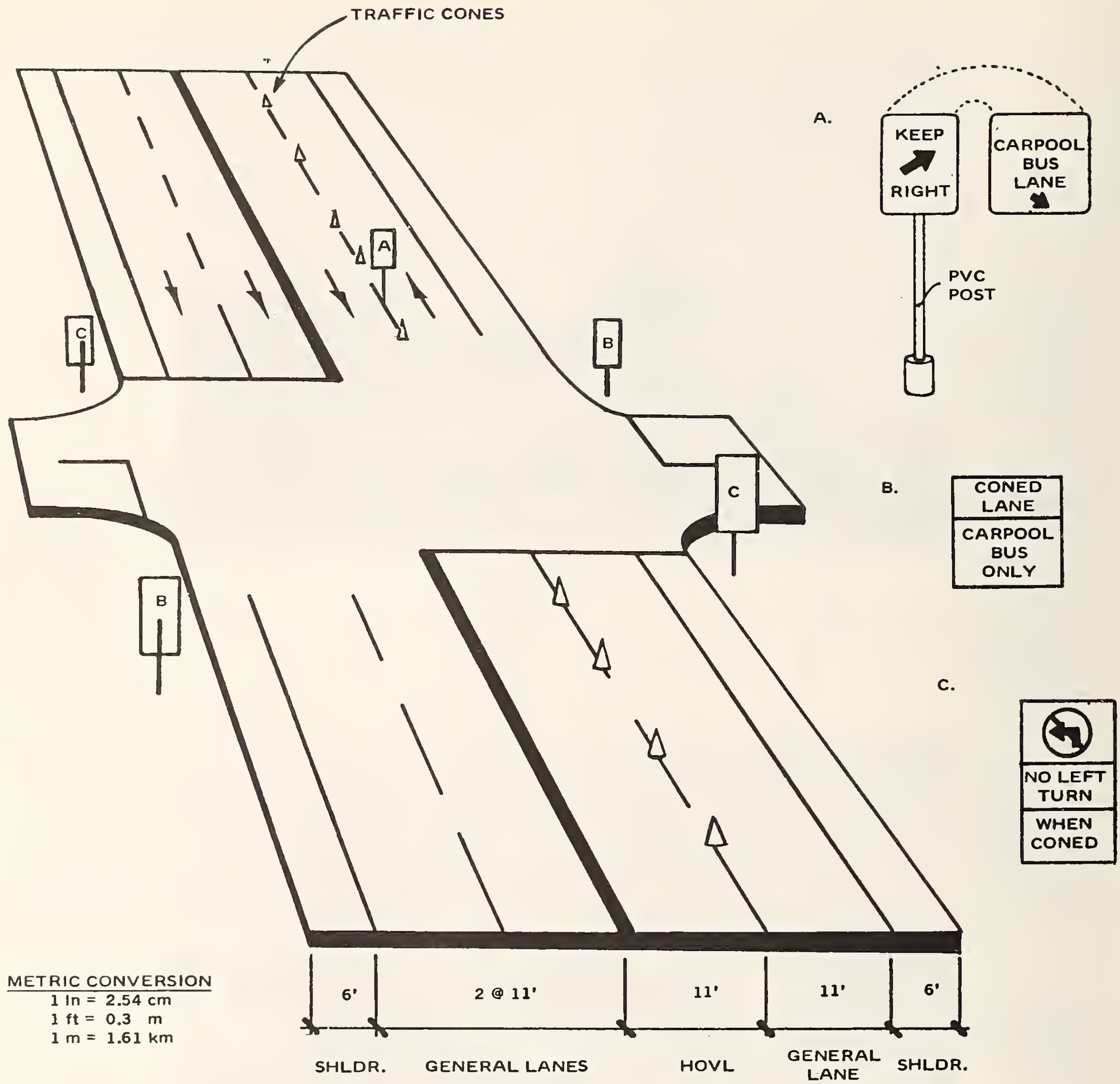
ALIGNMENT: linear
VERTICAL SIGHT DISTANCE: adequate to poor
POSTED SPEED: 35 mph
ROADSIDE HAZARDS: poles within several feet of roadway

MUTCD DESIGN FACTORS

LANE-USE CONTROL SIGNALS: none
ADVANCED WARNING SIGNS: non-standard
RESTRICTED LANE SIGNS: non-standard
END OF HOVL SIGNS: none
DIAMOND SYMBOL: none
HOVL DELINEATION: skip white marking and flexible posts

U.S. 1/SOUTH DIXIE HIGHWAY (CONTRAFLOW LANE), MIAMI, FLORIDA
FIGURE 19

U.S. 1/SOUTH DIXIE HIGHWAY (CONTRAFLOW LANE), MIAMI, FLORIDA
FIGURE 19 (CONT.)



AASHTO DESIGN FACTORS

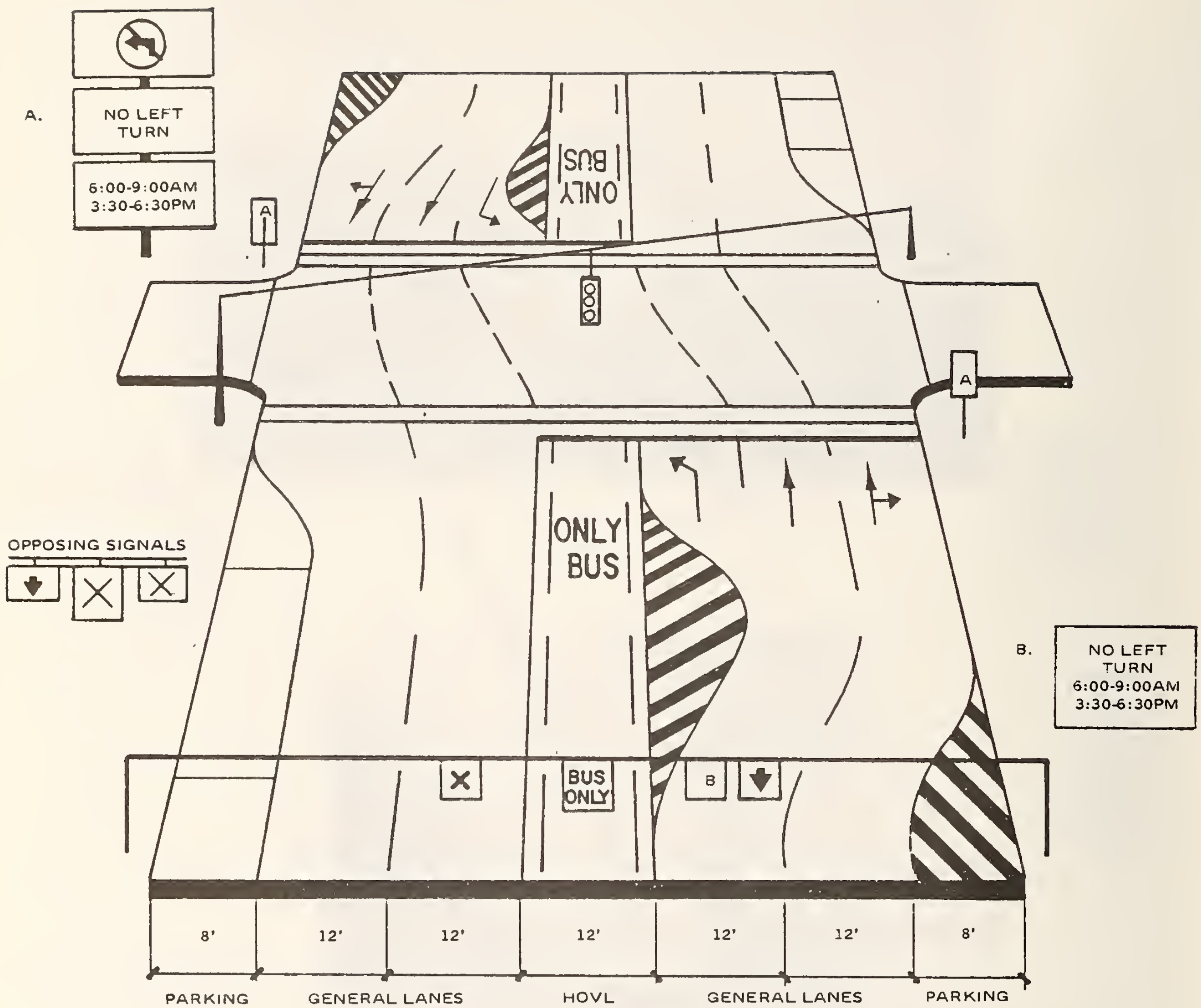
ALIGNMENT: linear
VERTICAL SIGHT DISTANCE: good
POSTED SPEED: 35 mph
ROADSIDE HAZARDS: foliage and poles 2 feet from roadway

MUTCD DESIGN FACTORS

LANE-USE CONTROL SIGNALS: none
ADVANCED WARNING SIGNS: none
RESTRICTED LANE SIGNS: non-standard, post-mounted
END OF HOVL SIGNS: none
DIAMOND SYMBOL: none
HOVL DELINEATION: white skip supplemented with cones and signs

KALANIANAOLE HIGHWAY (CONTRAFLOW LANE), HONOLULU, HAWAII
FIGURE 20

KALANIANAOLE HIGHWAY (CONTRAFLOW LANE), HONOLULU, HAWAII
FIGURE 20 (CONT.)



METRIC CONVERSION
1 in = 2.54 cm
1 ft = 0.3 m
1 mi = 1.61 km

AASHTO DESIGN FACTORS

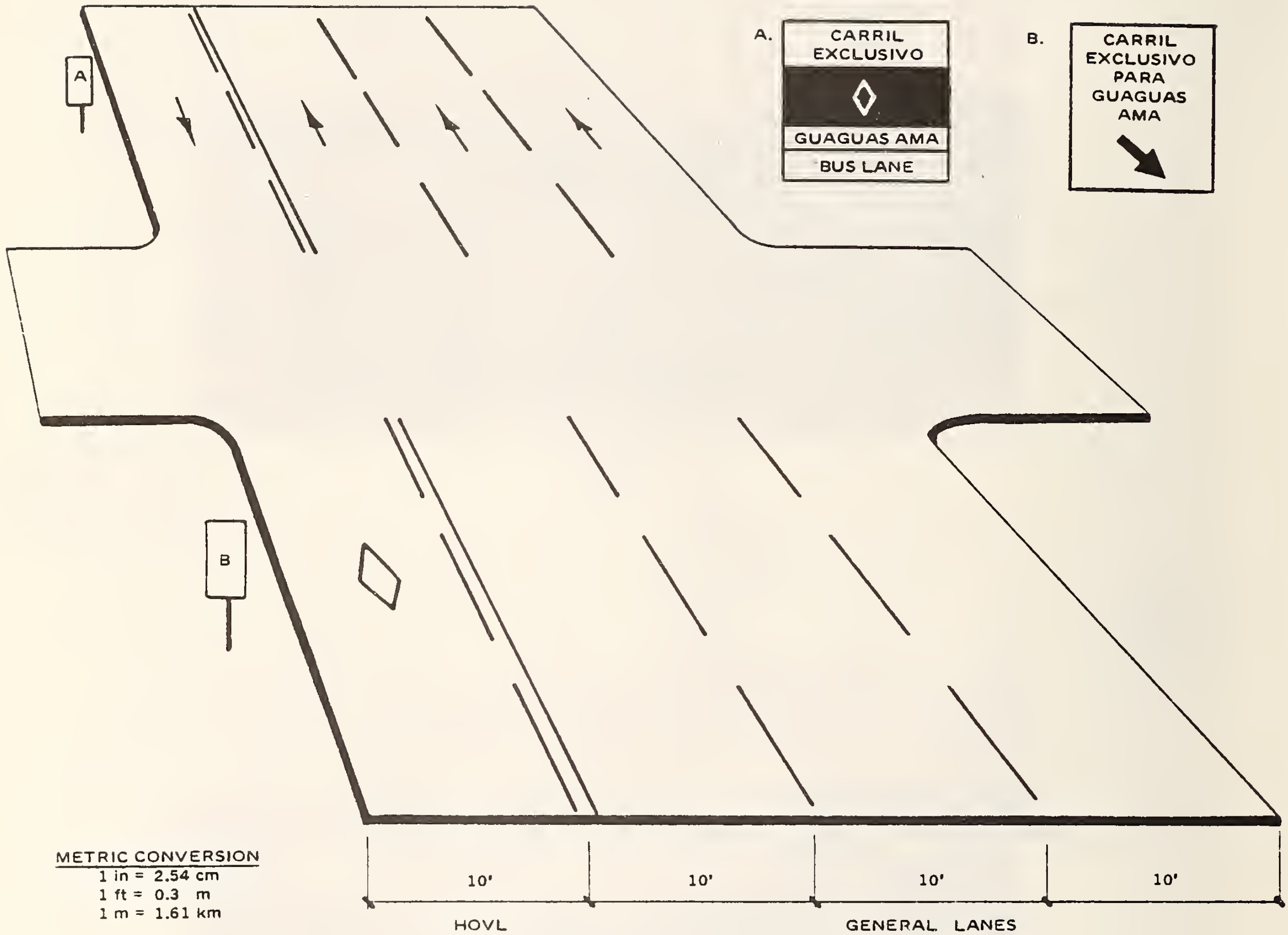
ALIGNMENT: linear
VERTICAL SIGHT DISTANCE: good
POSTED SPEED: 35 mph
ROADSIDE HAZARDS: none

MUTCD DESIGN FACTORS

LANE-USE CONTROL SIGNALS: overhead three lanes
ADVANCED WARNING SIGNS: none
RESTRICTED LANE SIGNS: none
END OF HOVL SIGNS: non-standard
DIAMOND SYMBOL: none
HOVL DELINEATION: solid and skip yellow marking

N.W. 7th AVENUE (REVERSE FLOW LANE), MIAMI, FLORIDA
FIGURE 21

N.W. 7th AVENUE (REVERSE FLOW LANE), MIAMI, FLORIDA
FIGURE 21 (CONT.)



AASHTO DESIGN FACTORS

ALIGNMENT: varies
VERTICAL SIGHT DISTANCE: good to poor
POSTED SPEED: 25 to 35 mph
ROADSIDE HAZARDS: poles within several feet of roadway

MUTCD DESIGN FACTORS

LANE-USE CONTROL SIGNALS: none
ADVANCED WARNING SIGNS: none
RESTRICTED LANE SIGNS: standard
END OF HOVL SIGNS: standard
DIAMOND SYMBOL: standard
HOVL DELINEATION: solid and skip white line marking

PONCE DE LEON/FERNANDEZ JUNCOS AVENUES, SAN JUAN, PUERTO RICO
FIGURE 22

PONCE DE LEON/FERNANDEZ JUNCOS AVENUES, SAN JUAN, PUERTO RICO
FIGURE 22 (CONT.)

On the N.W. 7th Avenue project, there were no significant deviations from AASHTO's geometric standards. All lanes were 12 feet (3.6 m) in width and 14 feet (4.2 m) on curb lanes. The only two minor variances were the narrow right-of-way in the one section and short lane alignment transitions in another section. The N.W. 7th Avenue bus priority system project was a temporary project (until express bus operations transferred to I-95) therefore the reduced taper was acceptable on this temporary basis. As the N.W. 7th Avenue project was soon to be terminated after the January 1, 1976, compliance date, the MUTCD requirements for HOV lanes were not implemented.

The Ponce de Leon/Fernandez Juncos Avenues project is deficient at some locations in lane width, proximity to roadside hazards and sight distance. The project has standardized lane-control signing (in Spanish) along the roadside and uses the diamond pavement marking. There is no physical separation between the curb contraflow lane and the general traffic lanes.

The deficiencies regarding lane width and proximity of roadside hazards are quite common for urban areas and especially for downtown areas where available right-of-way for streets and highways is scarce. These deficiencies more often would effect the operation of a curb bus lane than a median bus lane for the following reasons: 1) the curb bus lane is closer to roadside hazards off the curb; 2) the curb lane oftentimes slopes toward the gutter causing the bus to lean toward the roadside hazards; 3) the bus operation in a curb lane is commonly providing local service requiring the bus to stop as near the curb as possible for passenger loading and unloading; and 4) the bus volume in a curb lane tends to be higher. The existence of these deficiencies does not necessarily indicate that there is a safety problem, as safe operations can be achieved with lane widths of less than 12 feet (3.6 m) and roadside hazards within eight feet (2.4 m) of the roadway.

The configuration of traffic flow can impact safety. A one-way configuration is associated with a curb bus lane, generally on the side of the roadway that permits the bus to pick-up and discharge passengers. The vehicles would enter and exit the contraflow curb lane by turning movements from the cross streets. For a median contraflow lane, the vehicles would enter and exit the contraflow lane by 1) weaving through the general traffic lanes, 2) weaving through a cross-over of some type, or 3) executing a turning movement from a cross street. Quite possibly, special traffic control devices and supervisory personnel are required to guide the traffic through the entrance and exit points to the contraflow lane.

On a contraflow median lane, restrictions on left-turns may well be necessary and desirable. As discussed later in this chapter, a left-turn movement can adversely impact safety through hazardous movements or reduced capacity. The U.S. 1/South Dixie Highway and Kalanianaole Highway projects instituted a prohibition on left-turns. On the N.W. 7th Avenue project, left-turns were allowed only at several signalized intersections from left-turn lanes with exclusive left-turn signal phases in order to eliminate the bus/left-turn conflicts (see Figure 21).

The AASHTO geometric standards do not specifically address a contraflow or reversible HOV lane treatment, but it does provide generalized guidelines for the application of "reverse-flow" lanes and reserved bus lanes on city streets and arterials.[5] AASHTO limits the use of reverse flow lanes on

5. American Association of State Highway Transportation Officials (AASHTO), A Policy on Geometric Design of Urban Highways and Arterial Streets (1973 edition), pp. 180-183, 646-648, and 666-668.

undivided streets to . . . "where there is continuity in the route and width of street, where there is no median and where left turns and parking can be restricted." The concern with turning and parking restrictions is to insure adequate capacity in the minor (non-peak) direction.

AASHTO and the MUTCD recommend the use of overhead lane signals to control lane usage on reverse-flow (or reversible lane) operations.[6] The MUTCD states that each lane to be reversed shall have signal faces with a DOWNWARD GREEN ARROW on an opaque background, and a RED X symbol on an opaque background. Each nonreversible lane immediately adjacent to a reversible lane shall have a DOWNWARD GREEN ARROW displayed to traffic traveling in the permitted direction and a RED X symbol displayed in the opposite direction. The visibility of the colors of the various displays is prescribed to be one-fourth mile (0.4 km).

The N.W. 7th Avenue project complied with the requirements for the lane-use control signals, including the appropriate signals for the adjacent travel lanes, except for the visibility requirement. The reversible lane was controlled by bi-directional overhead changeable message signals (CMS). The spacing of the CMS was approximately one-fifth mile (0.3 km), however, the optical output of the CMS was inadequate with only about one-tenth mile (1.6 km) visibility. The CMS were not explicitly supported by any fixed message signs that identified the bus only use of the reversible lane.

The U.S. 1/South Dixie Highway project utilized overhead variable message signing to designate the HOV lane. The black-on-white sign read MTA BUS ONLY with a downward arrow for the contraflow lane traffic. The other side of the sign read LANE CLOSED also with a downward arrow. These signs were blank during non-HOV operating hours.

OPERATING CHARACTERISTICS

The extent of the safety impact for an HOV project is dependent, in part, on the operational effectiveness of the project. The major impact of an HOV priority treatment occurs during peak periods when congestion is high and most of the traffic stream is composed of daily commuters. The operational results of each project are displayed in Table 37. In most instances, only one peak period is presented—that which experienced the most serious safety problem, or for the peak period which had the most data. From Table 37, several of the more significant results are:

- A comparison of bus speeds on each project shows that the median HOV lane is associated with express bus service and the curb HOV lane is associated with local bus service. The median lane projects of U.S. 1/South Dixie Highway, Kalanianaole Highway and N.W. 7th Avenue respectively experienced bus speeds of 37, 23 and 29 mph (60, 37 and 47 kph). The curb lane project of Ponce de Leon/Fernandez Juncos Avenues experienced bus speeds of 11 mph (18 kph).
- The HOV lanes on the projects illustrate the efficiency of the operation. The contraflow bus lane of the U.S. 1/South Dixie Highway project moved 8 percent of the person movement in less than 1 percent of the vehicles. The contraflow bus/carpool lane on Kalanianaole

6. Ibid., p. 646-648.

United States Department of Transportation (Federal Highway Administration), Manual on Uniform Traffic Control Devices, 1971, pp. 249-252 (4E-8 to 4E-12).

TABLE 37

OPERATING CHARACTERISTICS
(Contraflow HOV Lane on Arterial Street)

		PROJECT/CONDITION								
		U.S. 1/South Dixie Highway[a]		Kalanianaole Highway		N.W. 7th Avenue				Ponce de Leon Avenue
VARIABLE	UNIT	Before	Bus-Only	Bus-Only	Bus/3 ppv Carpool	Before	Bus-Only	Before	Bus-Only	Bus-Only
Critical Peak Period	—	7 - 9 AM/4 - 6 PM	7 - 9 AM/4 - 6 PM	6-8 AM	6 - 8 AM	7-9 AM	7 - 9 AM	4-6 PM	4 - 6 PM	7 - 9 AM
Length of HOV Lane	Miles	—	5.5	1.9	1.9	—	7.3	—	7.3	13.6
Total Peak Directional Lanes	Lanes	3	4	3	3	2	3	2	3	b
Number of HOV Lanes	Lanes	—	1	1	1	—	1	—	1	b
Volume - All Lanes	Vehicles	14,674	14,330	3,883	4,756	1,461	1,300	1,825	1,569	5,574
Volume - HOV Lanes	Vehicles	—	60	15	990	—	23	—	21	129
Volume - HOV Lanes (bus only)	Vehicles	—	60	15	16	—	23	—	21	129
HOV Lanes/Total Volume	%	—	0.4	0.4	20.8	—	1.8	—	1.3	2.3
Auto Occupancy - All Lanes	PPV	1.38	1.6	1.74	1.90	1.30	1.28	1.45	1.40	1.46
Auto Occupancy - HOV Lanes	PPV	—	—	—	3.26	—	—	—	—	—
Person Throughput - All Lanes	Persons	20,250	22,640	7,410	10,070	1,895	2,413	2,641	2,900	13,749
Person Throughput - HOV Lanes	Persons	—	1,903	680	3,930	—	748	—	710	5,798
HOV Lanes/Total Throughput	%	—	8.4	9.2	39.0	—	31.0	—	24.5	42.1
Speed - General Lanes	MPH	19.4	16.9	14.1	17.3	21.0	29.0	19.8	25.0	na
Speed - HOV Lanes	MPH	—	36.7	na	22.9	—	31.7	—	28.8	12.1
Travel Time - General Lanes	Minutes	17.0	19.5	8.1	6.6	20.9	15.1	22.1	17.5	na
Travel Time - HOV Lane	Minutes	—	9.0	na	5.0	—	13.8	—	15.2	67.4
Violation Rate	%	—	0	0	9.0	—	3.0	—	3.0	0

a. This facility also has a concurrent flow carpool lane.

b. This facility consists of three or four general traffic lanes and one contraflow bus lane in the opposite direction.

Metric Conversion

1 mile = 1.61 kilometers

Highway moved 39 percent of the person movement in 21 percent of the vehicles. The reversible bus lane on N.W. 7th Avenue moved 24 percent of the person movement in 1 percent of the vehicles. The contraflow curb bus lane on Ponce de Leon Avenue moved 42 percent of the person movement in 2 percent of the vehicles.

- On the two projects having the applicable data, the total peak vehicular volume for the facility decreased with the establishment of the contraflow lane. The decrease was 2 percent on the U.S. 1/South Dixie Highway project and 14 percent on the N.W. 7th Avenue project.

- The U.S. 1/South Dixie Highway, N.W. 7th Avenue and Ponce de Leon/Fernandez Juncos Avenues projects did not have a problem of vehicles violating the contraflow lane. The projects experienced a violation rate of zero to 3 percent. The Kalanianaole Highway project experienced a 9 percent violation rate of the contraflow lane restrictions. Each project experienced both legal and illegal crossing movements across the contraflow lane.

ACCIDENT ANALYSIS

The accident data on the four contraflow HOV projects, that were studied in detail, is analyzed by 1) bus accident rates, 2) total facility accident rates, and 3) accident characteristics. It is also pertinent to compare the 24-hour accident rates on the HOV facilities with some control base for which data are generally available. Accident rates were computed in terms of accidents per million vehicle-miles (MVM) and million person-miles (MPM) of travel. These rates automatically take into consideration the effects of differing stage lengths and demand levels. Accident rates were tested with the "t" statistic to determine the statistical significance.

Bus Accident Rates

An analysis of the bus accident rates provides insight into the accident potential of vehicles traveling in the contraflow lane. The bus accident rates, as well as control accident rates, for each project are presented in Table 38 for the AM peak period, PM peak period, and 24-hour operation. A bus accident rate in the "before" condition is available for the N.W. 7th Avenue project and the Ponce de Leon/Fernandez Juncos project. There is no such "before" figure for the other two projects since the bus service for the contraflow lane was initiated as a new bus service. From the available data, the following general conclusions can be developed regarding bus operations in a contraflow bus lane:

- There is a wide range in the bus accident rates associated with this type of priority treatment. For the AM peak period, the rates ranged from 20 accidents/MVM (12 accidents/MVK) on Ponce de Leon/Fernandez Juncos Avenues (curb bus lane) to 400 accidents/MVM (248 accidents/MVK) on N.W. 7th Avenue (median bus lane).

- The PM peak period has bus accident rates that are higher than the AM peak period. For the U.S. 1/South Dixie Highway project, the PM peak period rate is approximately five times the rate in the AM peak period.

- The bus accident rate on Ponce de Leon/Fernandez Juncos Avenues project in its first year of operation is significantly higher than the bus accident rate on the facility in the

TABLE 38

BUS AND CONTROL ACCIDENT RATES

(Contraflow HOV Lane on Arterial Street)

VARIABLE / PROJECT	TIME PERIOD	HOV FACILITY							
		AM PEAK PERIOD			PM PEAK PERIOD		24-HOUR PERIOD OR COMBINED PEAK PERIODS		Control Accident Rate[c]
		Number of Accidents	Accident Rate[a] (acc/mvm)	Accident Rate (acc/mpm)	Number of Accidents	Accident Rate[a] (acc/mvm)	Number of Accidents	Accident Rate[a] (acc/mvm)	(acc/mvm)
U.S. 1/South Dixie Highway[b]									
• Bus-Only	7/74 - 4/76	7	89.4	2.8	36	460.0	43	274.7	49.5
Kalanianaole Highway[b]									
• Bus-Only	8/73 - 9/75	4	260.4	5.8	—	—	—	—	—
• Bus/Carpool	9/75 - 12/76	0	0.0	—	—	—	—	—	—
N.W. 7th Avenue									
• Before	8/74 - 1/75	b	—	—	b	—	5	91.0	51.4
• Bus-Only	1/75 - 3/76	22	400.0	13.8	38	666.7	60	535.7**	49.5
Ponce de Leon/Fernandez Juncos Avenues									
• Before	1/70 - 5/71	23	27.4	—	35	40.7	156	28.6	66.3
• Bus-Only	5/71 - 12/71	22	59.5**	—	53	139.5**	222	106.2**	51.2
• Bus-Only	1/76 - 12/76	12	20.3ns	0.5	23	37.7ns	105	27.9ns	64.7

a. Statistical significance of accident rates compared to the before condition:
ns indicates difference is not significant
* indicates a 95 percent level of significance
** indicates a 99 percent level of significance

b. No before data available.

c. Control Base: U.S. 1/South Dixie Highway - Dade County Metropolitan Transit Agency
N.W. 7th Avenue - Dade County Metropolitan Transit Agency
Ponce de Leon Avenue - San Juan city-wide transit agency

Metric Conversion

1 mile = 1.61 kilometers
1 acc/mvm = 0.62 acc/mvk

before condition. After five years of project operation, the bus accident rate is actually less, but not significant statistically, than the before condition.

- The bus accident rate on the Kalanianaole Highway project is lower during the bus/carpool lane operation than it is during the bus-only lane operation.

- For the N.W. 7th Avenue project, the bus accident rate increased nearly six times from the before condition with the introduction of the contraflow lane. The bus accident rate in the reversible bus lane section is nearly ten times the bus accident rate in the concurrent bus lane section of N.W. 7th Avenue.[7]

- Converting the accident rates from vehicle-miles to person-miles of travel enables the projects to portray a much lower accident rate in the contraflow bus lane. The range in accident rates based on MPM varies from 0.5 to 14 accidents/MPM (0.3 to 9 accidents/MPK).

- On each project, the bus accident rate during the first year of contraflow lane operation was several times greater than the control accident rate (city-wide bus accident rate). However, after five years of contraflow lane operation on Ponce de Leon/Fernandez Juncos Avenues, the bus accident rate for the project is less than one-half of the city-wide bus accident rate.

Throughout the course of the U.S. 1/South Dixie Highway and N.W. 7th Avenue projects, the bus accident rate was decreasing, perhaps indicating an adjustment period was taking place. A discussion of this trend is presented on page 137.

Total Facility Accident Rates

The total facility accident rates, as well as control accident rates, for each project are presented in Table 39 for the AM peak period, PM peak period and 24-hour periods. As the U.S. 1/South Dixie Highway, the Kalanianaole Highway and the N.W. 7th Avenue projects operate only in the peak periods with temporary traffic control measures, there would be no influence on accidents on these facilities outside these peak periods. For the U.S. 1/South Dixie Highway project, the accident rates regarding the total facility incorporates a concurrent flow carpool lane which was implemented simultaneously with the contraflow lane. For the Ponce de Leon/Fernandez Juncos Avenues project, data was only available for the 24-hour period of operation. From Table 39, the following general conclusions can be developed regarding the impact by the contraflow lane operation on the total facility accident rates:

- The total facility accident rate increased in all but one project (Kalanianaole Highway) with the establishment of the contraflow lane operation. The total facility accident rate with a contraflow lane operation ranges from 1.3 accidents/MVM (0.8 accidents/MVK) on the Kalanianaole Highway to 15.4 accidents/MVM (10 accidents/MVK) on the U.S. 1/ South Dixie Highway.

- The total facility accident rate is higher in the PM peak period than the AM peak period for each project.

- For the U.S. 1/South Dixie Highway project, the total facility accident rate in each peak period increased with the operation of the contraflow lane. These increases are statistically significant.

7. For accident information in the concurrent lane section of the N.W. 7th Avenue project, see Chapter 8.

TABLE 39

FACILITY AND CONTROL ACCIDENT RATES

(Contraflow HOV Lane on Arterial Street)

PROJECT \ VARIABLE	TIME PERIOD	HOV FACILITY							Control Accident Rate[c] (acc/mvm)
		AM PEAK PERIOD		PM PEAK PERIOD		24-HOUR PERIOD OR COMBINED PEAK PERIODS			
		Number of Accidents	Accident Rate[a] (acc/mvm)	Number of Accidents	Accident Rate[a] (acc/mvm)	Number of Accidents	Accident Rate[a] (acc/mvm)	Accident Rate[a] (acc/mpm)	
U.S. 1/South Dixie Highway									
• Before	7/73 - 6/74	70	5.2	123	9.2	193	7.2	5.2	8.0
• Bus-Only	7/74 - 6/75	117	8.8**	202	15.4**	319	12.1**	7.7**	7.5
Kalanianaole Highway									
• Before	1/72 - 8/73	20	1.7ns	—	—	—	—	—	2.8
• Bus-Only	8/73 - 9/75	27	1.7ns	—	—	—	—	0.9	2.3
• Bus/Carpool	9/75 - 12/76	14	1.3ns	—	—	—	—	0.6	2.2
N.W. 7th Avenue									
• Before	8/74 - 1/75	22	10.8	23	9.9	45	10.3	7.5	8.0
• Bus-Only	1/75 - 3/76	35	9.5ns	65	14.8ns	100	12.4ns	6.7ns	7.5
Ponce de Leon/Fernandez Juncos Avenues									
• Before	5/70 - 3/71	b	—	b	—	789	6.4	—	11.0
• Bus-Only	5/71 - 3/72	b	—	b	—	853	6.8ns	2.8	11.4
• Bus-Only	1/76 - 10/76	b	—	b	—	965	9.2**	3.8	10.1

a. Statistical significance of accident rates compared to the before condition:
ns indicates difference is not significant
* indicates a 95 percent level of significance
**indicates a 99 percent level of significance

b. No data available.

c. Control Base: U.S. 1/South Dixie Highway - Dade County (Miami) County-Wide Accident Summaries
Kalanianaole Highway - FAP Route 60 in Honolulu
N.W. 7th Avenue - Dade County (Miami) County-Wide Accident Summaries
Ponce de Leon Avenue - Puerto Rico Accident Summaries

Metric Conversion
1 mile = 1.61 kilometers
1 acc/mvm = 0.62 acc/mvk

- For the Kalanianaole Highway project, the total facility accident rate did not change with the operation of the contraflow lane. The rate was slightly lower under bus/carpool operation than bus-only operation.

- For the N.W. 7th Avenue project, the total facility accident rate decreased slightly in the AM peak period and increased in the PM peak period, resulting in an overall increase, with the operation of the reversible lane. This increase is not statistically significant.

- For the Ponce de Leon/Fernandez Juncos Avenues project, the 24-hour total facility accident rate increased slightly during the first year of contraflow lane operation and increased even more in the sixth year of operation. The one-year increase is not statistically significant, however the six-year increase is statistically significant.

- Converting the accident rates from vehicle-miles to person-miles of travel enables the projects to portray a lower total facility accident rate. The range in accident rates based on MPM varies from 0.6 to 7.7 accidents/MPM (0.4 to 5 accidents/MPK). On the N.W. 7th Avenue and Kalanianaole Highway projects, the total facility accident rates as based on person-miles of travel decreased with the operation of the contraflow lane. This trend for the N.W. 7th Avenue project is opposite of the accident rate as based on vehicle-miles of travel.

- As based on vehicle-miles of travel, the increasing trend of the total facility accident rates on the HOV projects is opposite to the trend of the control bases, which experienced decreasing rates during the same periods.

The N.W. 7th Avenue reversible lane project traveled through two different geometric sections. One section (see Figure 21) permitted left turns from left-turn lanes at signalized intersections. The other section completely prohibited left turns. The accident statistics for this project show that the section prohibiting left turns experienced a total facility accident rate of 3.2 accidents/MVM (2.0 accidents/MVK), whereas the section permitting left turns experienced a total facility accident rate of 28 accidents/MVM (17 accidents/MVK). Additional discussion on the influence of left turns on safety is presented on page 135.

Accident Characteristics

Table 40 presents for the combined peak periods the percentage breakdown by 1) accident severity and 2) accident type.

The percentage of total facility accidents that are injury-producing has decreased on each project with the introduction of the contraflow lane. The percentage of total facility accidents that are injury-producing ranges from a low of 25 percent on the Ponce de Leon/Fernandez Juncos Avenues project to a high of 49 percent on the Kalanianaole Highway project, under bus-only contraflow lane operation.

On the median contraflow lane projects, over 70 percent of the contraflow lane accidents involve a left-turn cutoff or right-angle type accident. On the curb contraflow lane project on Ponce de Leon/Fernandez Juncos Avenues, the major types of contraflow lane accidents are left-turn cutoff, right angle and pedestrian.

TABLE 40

ACCIDENT CHARACTERISTICS BY PERCENTAGE (COMBINED PEAK PERIODS)

(Contraflow HOV Lane on Arterial Street)

PROJECT / VARIABLE	U.S. 1/South Dixie Highway		Kalanianaole Highway			N.W. 7th Avenue		Ponce de Leon Avenue
	Before	Bus-Only	Before	Bus-Only	Bus/Carpool	Before	Bus-Only	Bus-Only
Accident Severity[a]								
• Injury	34	29	59	49	39	47	38	25
• Property Damage Only	66	71	41	51	61	53	62	75
Accident Type[b]								
• Left-turn Cutoff	—	67	—	—	50	—	72	20
• Right-angle	—	8	—	—	50	—	0	38
• Side-swipe	—	5	—	—	0	—	23	3
• Rear-end	—	3	—	—	0	—	5	3
• Head-on	—	3	—	—	0	—	0	3
• Pedestrian	—	11	—	—	0	—	0	32
• Fixed-object	—	3	—	—	0	—	0	0
• Parked	—	0	—	—	0	—	0	1

a. Total facility accidents.

b. Contraflow lane accidents only.

TABLE 41

CONTRAFLOW LANE VOLUMES AND BUS ACCIDENT RATES

(Contraflow HOV Lane on Arterial Street)

PROJECT	AM PEAK PERIOD	
	Average Hourly Contraflow Lane Volume	Bus Accident Rate (acc/mvm)
Kalanianaole Highway (bus-only)	8	260.4
N.W. 7th Avenue	12	400.0
U.S. 1/South Dixie Highway	15	89.4
Ponce de Leon/Fernandez Juncos Avenues	63	59.5
Kalanianaole Highway (bus/carpool)	450	0

Metric Conversion
1 mile = 1.61 kilometers
1 acc/mvm = 0.62 acc/mvk

TABLE 42

BUS ACCIDENT RATES BY THREE-MONTH PERIODS

(Contraflow HOV Lane on Arterial Street)

Quarter From Beginning of Contraflow Lane Operation	BUS ACCIDENT RATES (acc/mvm)		
	U.S. 1/South Dixie Highway AM Peak Period	U.S. 1/South Dixie Highway PM Peak Period	N.W. 7th Avenue Combined Peak Periods
1	88	965	842
2	0	627	750
3	91	912	500
4	93	370	440
5	93	93	286
6	185	93	a
7	92	92	a

a. Project was concluded.

Metric Conversion
1 mile = 1.61 kilometers
1 acc/mvm = 0.62 acc/mvk

The head-on accident problem has never seriously materialized on any of the contraflow lane projects. On all four projects, project officials did indicate that vehicles on occasion did enter the contraflow lane traveling in the wrong direction. Generally, these motorists quickly realized their mistake and exited the lane. On all three projects the sight distance in the contraflow lane is good except at a few locations on the Ponce de Leon/Fernandez Juncos Avenues project. On the U.S. 1/South Dixie Highway project, this sight distance is important since several of the head-on accidents occurred after the bus actually came to a stop in anticipation of the accident. The fact that bus drivers sit relatively high off the road tends to improve the sight distance for buses.

SAFETY CHARACTERISTICS

Causative Factors Influencing Safety

Over 70 percent of the accidents involving a contraflow lane vehicle were associated with a crossing maneuver of some type by the other involved party. These crossing maneuvers may involve 1) a vehicle turning left off of the main facility, 2) a vehicle crossing or turning onto the main facility from the side street, and 3) a pedestrian crossing the main facility. The overwhelming causative factor expressed by project officials for the occurrence of these contraflow lane accidents involving crossing maneuvers is the inability of motorists or pedestrians to recognize a facility's "wrong way" operation. Therefore, when performing crossing movements, these individuals may scan for traffic in the general lane direction and fail to look for contraflow traffic. These perceptual deficiencies occur because the design of contraflow facilities violate basic driver expectancy based on the following two human factors:

- The normal symmetrical lane-use distribution, which a driver encounters in nearly all of his driving experience, is violated by the non-symmetrical layout accompanying the contraflow facility.
- Traffic control devices—signing and marking—used for standard delineation and positive guidance are often "superseded" by temporary peak period traffic control measures defining the contraflow lane. However, the motorist or pedestrian may continue to behave in a manner responsive to the permanent traffic control devices.

The omnipresent safety hazard associated with this expectancy phenomenum is dramatically documented on the U.S. 1/South Dixie Highway project. On this project, there have been two contraflow lane accidents involving police officers responsible for project enforcement. These officers, while in pursuit of violators of the project's restriction, turned directly onto the path of oncoming contraflow lane buses. The officers, who are very familiar with the contraflow lane operation, simply "forgot" for the moment about the contraflow lane provision.

The significance of the other causative factors, related to the projects' physical layout and operations, depend to a great extent how this driver expectancy is violated.

A left-turn crossing movement occurs by a vehicle on the main facility turning left across the contraflow lane. Essentially, the inclusion of a contraflow curb lane to a one-way facility transforms the facility into a two-way operation. A vehicle in the general traffic desiring to turn left across the contraflow lane will always be facing the oncoming contraflow lane traffic. This left-turn across the contraflow curb lane can be made more difficult by the highly variable speeds associated with local bus travel in the contraflow lane.

On a two-way facility with a median contraflow lane, left-turning crossing movements can occur in either direction. For vehicles traveling in the opposite direction of the contraflow lane traffic, this left-turn movement occurs by facing the oncoming contraflow lane traffic. The left-turn vehicle must not enter the contraflow lane in order to accomplish the movement. However, the situation is much different for left-turns by vehicles traveling in the same direction as the median contraflow lane traffic. Such a left-turn would occur in the left-lane (or left-turn bay) with the contraflow lane being one lane over to the left. A contraflow lane, being a through lane, located to the left of the normal left-turn lane is contrary to driver expectancy. A motorist in conducting this left-turn maneuver may not realize the existence of the contraflow lane and, therefore, not look for this type of traffic. Because of the very serious violation of driver expectancy, left-turns in the direction of the contraflow traffic have been prohibited on both contraflow median lane projects. On the N.W. 7th Avenue reversible lane project, left-turns were only permitted from left-turn bays located at certain signalized intersections (see Figure 21). There tends to be a high violation of the left-turn restriction due to 1) it being applied throughout the project limits of the contraflow lane and not at isolated locations, and 2) the reluctance of the motorist to undertake an alternate route. When such a left-turn violation occurs, there is a potentially serious safety problem due to the possibility that the motorist is unaware of the contraflow lane traffic.

There tends to be a greater violation of driver expectancy for a left-turn if the median contraflow lane is associated with a physically divided facility than if it is associated with an undivided facility. The existence of a physical separation further reinforces the driver expectancy toward a symmetrical physical layout. The motorist needs to realize that a contraflow lane operates on the other side of the median some feet away from the left through lane. The U.S. 1/South Dixie Highway project operated with an approximate 15 feet (4.5 m) grass median containing trees, shrubs, and signs. This median certainly hindered the sight distance (or visibility) of the contraflow lane operating on the opposite side of the median.

Right-angle and pedestrian crossing movements of the main facility occur with the individual entering the main facility from a side street location. On a one-way facility with a contraflow curb lane, the individuals making these movements may perhaps expect a one-way traffic flow without realizing the contraflow operation. Under such a circumstance, these individuals could well enter the main facility by looking only in the one-way direction creating a high accident potential with a vehicle traveling in the contraflow lane. This situation tends to be more serious for the crossing movements that enter the main facility on the side of the contraflow curb lane because there is less reaction time than for the crossing movements that enter the main facility away from the contraflow curb lane. On a two-way facility with a median contraflow lane, right-angle and pedestrian crossing movements of the main facility pose a lesser safety hazard than on a one-way facility. The two-way traffic causes the individual to look both ways in accomplishing his crossing maneuver. By looking both ways, the individual has a better chance to see any oncoming contraflow lane traffic. For a median contraflow lane, a physical median may, in effect, hide the contraflow lane from view.

A high proportion of contraflow lane accidents can involve pedestrians because: 1) these facilities generally are located in urban centers where pedestrian flows are relatively high, and 2) the buses generally operate in local service picking up and discharging passengers thereby creating additional pedestrian movements. A pedestrian accident poses serious consequences for any contraflow lane project because of the vulnerability of the pedestrian and the possibility that the pedestrian could be an unsuspecting child or elderly person.

Operations of a contraflow HOV lane project may be expected to impact safety through 1) the period of operation, 2) the vehicular volume in the contraflow HOV lane, and 3) the length of time the contraflow operation has been underway.

The period of operation by the contraflow lane can impact safety through a peak-period-only operation versus a 24-hour operation. A contraflow lane that operates for 24 hours each day, like the Ponce de Leon/Fernandez Juncos Avenues project, can establish permanent traffic control guidance through appropriate signing and pavement markings. Motorists driving these two facilities at any time of the day will constantly be exposed to the contraflow lane, thereby improving the familiarity with the operation. On the other hand, a peak period operation must be operated with temporary traffic control measures which supersede the permanent controls. Motorists driving a facility with a peak period(s) operation would not be continually exposed to the contraflow lane thereby lessening the chance for total familiarity with the operations. The N.W. 7th Avenue reversible bus lane operated only in the peak periods and left-turns were permitted only at certain signalized intersections. During the off-peak periods the reversible lane functioned as a dual left-turn lane. The varying left-turn restrictions and the varying uses of the reversible lane caused some motorist confusion regarding the proper use of the reversible lane.

A PM peak period contraflow lane operation generally would be of greater safety concern than the AM peak period operation. In the PM peak period, there are a greater number of non-work trips on the facility, where motorists may not have the day-to-day familiarity that is gained by daily commuting to work on the facility. There is generally a lesser volume of traffic in the AM peak period than the PM peak period which presumably would mean fewer crossing movements (and chances for contraflow lane accidents) across the main facility. The U.S. 1/South Dixie Highway project experienced a contraflow lane accident rate of 90 accidents/MVM (56 accidents/MVK) in the AM peak period and 460 accidents/MVM (285 accidents/MVK) in the PM peak period.

There may be an indirect relationship between vehicular volume in the contraflow lane and the accident rate. In other words, the higher the volume, then the lower the accident rate. This relationship could result from motorists being more keenly aware of the contraflow lane due to a higher volume in the contraflow lane. A greater number of vehicles in the contraflow lane provides greater visibility to the motorists of the contraflow lane operation. Table 41 presents for each project the data on the AM peak period contraflow lane volumes and bus accident rates.

All four contraflow lane projects experienced bus accident rates that were higher during the early stages as opposed to the later stages of the project. Such accident rate trends may suggest that there is an adjustment period of some duration for the motorists driving the facility to better comprehend the contraflow lane operation. In other words, the driver expectancy may improve with the life of contraflow lane projects. Reasonably, after a certain (but unknown) life of the project there would be a leveling off of this adjustment period where the driver expectancy no longer improves. The existence of an adjustment period can be examined by the quarterly bus accident rates associated with the contraflow bus lane operations on the U.S. 1/South Dixie Highway and N.W. 7th Avenue projects. Table 42 presents this data. The quarterly accident rate overall showed a definite reduction in accident rates as the life of the project increased. On the U.S. 1/South Dixie Highway project, the adjustment period involved five quarters, after which the bus accident rate stabilized. On the N.W. 7th Avenue project, the adjustment period also involved five quarters, at which time the project was concluded.

From the accident data available on each contraflow lane project, it could not be concluded that project design variables such as signing, pavement markings, delineators and any other traffic control measures associated with the contraflow lane, had a measurable impact on safety. For the U.S. 1/ South Dixie Highway project, a number of project-related signs and poles were installed within the raised median area. Shortly after the project was initiated, a serious accident occurred as a vehicle hit one such sign pole. Action was subsequently taken to reduce the number of sign poles in order to reduce the safety hazard. On the N.W. 7th Avenue project, project officials did indicate that there was insufficient visibility of 1) the overhead changeable message signs designating reversible lane use and 2) the roadside static signs designating the left-turn prohibition. Several months after the reversible lane commenced operations, additional static no left-turn signs were placed overhead at numerous locations to improve the visibility of this restriction.

Difficult Maneuvers and Potential Safety Problems

An HOV priority treatment might be expected to generate potential safety problems on a transportation facility. Project personnel for the contraflow HOV lane projects identified several possible difficult maneuvers and safety problems that could be associated with this type of treatment. Such safety problems include:

- A variety of pedestrian and vehicular crossing movements may adversely impact safety when the crossing movement interacts with the HOV vehicle in the contraflow lane. The safety consequences of these movements have been discussed in the previous section. The conflicting vehicular crossing movements can include 1) side street to peak direction, 2) side street to off-peak direction, 3) peak direction to side street, 4) off-peak direction to side street, and 5) side street to side street.

- A motorist making a turning movement from a side street toward the off-peak direction of the main facility might inadvertently turn into the contraflow HOV lane. Oftentimes, the natural turning path for this left turn would place the turning vehicle in the contraflow lane; indeed, the traffic law generally requires left-turning vehicles to turn into the extreme left-hand lane.

- A motorist traveling in the off-peak direction might inadvertently swerve into the contraflow HOV lane in order to bypass traffic, to avoid a collision in his lane or by error.

- The terminal points to the contraflow lane result in unusual maneuvers for both the contraflow traffic and general traffic. These maneuvers result from 1) the HOV vehicles entering or exiting the contraflow lane and 2) whether one general lane in the off-peak direction is to be used as a contraflow lane for peak-directional traffic. The seriousness of the maneuvers around the terminal points will depend on the methods used to establish the contraflow lane and to provide access to it. If access is provided by a median crossover, contraflow vehicles may have to slow down in the left lane, forcing following traffic to brake or weave out of this lane.

- Since setting up and removing safety posts is presently a manual operation, the crews are always exposed to injury. This is particularly true in inclement weather, or periods of darkness.

RECOMMENDATIONS

The previous sections have shown that contraflow HOV lane treatment is potentially one of the most hazardous priority treatments that can be implemented on an arterial street. On the other hand, it is possible to employ this treatment effectively and safely provided certain precautions are taken. General recommendations on the safety of HOV priority treatments are presented on page 7. Specific recommendations that may improve the safety of a contraflow HOV lane on an arterial street include the following:

- Prohibit left-turns at all locations along the contraflow lane operation. This prohibition should also be considered for the off-peak periods. Provide rigorous enforcement of any left-turn prohibition. Reinforce left-turn prohibitions with physical impediments where possible.

- Provide traffic control devices—signing and pavement markings—that are highly visible and frequently spaced in order to make the motorists more fully aware of any imposed restrictions. The issue of driver expectancy is more pronounced for a median contraflow lane treatment than a curb contraflow lane treatment. Additionally on a median lane treatment, driver expectancy tends to be greater for a divided facility than an undivided facility.

- The contraflow lane demarcation should be a double yellow skip line indicating a reversible lane. Yellow flexible tubular delineators should be placed along the lane line. They should be reflectorized and spaced at a maximum distance of 40 feet (12 meters) intervals. The use of the diamond symbol on the contraflow lane is discouraged, as this implies vehicle classification and not direction.

- Signing in the off-peak direction approaching the contraflow section should consist of both advanced warning and restricted lane signing along the mainline. Messages such as "CAUTION—ON-COMING TRAFFIC AHEAD—X FEET (Y KM)" and "LEFT LANE CLOSED—ON-COMING TRAFFIC" with flashers and merge-right arrows, as appropriate, are more positive than the standard MUTCD restricted lane signing. Blank-out message signs are preferable to specified time periods due to the flexibility in operating hours.

- Signing in the off-peak direction at the end of the contraflow section should be the standard MUTCD end-of-HOV-lane sign. A lane control signal should be placed downstream with all green arrows permanently displayed over each off-peak directional lane.

- Signing in the peak direction would depend on the type of terminal treatment. Standard MUTCD signing should be used with emphasis on which vehicles may use the contraflow lane.

- It may be desirable to impose additional restrictions on both contraflow lane and/or opposing lane traffic. Reduction of the speed limit and spatial headways are the most common restrictions. A lower bus headway may make the motorists more aware of the contraflow lane operation. A bus headway of ½ to one minute may be necessary to accomplish this objective. For many express bus operations, it may not be financially feasible to operate with headways of ½ minute. In view of this, and the evidence supporting lower accident rates where HOV lane volumes are higher, consideration may be given to including registered carpools, taxis or other multipassenger vehicles in the HOV lane.

- Use warning horns and/or flashing lights on the buses traveling in the contraflow lane. This would improve awareness to the contraflow lane operation.

- Potential provisions that may alleviate, in part, the pedestrian safety problems are 1) strict enforcement of "jay-walking" ordinances; 2) pedestrian signing and markings stating "LOOK BOTH WAYS" at designated cross-walks; 3) special visual or audible warning devices installed on contraflow lane buses; 4) a special yellow stripe of one to two feet (0.3 to 0.6 m) width with a warning message painted on the sidewalk adjacent to the curb; and 5) for median contraflow projects with a divided median, application of a combination of fencing and foliage in the median to obstruct and channel the pedestrian traffic to particular locations equipped with pedestrian signals.

- In order to speed up the motorist familiarization process with the contraflow lane operation, undertake 1) an intense public education campaign, and 2) heavy enforcement of the contraflow lane restrictions from the onset of the project.

- Quick-reaction incident detection and removal systems should be incorporated into the project to minimize the potential for vehicles using on-coming lanes to bypass breakdowns in the contraflow lane.

CHAPTER TEN

SIGNAL PREEMPTION SYSTEM ON ARTERIAL STREET

DETAILED DESCRIPTION

A signal preemption system provides buses with a capability to control the traffic signals in order to obtain preferential treatment at signalized intersections. Signal preemption produces travel time savings to buses through the provision of increased green time when the applicable vehicle is approaching the signal. Signal preemption generally has the capability to 1) extend the main street green phase and/or, 2) accelerate the side street phase in order to advance a main street green signal. In short, signal preemption provides the bus with a high probability of receiving a green signal phase upon its arrival at each equipped traffic signal. Travel time savings to the bus can be further increased by the provision of a reserved lane for the bus, thereby allowing the bus to bypass any traffic queues and congestion, especially at the traffic signals.

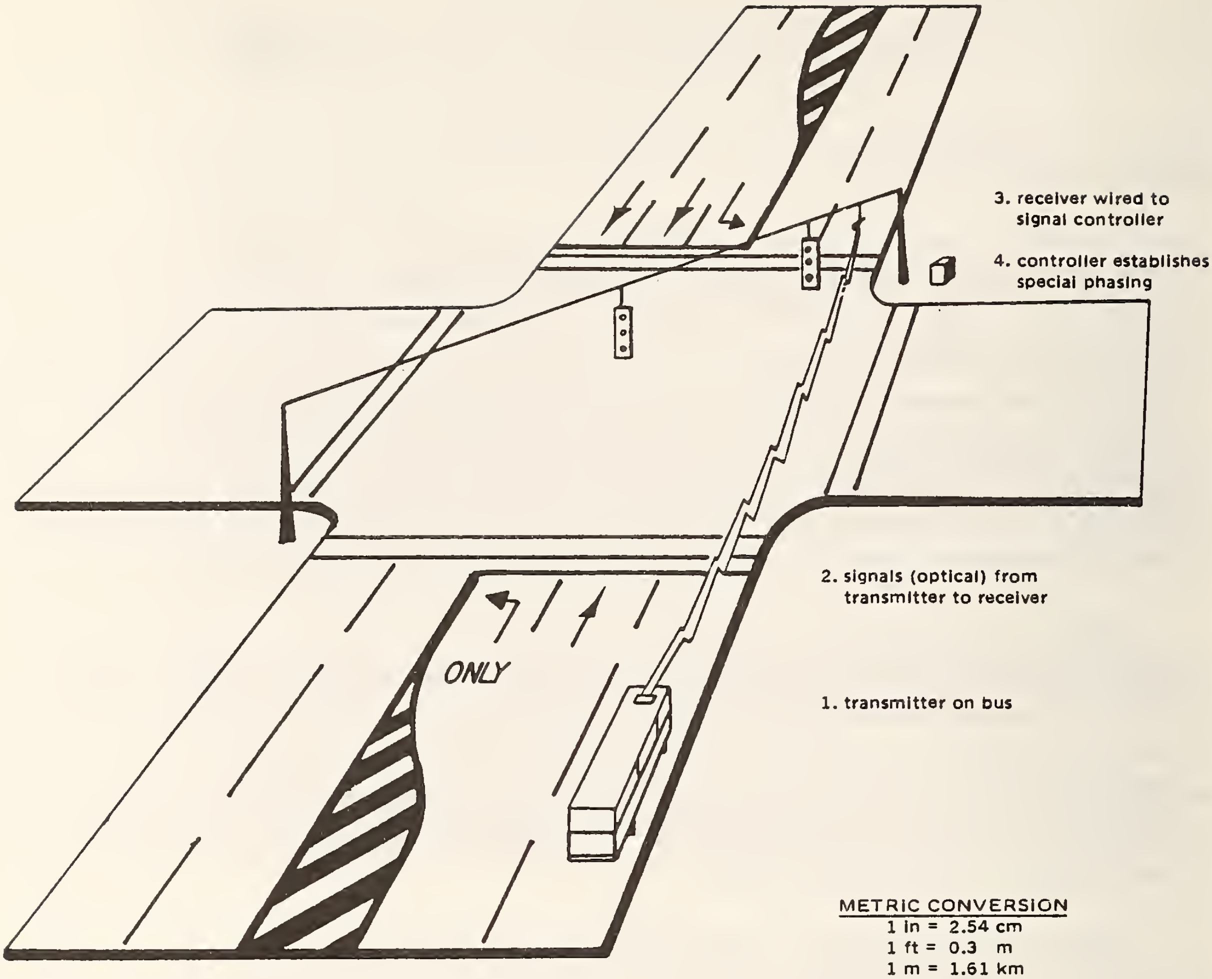
Signal preemption priority treatment can be associated with both express bus service and local bus service. Preemption design is simplified under an express bus mode of operations. Once the detector receives the signal preemption transmission from the bus, the arrival time for the bus at the signalized intersection can be more accurately predicted for express bus service since express buses generally try to travel at a constant speed with no stops for passenger loading and unloading. On the other hand, local buses travel at variable speeds with sporadic stops, and create difficulties with respect to predicting their arrival at intersections.

Signal preemption systems operate through some mechanism to transmit the proximity of the bus to a receiver at the signalized intersection. In general, bus priority signal preemption systems contain four basic components: 1) transmission component, 2) detection component, 3) communication component, and 4) logic unit. The bus presents its location by transmitting a certain signal(s) to a detector. This information is then communicated to the logic unit which adjusts the traffic signal in a prescribed manner. Current state-of-the-art transmission and detection systems include 1) optical signals, 2) radio signals, and 3) electro-magnetic signals.

This research examined one signal preemption HOV project—the N. W. 7th Avenue Bus Priority System in Miami, Florida—to identify possible impacts these elements may have on the safety of the project. This project is illustrated in Figure 23.

The N. W. 7th Avenue Bus Priority System operated in the peak periods (6:00 to 9:30 AM and 3:00 to 6:30 PM) from August, 1974, to March, 1976, at which time the bus service was transferred to the concurrent flow HOV lanes on Interstate 95. There was an evaluation of five distinct operating stages on the N. W. 7th Avenue phase combining differing signal strategies and reserved bus lane treatments. For this research, the interest is with Stage 1-buses operating in mixed-mode traffic with signal preemption.

A total of 37 traffic signals were equipped with signal preemption equipment. The signal preemption system for the N. W. 7th Avenue project was of the optical variety. An optical transmitter,



AASHTO DESIGN FACTORS

ALIGNMENT: linear
VERTICAL SIGHT DISTANCE: good
POSTED SPEED: 35 to 45 mph
ROADSIDE HAZARDS: poles within several feet of roadway

MUTCD DESIGN FACTORS

LANE-USE CONTROL SIGNALS: none
ADVANCED WARNING SIGNS: none
RESTRICTED LANE SIGNS: none
END OF HOVL SIGNS: none
DIAMOND SYMBOL: none
HOVL DELINEATION: none

N.W. 7th AVENUE (SIGNAL PREEMPTION), MIAMI, FLORIDA
FIGURE 23

N.W. 7th AVENUE (SIGNAL PREEMPTION), MIAMI, FLORIDA
FIGURE 23 (CONT.)

which emitted an intense, white stroboscopic light in front of the vehicle was mounted atop each of the express buses. The receiver was suspended on a span wire near the signal and had a reception zone of about 30^{o}, thus when properly positioned it could receive the optical signal (once in range) continuously until the bus passed under the receiver. The reception distance of the receiver was variable and in this application was set for 1,800 feet (540 m). A bus traveling at 30 mph (48 kph) would take 41 seconds to travel the distance, allowing sufficient time for signal preemption to orderly override the signalization.

Once a bus was detected by the receiver (after six seconds of continuous reception to avoid false calls due to spurious light signals), the preemption phase selector took command of the traffic controller and either extended the main street green phase or advanced into the desired preemption phase. The different possibilities are summarized as follows:

a) If the signal was already in the proper phase (main street green), the phase selector would hold the controller in that phase until the bus call expired. If, for some reason, the bus call was extended for a length of time (bus forced to stop or a long platoon of buses), a "call limit timer" set for 120 seconds would interrupt the detector call and release the controller to allow the cross street to be serviced.

b) If the signal was in a cross street phase or any other non-main street green phase, the phase selector would advance the signal off that phase and skip any other intermediate phases to bring the signal to the main street green or bus approach phase. If the bus call arrived within the minimum initial sequence or a pedestrian phase, those time sequences would be fully completed before the forceoff to the main street green phase could be affected.

With a signal preemption system, there is no need for system activation other than the bus driver activating the transmitter before his trip through the system. The transmitter then remains activated throughout the priority section.

A signal preemption system does not directly involve geometric design elements. Traffic control devices used in conjunction with signal preemption involves only traffic signals and the necessary preemption equipment. The MUTCD contains no guidelines and standards for traffic signal preemption.

Tables 2 and 3 present the national standards applicable to HOV priority treatments on arterial streets and highways. For the N.W. 7th Avenue project, there were no significant deviations from AASHTO geometric standards. All lanes were 12 feet (3.5 m) standard width, and 14 feet (4.2 m) on curb lanes. The only minor variance was the narrow right-of-way in the southern section. In the establishment of the restricted bus lane, non-standard HOV signing was used without the diamond symbol for pavement marking. This project was terminated several months after the MUTCD guidelines for HOV lane signing and pavement marking were to be in effect.

OPERATING CHARACTERISTICS

The extent of the safety impact for an HOV project is dependent in part on the operational effectiveness of the project. The operational data for the N.W. 7th Avenue project are presented in Table 43. From this table, several of the more significant results are summarized below.

- Because of higher traffic volumes and the introduction of the express bus service, total person throughput on N. W. 7th Avenue increased for both peak periods between the before and after conditions.

- Vehicle speeds for both auto and bus increased between the before and after conditions. A fully actuated signal operation system for N. W. 7th Avenue was implemented at the same time that the signal preemption was introduced. Since the entire facility was affected by this change, all vehicles benefited from this new signal operation. Also, it may be expected that autos received some spin-off benefits in travel speed through signal preemption and increased "green time" for N. W. 7th Avenue.

- There were no violations in the form of unauthorized preemption of traffic signals.

ACCIDENT ANALYSIS

The accident data on the NW 7th Avenue project is analyzed by 1) bus accident rates, 2) total facility accident rates, and 3) accident characteristics. Peak period data is for the periods 6:00 to 9:30 AM and 3:00 to 6:30 PM. The bus accident rate and total facility accident rate are compared against county-wide "control" accident rates. Accident rates were computed in terms of accidents per million vehicle-miles (MVM) and million person-miles (MPM) of travel. These rates automatically take into consideration the effects of differing stage lengths and demand levels. Accident rates were tested with the "t" statistic to determine the statistical significance.

Bus Accident Rates

Five bus accidents occurred on N. W. 7th Avenue during the signal preemption stage of operation. This constitutes a bus accident rate of 91 accidents/MVM (56 accidents/MVK). For the year 1974, the total accident rate for the county-wide transit system was 51 accidents/MVM (32 accidents/MVK). However, the difference in the two bus accident rates is not statistically significant because of the limited number of vehicle miles of travel for express buses on N. W. 7th Avenue. Table 44 presents the bus accident rate data. There was no express bus service operating in the before condition on N. W. 7th Avenue.

Total Facility Accident Rates

The total facility accident rate on N. W. 7th Avenue decreased with the introduction of the express bus service and signal preemption. The accident rate in the AM peak period decreased from 11.0 to 3.3 accidents/MVM (6.8 to 2.0 accidents/MVK) from the "before" to the "after" condition. This decrease for the AM peak period, is significant at the 99 percent level of statistical significance. Correspondingly, the accident rate in the PM peak period decreased from 9.4 to 4.8 accidents/MVM (5.8 to 3.0 accidents/MVK), which is significant at the 95 percent level of statistical significance. For the combined peak periods, the accident rate decreased from 10.1 to 4.1 accidents/MVM (6.3 to 2.5 accidents/MVK), which is significant at the 99 percent level of statistical significance. Table 45 presents the total facility accident rate data for N. W. 7th Avenue.

The total facility accident rate for the combined peak periods on N. W. 7th Avenue was compared

TABLE 43

OPERATING CHARACTERISTICS
(Signal Preemption on Arterial Street)

VARIABLE	UNIT	PROJECT/CONDITION N.W. 7th Avenue Before	Bus-Only	Before	Bus-Only
Critical Peak Period	—	7 - 9 AM	7 - 9 AM	4 - 6 PM	4 - 6 PM
Length of HOV Lane	Miles	—	9.9	—	9.9
Total Peak Directional Lanes	Lanes	2	2	2	2
Number of HOV Lanes	Lanes	—	0	—	0
Volume - All Lanes	Vehicles	1,461	1,655	1,825	1,905
Volume - Buses	Vehicles	—	23	—	21
Bus/Total Volume	%	—	1.4	—	1.1
Auto Occupancy - All Lanes	PPV	1.30	1.29	1.45	1.41
Person Throughput - All Lanes	Persons	1,895	2,777	2,641	3,221
Person Throughput - Buses	Persons	—	673	—	570
Bus/Total Throughput	%	—	24.2	—	17.7
Speed - Automobile	MPH	21.0	23.0	19.8	23.1
Speed - Bus	MPH	22.7	28.1	20.1	26.8
Travel Time - Automobile	Minutes	28.3	25.8	30.0	25.7
Travel Time - Bus	Minutes	26.2	21.1	29.6	22.2
Violation Rate	%	—	0	—	0

Metric Conversion

1 mile = 1.61 kilometers

TABLE 44

BUS AND CONTROL ACCIDENT RATES
(Signal Preemption on Arterial Street)

PROJECT \ VARIABLE	Time Period	Number of Accidents	Accident Rate (acc/mvm)
N.W. 7th Avenue (Peak Periods)	8/74 - 1/75	5	90.9
Control Base[a] (24-Hour)	1974	891	51.0

a. Control Base: County-wide bus accident rate.

Metric Conversion

1 mile = 1.61 kilometers
1 acc/mvm = 0.62 acc/mvk

TABLE 45

PEAK PERIOD FACILITY AND CONTROL ACCIDENT RATES

(Signal Preemption on Arterial Street)

PROJECT \ VARIABLE	BEFORE			AFTER		
	Time Period	Number of Accidents	Accident Rate (acc/mvm)	Time Period	Number of Accidents	Accident Rate[a] (acc/mvm)
N.W. 7th Avenue	1/74 - 8/74			8/74 - 1/75		
• AM Peak Period		30	11.0		18	3.3**
• PM Peak Period		31	9.4		30	4.8*
• Combined Periods		61	10.1		48	4.1**
Control Base[b]						
• Combined Periods		38,117	8.0		53,641	7.6

a. Statistical significance of accident rates compared to the before condition:
ns indicates difference is not significant
* indicates a 95 percent level of significance
**indicates a 99 percent level of significance

b. Control Base: All streets and highways in Dade County, Florida.

Metric Conversion

1 mile = 1.61 kilometers
1 acc/mvm = 0.62 acc/mvk

TABLE 46

ACCIDENT CHARACTERISTICS BY PERCENTAGE (PEAK PERIOD)

(Signal Preemption on Arterial Street)

CHARACTERISTIC \ PERIOD	AM PEAK PERIOD (7-9 AM)		PM PEAK PERIOD (4-6 PM)	
	Before	After	Before	After
Severity				
• Fatal	3	0	0	0
• Injury	37	50	39	20
• Property Damage Only	60	50	61	80
Vehicle Type				
• Auto	78	79	90	88
• Truck	15	6	5	5
• Bus	0	3	0	2
• Other	7	12	5	5
Pre-Collision Events				
• Intersection Collision				
• entering at an angle	27	11	13	17
• entering from same direction - both vehicles going straight	0	6	1	7
• entering from opposite direction - one straight, one left-turn	7	11	6	13
• other	27	11	13	7
• Non-Intersection Collision				
• both vehicles moving in same direction	10	28	26	20
• one car stopped	23	22	26	23
• other	7	11	16	13
Collision Type				
• Side-swipe	11	23	7	32
• Rear-end	48	39	59	34
• Angular	37	39	31	27
• Other	4	0	3	8

to the overall county-wide accident rate. The county-wide accident rate decreased from 8.0 to 7.6 accidents/MVM (5.0 to 4.7 accidents/MVK), from the same time periods as the before and after conditions on N. W. 7th Avenue. Thus, the decrease in the accident rate on N. W. 7th Avenue due to the express buses and signal preemption followed the overall county-wide trend. In the before condition, the accident rate on N. W. 7th Avenue was higher than the county-wide accident rate. Whereas in the after condition, the accident rate on N. W. 7th Avenue was lower than the county-wide accident rate. This indicates that overall traffic safety on N. W. 7th Avenue was improved by the express bus service and signal preemption operation. Table 45 presents the data for this accident rate comparison.

Accident Characteristics

Table 46 presents for each peak period the percentage breakdown of the accidents as to 1) severity, 2) vehicle type, 3) pre-crash direction, and 4) accident type. From this table, the following general points can be developed regarding the signal preemption operation and express bus service.

- The percentage of injury-producing accidents increased in the AM peak period but decreased in the PM peak period.
- The type of motor vehicle involved in the accident did not change significantly.
- With regard to accidents occurring at intersections, there was an increase for both the AM and PM peak periods in the percentage of accidents involving vehicles traveling in the same direction or opposite direction.
- For accidents occurring at non-intersection locations, the percentage of accidents involving vehicles traveling in the same direction increased for the AM peak period but decreased slightly for the PM peak period.
- The percentage of side-swipe/passing accidents increased for both the AM and PM peak period. The percentage of rear-end accidents decreased for both the AM and PM peak period.

SAFETY CHARACTERISTICS

Causative Factors Influencing Safety

The total facility accident rate on N. W. 7th Avenue decreased with the introduction of the express bus service and signal preemption. Project officials believed the principal cause for this result was the overall upgrading of N. W. 7th Avenue. Accompanying the implementation of signal preemption was the installation of totally new signalization, new pavement markings and new signing. Prior to the signal preemption project, N. W. 7th Avenue operated with local signal control at each signalized intersection.

Signal preemption by the bus has the observed impact of producing a vehicle clustering effect, or in other words, vehicles traveling in close proximity to one another. This clustering effect is caused by 1) vehicles attempting to follow the express buses closely in order to gain the benefits of signal preemption, and 2) signal preemption producing some platooning of vehicles. The latter circumstance is produced by signal preemption providing the express bus, which travels at a relatively uniform speed, a green signal upon its arrival at the signalized intersection. Other vehicles traveling in a through movement in the proximity of the bus would receive a green signal band much like signal progression. If traffic congestion happens to slow the travel speed for both the bus and other vehicles, signal preemption would hold the main street green phase until the bus and the clustering vehicles have passed through.

This clustering effect with a smooth progression-like traffic flow could cause 1) an increase in side-swipe/passing accidents because of the close proximity of the vehicles, and 2) a decrease in rear-end accidents because of the higher quality of flow produced. The bus accident rate on N. W. 7th Avenue being higher than the county-wide bus accident rate may be the result of the clustering effect that occurs around the express buses operating with signal preemption. Overall, by examination of the total facility accident rates on N. W. 7th Avenue, the traffic flow improvement by signal preemption more than offsets any possible deleterious effects associated with this "clustering" phenomenon.

<u>Difficult Maneuvers and Potential Safety Problems</u>

There are no inherently difficult or hazardous maneuvers associated with signal preemption priority treatment. Buses simply operate in mixed-mode with auto traffic and as they approach an intersection, the signal would be either held in the main street green phase or be forced to this phase from another signal phase. The preemption signal phase can be designed to allow any queued traffic to clear ahead of the bus in order to minimize delay to the bus. The force-off to the side street can be designed to be completely normal and would appear to the driver to be no different than a similar phase shift in the absence of a bus.

On the other hand, project personnel for the N. W. 7th Avenue Bus Priority System anticipated several safety problems with signal preemption operation. These potential safety problems included:

- Two buses preempting the same signal from two different directions on the intersecting streets.
- Bus operators driving with the expectation that he is guaranteed a green signal at the equipped traffic signals and violating the yellow or red phase.
- Uncertain movements by auto traffic and pedestrians due to short or variable cycle and phase lengths of signal preemption.
- Automobiles clustering around the bus in order to receive the benefits of signal preemption.

In the PM peak, the express buses entered N. W. 7th Avenue at intermediate points and could preempt the signals to have the green phase for their approach. This posed a possible conflict between two buses arriving at the signal simultaneously—one from the cross street and the other from N. W. 7th Avenue. For such a situation, the signalization was designed to provide the green phase to the bus first controlling the signal while the other bus would have to wait. The safety concern was that each driver would believe he would receive a green signal and become unattentive to the potential hazard. This safety problem did not materialize on the project.

Similarly, at any signal equipped for signal preemption, the bus driver could be lulled into a false sense of security believing he is certain to receive a green signal. In this manner, the bus driver's attentiveness toward his driving could be lessened. On N. W. 7th Avenue, the signal may not be green for a bus due to 1) signal malfunction, 2) signal preemption malfunction, or 3) a series of buses resulting in a "max-out" of the call limit timer causing the bus to be "cut-off" (given a red signal) after 120 seconds of preemptive control. A comprehensive bus driver training program was undertaken successfully addressing this potential safety problem.

Motorists and pedestrians may be accustomed to certain signal timing and be unaware that signal preemption could disrupt it. This could result in uncertain and hazardous movements especially on the cross streets where signal preemption may reduce the cross street green phase. For example, a driver on the cross street could receive a green phase just before a bus arrived to force the signal off, and thereby receive a minimum green phase length to which he may not be accustomed. He may not even notice the relatively quick change to the red phase and proceed into the intersection in front of main street traffic. Pedestrians could similarly be "stranded" in the intersection by the shortened cross street phase lengths. This anticipated safety problem cannot be substantiated on the N. W. 7th Avenue project. Two hazardous situations could have resulted from this problem. First, the driver might not observe the signal change to red and proceed into the intersection and be subsequently struck in the side by oncoming vehicles. The resulting accident configuration would be "T" or "angular" type. However, the statistics did not reveal any significant increase in angular collisions during the priority periods of operation. The second type of accident associated with this problem would have resulted from the driver perceiving the changing red light at the last moment before entering the intersection and being struck in the rear by the following vehicle due to his quick stop. Again, the statistics did not show any significant increases in the number of rear-end accidents on the cross streets. However, the design of the signal preemption system on N. W. 7th Avenue did provide for a minimum time length for the cross street green phase that would allow safe crossing by both automobiles and pedestrians under normal conditions.

As the general public began to notice the successful travel of buses (assisted by publicity stating as much), there was a concern that automobiles would tend to group around the bus in order to receive the benefits of the preferential treatment. This phenomenon was indeed observed by project personnel as buses frequently had autos "clustered" around them. The safety potential of this effect has been discussed in the previous section. Additionally, motorists may speed or make erratic passes of slower motorists in order to catch a bus using signal preemption.

RECOMMENDATIONS

The previous sections have shown that a signal preemption project can be operated safely and even improve safety, but there is the possibility of safety problems occurring. General recommendations on safety of HOV priority treatments are presented on page 7. Specific recommendations that may improve the safety of a signal preemption operation include the following:

- A more inconspicuous preemption system may be used to reduce the visible awareness of the preemption system. However, this could deter the marketing effort that makes use of such visible impact of express buses operating with signal preemption.
- Longer bus headways could be used to avoid disrupting the signal system respectively.

This can be accomplished by maximizing platooning of buses. By platooning the buses, there are fewer opportunities for clustering to occur.

- Bus speeds should be reduced if the bus drivers with signal preemption are able to drive faster than the posted speed limit. A lower bus speed should reduce the clustering effect. However, lower bus speeds may lower the appeal of the express bus service.

- The drivers of the buses utilizing signal preemption should be permanent drivers regularly assigned to these bus trips. A comprehensive driver training program should be conducted.

- The signal preemption strategy and timing package should be carefully designed to provide minimum phase lengths that will insure pedestrian clearance and/or driver expectation intervals prior to any force-offs from side street phases.

CHAPTER ELEVEN

LEGAL ISSUES OF HOV PRIORITY TECHNIQUES

INTRODUCTION

Priority techniques for high-occupancy vehicles present two basic legal issues: First, whether or not the particular agency has the authority to conduct an HOV project, and, second, what risks of legal liability are faced by the agency when traffic accidents occur causing damages and injury.

It is impossible to prepare an answer that is universally applicable to questions such as these. The law varies from state to state so far as the details of governmental authority and governmental liability are concerned. For this reason, any particular project should be reviewed by the proponents of the project as a part of the development of that specific proposal. Nevertheless, it is entirely feasible to make some generalized statement as to the procedure for approaching these issues and for the probable result if they are approached correctly.

In respect to the question of authority to conduct an HOV project, it can be stated without trepidation that the legislature in any state has the power to authorize such projects. As a general matter, it cannot be denied that these projects fall within the typical police powers of the state. It is quite another matter, however, as to whether a particular agency has had delegated to it by the legislature the authority to conduct such a project. Determining this would require examining the basic legislation establishing the agency in question and also, any specific legislation that may have been enacted to authorize an HOV project. If the implementing agency is a municipality, an affirmative answer to the question would be less likely than if the agency is a state authority such as a department of transportation. The amount of power inherent in municipalities to conduct innovative programs is generally restricted, but varies greatly from state to state, depending upon the amount of home rule authorized in the basic law of the state. Moreover, just as a state agency might be specifically authorized to carry out such a program, so also a municipality might be authorized by the legislature to do so. Hence, in making any meaningful statements about the authority question, one needs to know what state and what agency are to be involved.

The scope of tort liability is the second major legal issue to be addressed. Under the present state of the law, if there is to be liability imposed upon an agency in respect to an HOV project, it would be under that branch of the law known to lawyers as the law of negligence. A second aspect of the liability question involves an analysis of the doctrine of sovereign immunity. Traditionally, in this country, governmental agencies were not held accountable for negligent acts on the theory that the government was immune to suit. That theory has broken down to some extent in almost every state, if not every state, and has been completely abrogated in some states.

LEGAL AUTHORITY TO CONDUCT HOV PROJECTS

State Authority to Conduct HOV Projects (Police Power)

A State's authority to plan, design, construct and operate an HOV project would be derived from what is known as its police power. It is not limited to law enforcement, but can be broadly defined as the sovereign power to carry out all the functions of civil government. The only limitation upon a state's exercise of this fundamental power are those explicitly or impliedly contained in state and federal constitutions.

The recognized rule and basic standard by which the validity of any exercise of the police power is tested is that it must be "reasonably necessary." The classic statement of the rule was set out in 1894 by the United States Supreme Court in Lawton v. Steele[1] as follows:

> To justify the State in thus interposing its authority in behalf of the public, it must appear, first, that the interests of the public . . . require such interference, and, second, that the means are reasonably necessary for the accomplishment of the purpose, and not unduly oppressive upon individuals.

Even with this limitation, however, the courts in examining the reasonableness of police power legislation have given great deference to legislative discretion. The legislature's judgment as to the fitness and efficiency of its laws and the determination of what the public interest requires is not easily overturned. It has often been said that such legislation must stand if "in any degree" or "under any reasonably conceivable circumstances,"[2] there is a relationship between the means and the end.

As one of the attributes of sovereignty, the construction of highways and streets for the use of the public is inherent in the law-making power of the State under the police power.[3] The fact that HOV projects are a unique variety of highway design would not, in itself, affect the broad nature of the police power. The United States Supreme Court has said that the States have the constitutional authority to "experiment with new techniques."[4] Furthermore, the police power is recognized to embrace legislation designed to promote public convenience and not solely the interests of public health, safety and morals.[5] High occupancy vehicle projects are designed for public convenience by facilitating an increase in the total number of people that can be accommodated on heavily used highways.

The issue of the basic power of the state to spend public funds on an HOV project that excludes certain classes of users from certain of the facilities was recently contested in Peden v. Seattle,[6] a case from the State of Washington. In Peden the complainant maintained that the State had no authority to limit certain access ramps from a public street to use by buses that were a part of the "Blue Streak" HOV bus system. Peden argued that "governmental agencies lack authority to exclude him and other members of the general public" from the use of the facilities. Peden made his argument both on statutory and constitutional grounds. As to the power of the state to do so under its police powers, the court said:

> The legislature within applicable constitutional limitations may regulate traffic over the highways of this state. The essential principle to be kept in mind is that the legislature, within constitutional limitations, has absolute control over the highways of the state, both rural and urban.

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1. Lawton v. Steele, 152 U.S. 133, 137 (1894).
2. Stephenson v. Binford, 287 U.S. 251, 272 (1932).
3. New Orleans Gas Co. v. Louisiana Light Co., 115 U.S. 650, 661 (1885).
4. Day-Brite Lighting, Inc. v. Missouri, 342 U.S. 421, 423 (1952).
5. Chicago, B & Q. R. Co. v. Illinois, 200 U.S. 561, 592 (1906).
6. Peden v. Seattle, 9 Wn App. 106, 510 P.2d 1169 (1973).

By instructing the highway authorities to coordinate the development of public highways and urban public transportation systems, the legislature is exercising its legitimate police power.

The legislature has declared that separate and uncoordinated development of public highways and urban public transportation systems is wasteful of the state's natural and financial resources. . . . The "Blue Streak" project was conceived to meet this drain on resources. It can reasonably be concluded that the program is within the general public welfare and a proper exercise of police power.

We find that the "Blue Streak" project, an experimental rapid bus system, is reasonably calculated to correct a discernible public problem. The slight inconvenience caused to Peden on account of this public program is of no constitutional consequence. The public right to use the highways is not absolute; it may be reasonably regulated pursuant to legitimate exercise of state police power.

A similar issue was raised concerning a "Blue Dash" contraflow lane HOV project being employed by the Dade County (Miami), Florida government. Upon petition of citizen complaints, a trial court judge refused to halt implementation of the project on grounds of alleged hazardness, but did designate an ad hoc committee to assist the court in examining the safety of the operation. On appeal, even this intrusion by the court into the legislative use of the police powers was denied. According to the Florida appellate court in Dade County v. Palladeno:[7]

"The right to use the highways and streets for purposes of travel, however, is not an absolute and unqualified one, but may be limited and controlled by the state in the exercise of its police power, whenever necessary to provide for and promote the safety, peace, health, morals, and general welfare of the people, and is subject to such reasonable and impartial regualtions adopted pursuant to this power as are calculated to secure to the general public the largest practical benefit from the enjoyment of the easement, and to provide for their safety while using it.

It is the province of the legislature to decide upon the wisdom and expediency of such regulations and restraints, and the courts cannot declare them void, or interfere with their operation, unless they are so manifestly unjust and unreasonable as to destroy the lawful use of property, and hence are not within the proper exercise of the police power of the government. Therefore, it is our determination that any further scrutiny of the "Blue Dash" program should be undertaken by the proper county authorities and not under the supervision of the court."

These cases addressing themselves specifically to HOV projects and scores like them addressing similar issues establish that state legislative bodies have the basic power to design, construct and operate HOV projects that are reasonably related to meeting the transportation requirements of the people. A State that has an HOV project designed and constructed will not be vulnerable to a claim that it lacked the authority to do so, since the construction of highways is an inherent responsibility of the State to be carried out by exercise of its police powers.

Delegation of State Authority to State Agencies and Local Governments

The establishment of highways is a governmental function of the State.[8] The State may exercise its authority directly through State agencies or delegate it to municipalities of special authorities. In most states, statutes make provision for the election or appointment of officers who are invested with certain

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7. Dade County v. Palladeno, 303 So. 2d 692, 693, 694 (Fla. App. 1974).

8. New Orleans Gas Co. v. Louisiana Light Co., supra, n. 3.

duties pertaining to the construction and maintenance of highways.[9] Local governments ordinarily are without authority, or at least have only a limited authority, to construct and maintain highways. Any question of the proper exercise of a state agency's authority or the authority claimed by a municipality would have to be resolved by an examination of the statutes creating the authority.

Departments of transportation, highway boards and highway commissions will be allowed some implied authority necessary to accomplish the purpose for which they were created. For example, a State highway commission would be expected to acquire and maintain construction machinery even if not expressly outlined in the statute creating the commission. No useful generalizations can be made as to the extent of powers that would be upheld as being within the implied authority of a commission. In some states, implied powers would be recognized more liberally than in others.

That local governments may be specifically authorized by a state legislature to conduct HOV projects cannot be reasonably contested. It is well established that the legislature can delegate police power functions to its political subdivisions, such as municipalities and counties, just as it can to state agencies. By contrast, however, it can be doubted that local governments, particularly municipalities, have any implied authority to conduct such projects in the absence of express authorization. The operation of local government is strongly affected by the structural organization that is created under the state constitution.

In most states of this country, the courts historically have acknowledged no inherent powers in municipalities. Instead, the general rule on home rule is expressed by the so-called Dillon's rule. That is, municipal governments have only the powers expressly authorized them by the legislature, those necessarily implied in the expressed power, and those essential to the carrying-out of authorized functions. When there is any doubt as to the existence of power, it should be decided against the municipality. Applying Dillon's Rule to a municipal charter that only gave the authority to build and maintain public streets, most courts should be expected to decide that the charter did not authorize the employment of HOV projects. Local governments so limited would have to seek a special delegation of legislative power before proceeding with an HOV project.

Dillon's Rule does not apply to local governments that have had home rule powers bestowed upon them by either legislative or constitutional grant. There have developed throughout the country two basic modes of home rule powers. One is the so-called "imperium in imperio." The imperio rule implies that the home rule power is superior to the power of the legislature within the scope of its operation. Specifically, this scope is delineated by a term such as "for a municipal purpose." It is the courts that ultimately decide whether state law or municipal power prevails in the case of a conflict. If the imperio power is embedded in a constitution, then it is beyond the ability of the legislature to modify it.

An alternative home rule model that is known as the National League of Cities' model. The National League of Cities' model transfers upon home rule municipalities the authority to exercise any power for public purpose. Receding from this broad grant, however, is a limiting provision making the home rule power subject to state legislative control through general law. Consequently, it is the state legislature and not the courts that ultimately will determine the permissible scope of home rule authority under the National League of Cities model.

9. See e.g., Ill. Highway Code §4 et seq. (1959), N.Y. Highway Law § 10 (McKinney 1936), Okl. Highway Code §301 et seq. (1968).

Variation exists in the methods by which a local government may claim home rule power. First, there is a division between constitutional home rule and legislative home rule. Constitutional home rule implies that the state constitution sets forth the home rule provision, putting the provision itself beyond legislative control. By contrast, legislative home rule implies that the legislature has delegated some of its authority to the local government. Home rule of this nature is tenuous, of course, because what has been given can always be retracted.

From this analysis it can be seen that legislature authority to conduct HOV projects can be delegated to both state agencies and local governments. A specific delegation will be effective as to any agency. Implied delegations are much more likely to be acknowledged from statutes creating state agencies with broad powers to develop and implement transportation policies, such as state departments of transportations, and highway boards and commissions. Much less likely is such power to be implied in charters of municipalities and counties, especially those that have no broad grants of home rule power. Even where home rule exists whether or not the right to conduct a particular project without specific authorization could be determined only by careful scrutiny of the particular laws and charters involved.

Specific Applications for HOV Projects

Examination of many of the existing HOV projects shows that most have been employed under the auspices of state agencies that have derived their authority either from broad grants of power to develop and implement transportation policies or from specific grants of power. The Seattle "Blue Streak" project that was the subject of the Peden case discussed earlier is illustrative of a specific grant of power and, also, is illustrative of a joint state-city program authorized by a legislative statute granting the authority to enter into inter-governmental agreements. There the legislature had empowered the state highway commission to "adopt regulations for the control of vehicles entering any state limited access highway . . ."[10] From this, the power to conduct the "Blue Streak" restricted access program was implied. In Virginia, the Shirley Highway project is authorized by specific grant of authority, as follows:[11]

> In order to facilitate the rapid and orderly movement of traffic to and from urban areas during peak traffic periods, the State Highway Commission may designate one or more lanes of any highway in the interstate, primary or secondary highway systems as commuter lanes. When such lanes have been so designated, and have been appropriately marked with such signs or other markers as the Commission may prescribe, they shall be reserved at such periods as the Commission may designate, for the exclusive use of buses, whether publicly or privately operated. Provided, however, that if the Commission shall deem it appropriate in order to further the objectives of this section, it may also designate that any such commuter lane may be used during such periods by any private passenger motor vehicle transporting multiple occupants as it may designate. Provided further, that any local governing body may designate such lanes with respect to roads and streets under its exclusive jurisdiction.

The opinion in the Palladeno case discussed previously assumed that adequate legislative authority to conduct the "Blue Dash" program existed. No examination of the details was made beyond the determination of the authority inherent in the police powers themselves. A legal opinion issued by the Dade

10. R.C.W. 47.52.026, 1974 ex.s. c 133 § 3.

11. Virginia Highway Laws, § 33.1-46.2 (1973, c. 322).

County Attorney on May 5, 1972, construed certain provisions of the general laws of the state (specifically, Fla. Statute §316.008) as impliedly authorizing such projects. The HOV projects conducted in California, New York and New Jersey also were conducted under broad grants of authority to regulate traffic delegated to state transportation agencies.

LEGAL LIABILITY

The past two decades have seen dramatic changes in the public law, particularly as it pertains to the duty of public agencies to answer through the law of torts for civil wrongs done to private persons. The judiciary has peeled away in part or in the whole the armor of sovereign immunity that so long shielded governmental agencies from tort liability. This change can produce awkward decisions for operating agencies as illustrated by the implementation of HOV projects. These projects are intended to advance a number of public interests. Nevertheless, their employment coupled with expanded liability of public agencies illustrates but one of many situations in which innovative changes in public policy may run head long into new standards of public liability. Plainly stated, some beneficial policies may be so risky from a financial point of view that the budgets of public agencies preclude their use.

The potential cause of action that might be available to a person hurt in an HOV project would be what is known as the tort of negligence. The negligence cause of action requires that the plaintiff prove four elements: duty, breach, cause and damages. Once established, the cause of action can be wholly defeated or partially defeated by the defendant's proof of certain defenses, including contributory negligence, assumption of risk and sovereign immunity.

Law of Negligence: Prima Facie Case

The concept of duty in the law of negligence simply recognizes that certain situations impose a legal obligation upon persons to look out for the well being of other persons. While the existence of legal duty can be strongly influenced by the presence of a special relationship (such as doctor and patient) and can be affirmatively imposed by law (such as the duty to observe traffic laws), it is not limited to such circumstances. Indeed, the duty to any other person to exercise care for the other's safety exists whenever the prevailing context would lead a reasonable person to realize that his acts could harm the other. Perhaps, the best and most famous description of duty is that "the risk reasonably to be perceived defines the duty to be obeyed . . ."[12] Whether or not a given situation imposes a legal duty is hard to predict in the absence of a precedential legal opinion based upon identical facts. It is safe to say that the closer the relationship in time and proximity between the actor's actions and the harm befalling the victim the more likely a duty will be acknowledged.

Whether or not a legal duty exists is said to be a question of law, meaning that the issue is decided by the judge and not the jury. Not only does this mean that the issue is resolved by a legal specialist instead of lay persons, but also it means that it can be resolved during the pleading stage of a law suit,

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12. This is Justice Cardozo's famous statement of duty in the Palsgraf case. Palsgraf v. Long Is. R.R. Co., 248 N.Y. 339, 162 N.E. 99 (1928).

before trial. Hence, disposition on this issue is free of the vagaries of jury discretion and is somewhat more predictable on the basis of prior decisions than are jury issues. As mentioned above, the burden of establishing the presence of duty is upon the plaintiff. This means that if the facts argue no more strongly for duty than they do for no duty, then the plaintiff must lose.

Violation of a legal duty is known as breach. In the law of negligence, duty creates an obligation of an actor to exercise the degree of care that would be taken by a reasonable person of ordinary prudence under the circumstances to look out for the safety of the plaintiff. This conception of breach is objective, thereby defining liability in populist sense, and is peculiarly well suited for evaluation by lay people. Hence, it is the jury of ordinary people, and not the trained judge, that decides whether or not a defendant's act constitutes clupable breach.

While the objective standard of a reasonable person of ordinary prudence is the heart of the negligence doctrine, the peculiar attitudes of particular individuals are not totally irrelevant. These peculiar attributes often are taken into account as part of the circumstances. For example, children are not held to adult standards. More important, persons engaging in a profession or calling of special skill and training are held to the standard of a reasonable person in that profession or calling.

Proof of the existence of a legal duty and the breach of the standard of reasonable care is not enough to pin liability on a defendant. The plaintiff must also prove that the injuries he suffered were caused by the same acts that constituted a breach of the defendant's duty to him. Causation takes on two somewhat differing implications in the law. The plaintiff must establish cause-in-fact, which is a shorthand way of describing a cause and effect relationship between the actor's negligent acts and the victim's injuries. The actor sets forces in motion that either solely or in combination with other factors end up doing harm. Usually, but not always, the application of a "but-for"[13] test will establish cause-in-fact. That is, if it can be shown that "but-for" the defendant's negligence the victim's injuries would not have occurred, then cause-in-fact is established. Cause-in-fact does not require any set time sequence of factors contributing to the harm.

The "but-for" test of cause-in-fact is extremely sweeping in coverage and often extends liability further than courts think it should go. To restrain the limits of liability the aspect of causation known as proximate causation (or, sometimes, legal cause) must also be established by the plaintiff.[14] The doctrine of proximate causation is a restraint on liability and not an extension of it and must be recognized as such. For example, a negligent design might cause vehicle A to crash. Hours later a wrecker might be removing vehicle A from the roadway. If vehicle B runs into the wrecker at the same point removed from the point of negligent design, it can still be said that the negligent design was a cause-in-fact of the second crash. But-for the bad design the first crash would not have occurred and the wrecker would not have been where it was. Yet, the relationship between the bad design and injury to some unknown person at a later time clearly is very tenuous in the sense of predictability. When the relationship becomes so tenuous that reasonable people do not believe the actor ought to be held responsible,

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13. See, e.g., Prosser, Torts (4th Ed. 1971), 238-241.

14. "The law enacts from one voluntarily intoxicated the same care as it would from a sober person of ordinary prudence under like circumstances." Hamilton v. Kinsey, 337 So. 2d 344, 345 (Ala. 1976). See, also, Prosser, id., 236-290.

then plaintiff has failed to establish proximate causation. The more remote and attenuated the relationship between the negligent act and the harm as perceived by the court, the less likely it is to allow a finding of proximate causation. The most frequently used test is what the courts call "foreseeability." If a reasonable person could have foreseen the chain of events, then proximate causation would be established.

Proof of damages is the final element of a plaintiff's prima facie case. While complex issues concerning what are recoverable items of damages do exist in the law, the existence of some damage (personal injury, death and property loss) is present in a typical automobile crash. Nothing more is required to satisfy the damage element of liability.

Clearly, the nature of HOV projects and the intended use of them give rise to some perception of fairly specific risks to intended users. Hence, there is a basis for a legal duty to be associated with an HOV project. So far as HOV projects are concerned, a design that was produced with appropriate care and attention being given to assure safety will not be the basis for recovery when a defect that could not reasonably be foreseen and avoided causes harm in the first instance. But, when the operators of the project have a reasonable basis to discern the potentially dangerous condition, then a duty to prevent harm is created. A negligently designed element of an HOV project might await the passage of much time before the juxtaposition of events resulted in a crash. The but-for test still would make the bad design a cause-in-fact if the crash would not have occurred had the design been reasonably safe. Presumably, the kinds of harm that will come about when HOV project goes awry are quite predictable. As to those situations neither duty nor proximate cause will pose a problem to plaintiff.

Law of Negligence: Defenses and Immunities

Even if a plaintiff is able to prove a prima facie case, liability may ultimately be defeated or reduced by defenses or excluded by an immunity. A defense is a defendant's counterpart to a plaintiff's prima facie case. It simply thrusts liability back onto the plaintiff by showing him to have been at fault too. An immunity is a pure shield from liability. It acknowledges a status that immunizes the defendant from liability even though the plaintiff can prove a prima facie case and even though the defendant has no defense.

Two ordinary defenses could be utilized by the defendant. The first is contributory negligence. The elements of contributory negligence are identical to the elements of plaintiff's prima facie case except the defendant has the burden of pleading and proving them. Under the common law, if a victim were contributorily negligent in any degree (that is, he failed to exercise the degree of care for his own safety that a reasonable person of ordinary prudence would have employed), then he must lose notwithstanding the defendant's negligence. To ameliorate the harshness of the common law rule, some states either by statute[15] or court decree[16] have supplanted the contributory negligence doctrine with comparative negligence. Under this doctrine the amount of a victim's recovery is reduced to account for his own fault, but not totally eliminated. In most instances, a determination would be made as to the proportion of the fault attributable to the plaintiff, the proportion attributable to the defendant, and the amount of plaintiff's losses. Plaintiff's recovery then becomes the product of the defendant's fault and plaintiff's losses.

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15. See, e. g. Prosser, Torts (4th Ed., 1971), 436-439.
16. See, for example, Hoffman v. Jones, 280 So. 2d 431 (Fla. 1973) and Nga Li v. Yellow Cab Company of California, Cal. 3d 119 Cal. Rptr. 858, 532 P. 2d 1226 (1975).

The second ordinary defense is assumption of risk. This defense applies to defeat liability when a victim has voluntarily exposed himself to a risk which he knows of when he had available reasonable, less risky alternatives. It typically applies when a person, knowing of the risks, voluntarily enters into some hazardous activity. For example, a person who chances to jaywalk across a fast moving stream of traffic, when there is a safe crosswalk nearby, is assuming certain risks. By contrast, a person is contributorily negligent when he thoughtlessly walks into a cross-walk without looking. Assumption of the risk has been described as unreasonable venturesomeness; whereas contributory negligence is better described as unreasonable carelessness.[17]

The American doctrine of sovereign immunity originated in English common law.[18] It stems from the idea that King can do no wrong, or, at least, he is not subject to suit when he does. Imported into this country, the doctrine can be expressed in more democratic terms as governmental immunity. The government must be free to govern and should not be subjected to second guessing in the courts when things go wrong. In the past, the judge-created doctrine of sovereign immunity was applied blanket-wide to prevent all tort suits against federal, state, county and local governments.[19] Application of the doctrine denies any recovery to a plaintiff no matter how flagrant may be the conduct of the defendant and no matter how innocent of negligence the plaintiff may be.

Recognizing that such sweeping immunity is uncalled for and unjust in many situations, legislators in most states have partially waived blanket immunity or courts have weakened it by judicial opinion. The law of sovereign immunity is practically unique in every state, nevertheless certain general statements can be made. First, the immunity of municipal government is more likely to have been weakened than that of state and county governments. Thus, municipal departments are more likely candidates for liability than are state or county departments. Perhaps none is still totally immune anywhere, however. Second, proprietary activities are less likely to be immune than governmental departments. Thus, a public utility operation is a more likely candidate for suit than is a police department. Third, mismanagement of ministerial function is more likely to create liability than is mismanagement of a discretionary function.

While the foregoing analysis describes general trends, the reader should be aware that other variations exist. The reader also should be aware that the law of a given state may include a mixture of these. For example, a state may possibly have waived immunity only for municipalities, and only then for proprietary and ministerial functions. The status of immunity in any given locality can be determined only by examination of the peculiar law of that locality. At this stage in the history of sovereign immunity in American jurisdictions, no agency should assume that it exists.

A governmental agency employing an HOV project can expect no more or less protection from defenses than could a private citizen as a defendant. The nature of the HOV project lends itself more appropriately to a contributory negligence analysis in most instances. For example, motorists who drive too fast and those who drive while drinking are not being careful as to their own safety. If they then

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17. See Morris on Torts, 230-231 (1953).

18. See, e.g., Prosser, Torts (4th Ed., 1971), 970-971.

19. On the federal level this has been stated as a "jurisprudential principle that no action lies against the United States unless the legislature has authorized it." Dalehite v. United States, 73 S. Ct. 956, 965, 346 U.S. 15 (1953). Dalehite dealt with the extent of federal waiver of immunity in the Tort Claims Act.

come upon a negligently designed HOV project that is unknown to them and a crash occurs, then it can be said that the plaintiffs were contributorily negligent. By contrast, if the plaintiff was well aware of the hazard and voluntarily decided to risk it, then it could be said that he assumed the risk.

The decision to employ an HOV project is a discretionary function. Hence few, if any, courts are likely to entertain a tort lawsuit alleging that the basic decision to try an HOV project was not a reasonable one. On the other hand, the design of the elements of an HOV project is ministerial. The designers simply are carrying out the policy decision already made. Hence, where immunity has been waived, one would expect the function of designing specific elements no longer to be protected.

CHAPTER TWELVE

SUMMARY

This report presents the results of the research study into the safety evaluation of priority techniques for high occupancy vehicles. The research focused on five major areas of HOV projects: 1) an examination of the pertinent accident rates, 2) an analysis of causative factors influencing safety, 3) an identification of difficult maneuvers and potential safety problems, 4) the development of recommendations to improve safety and 5) a review of the legal authority and legal liability issues faced by HOV projects. Sixteen HOV projects were visited for research purposes by the research team. These projects encompassed virtually every type of preferential treatment strategy currently deployed in the United States on both freeway and arterial facilities. The major conclusions by chapter are summarized below.

Each HOV priority treatment chapter presents the results of the accident rates investigations. The accident data on the HOV projects were analyzed by 1) HOV lane accident rates, 2) facility accident rates and 3) accident characteristics. Accident rates were computed in terms of accidents per million vehicle-miles (MVM) and million person-miles (MPM) of travel. Accident rates were tested with the "t" statistic to determine the statistical significance of any changes and they were compared to control base accident rates.

Tables 47 to 49 present a summary of the facility and bus accident rates by HOV priority treatments. The facility accident rates (Tables 47 and 48) illustrate the safety influence on the facility by the HOV project. The bus accident rates (Table 49) illustrate the relative safety of vehicles traveling in the HOV lane. Absolute comparisons between HOV priority treatments should not be made because localized, site-specific factors can contribute significantly to a facility's safety performance. From Tables 47 to 49, the following general conclusions can be made:

- The introduction of an HOV project on the facilities investigated have tended to increase the facility accident rate. From the "before" condition based on vehicle-miles of travel, six projects experienced a statistically significant increase of peak period facility accident rates, five projects experienced a non-statistically significant increase, one project experienced a statistically significant decrease, and three projects experienced a non-statistically significant decrease. By basing the accident rates on person-miles, there was a small improvement in this safety performance.

- In general for each priority treatment, the average bus accident rates for freeway projects are slightly higher than the corresponding overall average freeway accident rates.

- In general, the average bus accident rates for arterial street projects are many times higher than the average bus accident rates for freeway projects.

CHAPTER 1 — INTRODUCTION

Priority treatments for high occupancy vehicles (HOV) can introduce new safety problems due to operational or geometric modifications. At the same time, they can reduce the accident potential

TABLE 47

PEAK PERIOD FACILITY ACCIDENT RATES BY HOV TREATMENTS

TREATMENT	PEAK PERIOD	NUMBER OF PROJECTS	ACCIDENT RATE (acc/mvm)		
			Average[a]	Highest	Lowest
FREEWAY-RELATED					
• Separate Facility	AM & PM	3	1.5	2.2	1.1
• Concurrent Flow Lane	AM & PM	4	6.7	8.4	4.2
• Contraflow Lane	AM or PM	3	3.1	2.9	3.3
• Toll Plaza Lane	AM	1	4.7	—	—
• Ramp Metering Bypass	AM or PM	1	17.3[b]	—	—
ARTERIAL-RELATED					
• Separate Facility	—	0	—	—	—
• Concurrent Lane (Median)	AM & PM	3	6.6	10.5	4.6
• Concurrent Lane (Curb)	AM & PM	1	6.5	—	—
• Contraflow Lane (Median)	AM & PM	3	8.6	12.4	1.3
• Contraflow Lane (Curb)	AM & PM	1	9.2	—	—
• Signal Preemption	AM & PM	1	4.1	—	—

a. This figure is calculated by dividing the sum of the accident rates by the number of projects.

b. This rate refers to accidents/year for 21 ramps.

Metric Conversion

1 mile = 1.61 kilometers
1 acc/mvm = 0.62 acc/mvk

TABLE 48

CHANGE IN PEAK PERIOD FACILITY ACCIDENT RATES FROM BEFORE CONDITION

TREATMENT	PEAK PERIOD	ACCIDENT RATE CHANGE FROM BEFORE CONDITION[a]			
		Vehicle-Miles		Person-Miles	
		Increase[b]	Decrease[b]	Increase[b]	Decrease[b]
FREEWAY-RELATED					
• Separate Facility	AM & PM	1 project ns	—	1 project ns	—
• Concurrent Flow Lane	AM & PM	2 **	1 ns	2 **	1 ns
• Contraflow Lane	PM	1 ns	—	1 ns	—
• Toll Plaza Lane	AM	1 ns	—	1 ns	—
• Ramp Metering Bypass	AM or PM	1 **	—	1 **	—
ARTERIAL-RELATED					
• Separate Facility	—	—	—	—	—
• Concurrent Lane (Median)	AM & PM	2 ns/**	1 ns	2 ns	1 ns
• Concurrent Lane (Curb)	—	—	—	—	—
• Contraflow Lane (Median)	AM & PM	2 ns/**	1 ns	1 **	2 ns
• Contraflow Lane (Curb)	AM & PM	1 **	—	1 **	—
• Signal Preemption	AM & PM	—	1 **	—	1 **
TOTALS					
• Significant Change		6	1	5	1
• Non-significant Change		5	3	5	4

a. Some projects do not have comparative before data.

b. Statistical significance of accident rates compared to the before condition:
ns indicates difference is not significant for each project.
**indicates a 95 percent or higher level of significance for each project.

TABLE 49

PEAK PERIOD BUS ACCIDENT RATES BY HOV TREATMENTS

TREATMENT	PEAK PERIOD	NUMBER OF PROJECTS	ACCIDENT RATE (acc/mvm)			CHANGE FROM BEFORE CONDITION[b/c]	
			Average[a]	Highest	Lowest	Increase	Decrease
FREEWAY-RELATED							
• Separate Facility	AM & PM	1	4.4	—	—	1 ns	0
• Concurrent Flow Lane	AM & PM	3	7.5	18.6	0.0	—	—
• Contraflow Lane	AM or PM	3	5.1	8.6	1.7	—	—
• Toll Plaza Lane	AM	1	4.8	—	—	1 **	—
• Ramp Metering Bypass	AM or PM	1	0.0	—	—	—	—
ARTERIAL-RELATED							
• Separate Facility	—	0	—	—	—	—	—
• Concurrent Lane (Median)	AM & PM	3	304.5	851.1	8.9	—	1 ns
• Concurrent Lane (Curb)	—	0	—	—	—	—	—
• Contraflow Lane (Median)	AM & PM	3	323.0	535.7	158.5	1 **	—
• Contraflow Lane (Curb)	AM & PM	1	56.4	—	—	1 **	0
• Signal Preemption	AM & PM	1	90.9	—	—	—	—

Metric Conversion
1 mile = 1.61 kilometers
1 acc/mvm = 0.62 acc/mvk

a. This figure is calculated by dividing the sum of the accident rates by the number of projects.

b. Some projects do not have comparative before data.

c. Statistical significance of accident rates compared to the before condition:

ns indicates difference is not significant
**indicates a 95 percent or higher level of significance

by improving overall traffic operations.

Geometric design elements that could affect roadway safety include 1) the number of lanes, 2) lane width, 3) curb or shoulder, 4) median, 5) alignment, 6) design speed, 7) sight distance, 8) roadside hazards and 9) pedestrian facilities. Current national standards on geometric features for freeways and arterial streets are established by AASHTO's A Policy on Geometric Design of Urban Highways and Arterial Streets.[1] The geometric features of the terminal treatments of an HOV lane can also impact safety. The types of terminal treatments vary greatly with the specific type of HOV treatment; thus there are no explicit geometric standards which apply universally.

Current national standards on traffic control devices for freeways and arterial streets are established by FHWA's Manual on Uniform Traffic Control Devices (MUTCD). The MUTCD has established special pavement markings and signing for preferential lane-use control.[2] An HOV lane on a freeway may require additional signing (e.g. warning signs for motorists opposing contraflow lanes) in order to improve traffic safety and capacity. Similarly, an HOV lane on an arterial street could very well have additional signing requirements for turning and parking restrictions in order to improve traffic safety and capacity. Violations of these restrictions can impact safety greater than violations of the occupancy restriction of the HOV lane. The placement of delineators on an HOV lane project that operates during the peak periods requires appropriate system activation and deactivation at the appropriate times. There is a potential safety problem due to a truck with work crew traveling slowly in the HOV lane.

The major involvement of transit agencies, aside from being designated users of the HOV system, is to train the drivers in the proper procedures to enter/exit the HOV lane and to operate in the lane. Drivers must be aware of any special potential hazard associated with operating in the lane. From a safety standpoint, it is preferable that the same drivers always be assigned on the HOV lane routes; however, because of operational conditions or institutional reasons, this is not always possible.

HOV lane operations generally place additional emphasis on the enforcement of the particular facility.[3] This is especially true for a peak period operation where the traffic control measures are temporary. More policing and manpower may be required for system monitoring. An enforcement program on an HOV facility can have a substantial effect on safety. These safety impacts can occur 1) through the enforcement personnel detecting, apprehending and detaining violators or 2) by violators maneuvering to avoid enforcement. Violators of HOV-related restrictions can contribute heavily to the operational problems the traffic engineer has attempted to solve.

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1. American Association of State Highway and Transportation Officials (AASHTO), A Policy on Geometric Design of Urban Highways and Arterial Streets (1973 edition), published by AASHTO, Washington, D.C.

2. United States Department of Transportation (Federal Highway Administration), Manual on Uniform Traffic Control Devices—Official Rulings on Requests, Volume VI, June 1975, pp. 7-8 and 41-42.

   Federal Highway Administration, "Changes in the Manual on Uniform Traffic Control Devices to Provide Pavement Marking and Signs for Preferential Lane Use Control," FHWA Notice N 5160.8, March 17, 1975.

3. For a complete evaluation of enforcement of HOV priority treatments, see Beiswenger, Hoch and Associates, Enforcement Requirements for High-Occupancy Vehicle Facilities, Federal Highway Administration, DOT-FH-11-9240, 1978.

There are certain general recommendations for safety on HOV priority treatment projects which are common to all freeway and arterial street applications. Specific recommendations on the particular HOV priority treatments are presented in Chapters 2-10. The general recommendations are:

- Every affected agency and the public should be included in the planning and decision-making stages. Enforcement agencies have an obvious interest as they will be largely responsible for the operation later, but equally important, they can often also foresee potential safety problems resulting from the operation.
- Whenever possible, the HOV lane should be an added lane and not be established by the taking of an existing general traffic lane. Oftentimes, this recommendation cannot be followed due to right-of-way, cost or schedule considerations.
- AASHTO and MUTCD standards should be rigorously adhered to as much as possible. Existing deficiencies should not be exaggerated by the HOV project design.
- The opening of an HOV lane should be well publicized using a variety of media and including "news" features.
- Incidents should be detected and removed from the facility, especially the HOV lane, as quickly as possible.
- The enforcement plan should be formally planned in advance. Aggressive enforcement should begin immediately upon the opening of the HOV lane(s), even if only warning citations are issued initially. Enforcement of the HOV project should be well publicized.

CHAPTER 2 — SEPARATE HOV FACILITY ON FREEWAY

Separate HOV facilities are roadways or lanes which are physically separated from the general freeway lanes. These facilities are designated for exclusive use by specified HOV vehicles and all other vehicles are expressly prohibited. The separation can be either permanent or partial. The separate roadway can lie within the median of the freeway or it can be entirely removed from the freeway. Completely separated roadways are really independent highways with no interaction with the general lanes, except at the terminal points. Partially separated lanes can have shared medians or shoulders which reduces right-of-way requirements. In this design, the restricted lanes are accessible (illegally) from the general lanes by penetrating the joint-use shoulder causing a safety hazard.

Separated HOV facilities on freeways generally operated with a relatively high degree of safety, particularly within the HOV lanes. Bus-only operations provided a higher degree of safety on the HOV lanes than bus/carpool operations. Only where interactions with general lanes occurred were problems of any consequence detected. The extensive degree of restriction and physical separation generally precluded implementation problems. However, the separate roadway treatment can be very disruptive to general traffic when the HOV lanes are constructed in the median.

Difficult maneuvers and potential safety problems for this HOV treatment include:

- The limited access operation of separated HOV facilities concentrates weaving in the general lanes to particular locations upstream of HOV access terminals and downstream of HOV egress terminals.

- Incidents can seriously interfere with traffic flow, if roadway and shoulder widths are insufficient to allow storage of disabled vehicles.

- On partially separated facilities, motorists can make illegal maneuvers through the separation between the HOV and general lanes, and thereby create merging problems by entering the facility at unassigned locations. This hazardous situation could be further compounded by the speed differential between the HOV lanes and general lanes.

Specific recommendations that may improve the safety of this HOV treatment include:

- The ideal terminals to and from the separated HOV lanes are exclusive ramps. At the output terminal, it is best to add a lane or provide an adequate acceleration lane for HOV vehicles merging into general traffic.

- On partially separated HOV lanes, supplemental signing should be provided at inputs to identify the legal exits from the limited access facility. This is to avoid erratic maneuvers by drivers needing to exit at locations other than the HOV lane terminals.

- On partially separated facilities having a common shoulder, the shoulder should have chevrons, cross-hatching, word messages and safety posts to discourage crossing of this shoulder.

CHAPTER 3 — CONCURRENT FLOW HOV LANE ON FREEWAY

Concurrent-flow HOV lane priority projects on freeways generally involve the designation of the median lane(s) for use by buses alone or by buses and carpools. Access to the restricted lane is most often continuous, that is, there is no physical separation or other barrier between the HOV lane and general lanes. The lack of physical separation of the HOV lane from the general lanes is the source of several operational and safety problems not experienced in other HOV treatments on freeways. Concurrent HOV lanes can be created by either reserving an existing lane for HOVs or, more commonly, by constructing new lanes in the median. These two approaches have differing effects on the operation of the facility. First, the addition of lanes increases capacity but in order to do so often eliminates or reduces median shoulders or refuge areas, which could formerly be used by disabled motorists and enforcement operations. Secondly, the "taking a lane" for HOVs will reduce capacity for general traffic and increase the congestion in the general travel lanes. The public acceptance of the concurrent HOV treatment has been much better when new lanes are constructed for the HOVs.

The elimination of median refuge areas and resulting small distances to the concrete barrier wall are contributing safety factors. The existence of such safety factors are related to the manner of implementation of the HOV lane. Motorists, out of necessity or by error, have used the median lane for pulling over and stopping on the facility. A motorist traveling in the median lane or left interior lanes may not be able when his vehicle becomes disabled to pull off the facility because of the congestion or other circumstances.

High differential speeds between continuously accessible HOV lanes and adjacent general lanes, coupled with merging into and out of the HOV lane appeared to be the most significant cause of accidents in general. Weaving across several general lanes to gain access to, or leave the HOV lane, was a secondary factor. Incidents blocking any lane, but particularly the HOV lane, were a major cause of accidents.

Difficult maneuvers and potential safety problems for this HOV treatment include:

- Continuous access/egress to a restricted median lane could be expected to increase weaving on the freeway as HOVs cross the freeway to enter and exit the HOV lane.

- Where no median refuge area exists, it may be extremely difficult for disabled vehicles to get off the roadway, if they are in the left lanes. While this is true in general, implementation of HOV lanes where a left shoulder once existed can create this problem.

- A large speed differential between the HOV lane and adjacent general lanes cause slower vehicles to merge into a high speed HOV lane or faster vehicles in the HOV lane having to decelerate rapidly to merge into the general lane. Either action could result in side-swipe or rearend accidents.

- Some motorists may be confused about the proper use of the median lane in the off-peak periods. If a motorist incorrectly believes it to be a refuge area, a safety problem occurs if he stops his vehicle in the lane which is being used by general traffic. This problem occurs only where there is no median refuge area.

Specific recommendations that may improve the safety of this HOV treatment include:

- It is strongly urged that concurrent HOV lanes be added to the facility rather than "taken" from existing general use, particularly on heavily congested urban freeways.

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

- If the HOV lane is a continuously accessible lane, the lane demarcation between the HOV lane and general lane should be a conspicuous white line. Where solid lines are used, there should be a left shoulder and/or clear indication that the HOV lane is a traveled lane and no stopping is allowed. On the other hand, some special treatment of the HOV lane line is appropriate and may be accomplished by using wider skipped lines or by using delineators.

- The speed differential between the HOV lane and general-use lanes should be controlled if necessary and possible. This may be accomplished by metering general lane traffic at on-ramps, using variable speed control signing on the HOV lane, or a combination of both.

CHAPTER 4 — CONTRAFLOW HOV LANE ON FREEWAY

The common application of contraflow HOV lanes is to assign the inside (median) lane in the opposing (off-peak) direction to a special class of vehicles. The contraflow lane is separated from the other travel lanes by insertable plastic posts. If sufficient capacity remains in the off-peak direction, an additional lane can be taken for use as a buffer lane. The vehicles qualified to use the contraflow lane are usually buses, although one project also allows taxis with passengers to use the contraflow lane. Typically, the contraflow lane section begins or ends upstream of a major bottleneck location such as a bridge, tunnel or toll facility. Buses (and other vehicles if permitted) enter the lane via a median cross-over or by a special ramp and proceed in the peak direction against the flow of off-peak direction general traffic, thereby bypassing congested traffic in the peak direction. The output terminal depends on the site and may be a cross-over merging with the general freeway or it may terminate at a bridge, tunnel or toll facility.

The most apparent causative safety factor related to contraflow HOV lane operations is the capacity reduction in the off-peak direction. The projects on facilities with superior geometric features generally had fewer and less severe safety problems overall.

One inherent problem with contraflow operations is pedestrians (or motorists) forgetting that buses are traveling in the opposite direction. While pedestrians crossing the freeway is not a common problem, drivers of disabled vehicles often need to cross the facility. If glare fencing is added atop the median wall, this safety problem can be greatly reduced.

Difficult maneuvers and potential safety problems for this HOV treatment include:

- Clearly, the most obvious safety problem on contraflow HOV lane projects is the potential for conflict between opposing traffic. The danger of a vehicle losing control and penetrating the safety delineators into on-coming contraflow vehicles is always present. An accident situation may cause an erratic maneuver resulting in a vehicle traveling the "wrong way" in the contraflow lane.

- However, if access is provided by a median crossover, contraflow vehicles may have to slow down in the left lane, forcing following traffic to brake or weave out of this lane.

- Incident removal from contraflow lanes is extremely hazardous especially if no buffer lane exists. Stalled vehicles must either be pushed to the end of the lane or removed by tow truck. If towing is required, the tow vehicle must generally approach the disabled vehicle from the opposing direction and turn around. This necessitates stopping the off-peak general traffic, which is always a hazardous condition on a freeway.

Specific recommendations that may improve the safety of this HOV treatment include:

- The ideal terminals to and from the contraflow lane are exclusive ramps or toll booth lanes if the output is to a toll plaza. Where median crossovers are required at the input, a short access lane allowing for deceleration should be provided upstream of the crossover.

- Where no buffer lane can be provided between the contraflow lane and the general-use lanes, the proper lane use should be designated by overhead lane use control signals. Where a buffer lane can be provided between the contraflow lane and the general use lanes, overhead lane use control signals are not necessary to designate proper lane use if sufficient physical separation and signing is provided.

- Use of the contraflow lane should be restricted to experienced and trained operators. In addition to transit operators, operators of other vehicles (charter buses, mini-buses, vanpools, taxis and carpools) could be permitted use of the contraflow lane if special licensing requirements are met.

- It may be desirable to impose additional restrictions on both contraflow lane and/or opposing lane traffic. Reduction of the speed limit and spatial headways are the most common restrictions.

- Quick-reaction incident detection and removal systems should be incorporated into the project. If possible, median cuts should be provided if there is no buffer lane so emergency vehicles can approach in the proper direction; however, these should not be penetrable by general traffic nor present a collision hazard themselves.

CHAPTER 5 — TOLL PLAZA HOV LANE

A toll plaza is inherently a bottleneck on a freeway. In such instances, the capacity of the toll plaza is generally equal to or less than the upstream demand, resulting in extensive queuing in peak periods. This HOV priority treatment is relatively simple to implement if lanes and/or toll booths are redesignated from general traffic use to exclusive use by HOVs. Since toll plaza configurations vary greatly, there is no "typical" manner of implementing restricted lanes or booths for HOVs. Thus, exclusive toll plaza lanes serve several purposes. They allow HOVs to 1) bypass queues on the approach, 2) move through the toll station with minimal delay, and 3) gain preferential access to the toll facility itself.

Toll plaza HOV lanes are generally "taken" from general lanes, as opposed to being newly constructed. This is because the capacity of the toll facility is fixed and adding capacity is generally not a feasible alternative. This method of implementing the HOV lane results in 1) extending the queuing area in the general lanes further upstream and 2) introducing a speed differential between the HOV and general lanes.

Difficult maneuvers and potential safety problems for this HOV treatment include:

- A major amount of weaving by some HOVs may be required to gain access to the HOV lane.
- The safety problem created by the reduction in the number of lanes after the toll booths is aggravated by the speed differential between the HOV and general lanes.
- Motorists may weave into the HOV lane at any time before or after the toll booths.

Specific recommendations that may improve the safety of this HOV treatment include:

- Ideally, the HOV lanes and general lanes should be separated by a physical barrier or raised curb, so long as such a barrier does not pose a safety hazard itself. Where physical barriers are impossible to implement, some type of lane delineation should be incorporated. Any stanchions delineating the HOV lane should be placed close enough to prevent lane change movements.
- The weaving area to gain access to the priority lane should be of sufficient length to minimize conflict. This is especially true where multiple roadways access the toll facility. Similarly, adequate merging distance should be provided to the priority lanes where they rejoin the general traffic lanes after passing through the toll booths.
- When possible, special refuge areas or shoulders should be provided adjacent to the HOV lanes. Such areas aid both disabled HOVs and enforcement operations.

CHAPTER 6 — HOV RAMP TREATMENTS

There are commonly two types of HOV treatments on ramps: 1) HOV bypass of ramp metering at on-ramps, and 2) exclusive on- or off-ramps for HOVs.

Ramp metering has been used for nearly two decades to improve general operations on freeways by limiting access onto the mainline of the freeway. As an incentive to HOVs, bypass lanes have been constructed which allow these vehicles "free" access to the freeway without the delays encountered by low occupancy vehicles at the ramp signal. The ramp metering bypass (RMB) technique can be used at isolated ramps, or can be incorporated into a series of ramps which collectively form a RMB HOV priority system. RMB lanes are generally constructed by widening existing ramps, or redesignating one lane of existing multi-lane ramps. RMB lanes can be the right or left lane depending on the geometric configuration of the ramp. RMB lanes can also be physically separated from the general lanes. This eliminates the interaction between HOVs and general traffic, thereby enhancing safety and enforcement.

Exclusive HOV ramps are generally of two types. One type connects general-use lanes with HOV-specific facilities, such as bus terminals, in order to allow direct access to or from these restricted areas. The second type is the "typical" HOV priority facility which is intended to give preferential service to HOVs by serving desirable origin-destination patterns of motorists.

The RMB treatment can adversely impact safety. There is a recurring conflict between vehicles entering the ramp from several surface street approaches and having to split into the two lanes. Often, some weaving can be expected in these maneuvers and accidents can result from the somewhat unpredictable movements by entering vehicles. On the other hand, the exclusive HOV ramp has not been shown to have general safety problems unless they are site-specific.

Difficult maneuvers and potential safety problems for this HOV treatment include:

- On RMB ramps, the HOVs move through the metering signal station without stopping, while vehicles in the metered lane must stop and queue up. The potential exists that a violator (or HOV finding itself in the wrong lane) may attempt to change lanes into the faster HOV lane.

- Where the RMB lane and the metered lane converge after the metering signal station, there is the potential for merging related accidents to occur. This condition is not unique to an HOV treatment.

- Commonly, vehicles may enter the ramps from several surface street approaches and have to split into two lanes. This safety problem is further compounded if the metered queue extends back onto the surface street. In this event, HOVs "trapped" in the queue on the surface street may attempt erratic maneuvers to bypass this temporary delay, and move directly onto the ramp in the HOV lane.

Specific recommendations that may improve the safety of this HOV treatment include:

- Ideally, the HOV lane should be physically separated from the metered lane(s), either by being constructed separately (thus having many characteristics of exclusive ramps) or by barriers. This is particularly important at the ramp entry.

- When separation is not possible and if the ramp is long and has sufficient storage capacity, begin the HOV lane after the entrance point so there is a single entry lane.

- Sufficient merging distance should be provided on the body of the ramp so that HOVs and general traffic can merge together and assume the same speeds prior to merging on the freeway.

- Exclusive HOV ramp locations should be carefully selected and consideration should be given not only to the access needs of the HOVs, but also to any resulting adverse impacts of displacing traffic.

- The intersection with surface streets is of particular concern for HOV ramps. This is especially true if the ramp is reversible. Hazardous maneuvers or conflicts with surface traffic should be minimized by proper geometric design and/or traffic controls.

CHAPTER 7 — SEPARATE HOV FACILITY ON ARTERIAL STREET

Separate facilities on an arterial street system are commonly referred to as "transitways" because the only type of vehicle that is generally permitted to travel on such a facility is the transit coach. There are two types of transitways, each serving a different objective. A transitway may serve as a major transit collection/distribution route providing benefits of transit accessibility and separation of different classes of vehicles. Also, a transitway may serve the line-haul portion of transit service providing the more traditional HOV benefits of travel time savings and increased total person through-put.

Generally, the separate facility is established by restricting, for the desired length, an arterial street that previously handled through traffic. For this treatment, the approaching general traffic on the arterial can be channeled and guided from the transitway much in the manner of a non-through leg of a T-intersection.

The overall safety experience of separate facility transitways has been very good. A difficult maneuver could exist in the vicinity of the entry/exit locations to the transitway. Partly because of this potential, the only entry/exit locations generally occur at the terminals, thereby eliminating turning movements onto or off the transitway at intermediate locations.

Potential safety problems for a transitway might include 1) pedestrian conflicts, or 2) conflicts with cross street general traffic. Pedestrian conflicts are likely to be the main safety concern because of large pedestrian volumes attracted by the pedestrian mall and the transit collection/distribution service. Pedestrian movements can be quite varied and are difficult to control. There may be conflicts as a result of the cross street traffic not realizing the existence of the transitway.

Specific recommendations that may improve the safety of this HOV treatment include:

- Cross streets across the transitway should be eliminated whenever possible. When the elimination of cross streets is impossible, the turning movements between the transitway and the cross streets should be restricted. A one-way cross street is preferred to a two-way cross street because of the fewer potential conflicts and traffic operational requirements.

- Procedures regarding bus operations on the transitway should include 1) low bus speeds, and 2) increased driver awareness and courtesy.

- All appropriate pedestrian controls should be instituted. These include pedestrian crosswalks, pedestrian signals and strict enforcement of "jay-walking."

CHAPTER 8 — CONCURRENT FLOW HOV LANE ON ARTERIAL STREET

Concurrent flow priority applications involve reservation of either the curbside lane or the median lane for HOVs. These applications have differing operational objectives and requirements. Curbside lanes have historically been installed to provide better transit circulation in the CBD and/or to improve downtown traffic flow through the segregation of buses and autos. A second objective may be to provide a travel time improvement (not advantage) for buses. Taxi-cabs, other vehicles loading and unloading passengers, right-turning vehicles, motorcycles and bicycles may also be permitted to travel in the curb HOV lane. Median lanes are generally intended to provide high-occupancy vehicles with travel time advantages by bypassing traffic congestion in the general traffic lanes. This type is commonly associated with express bus service operating in a through or express mode.

On a concurrent flow curb HOV lane, restrictions on right turns and parking are desirable. The restriction against right turns however is generally impractical; thus right turning vehicles are generally permitted to use the curb lane in order to execute the turn. On a concurrent flow median HOV lane, restrictions on left turns may be desirable.

A major causative factor for safety is whether the HOV lane is established by either adding a lane or "taking" a lane away from general traffic. Adding a lane provides additional capacity and can greatly decrease the peak period congestion. Conversely, taking a lane for HOV use can greatly increase the peak period congestion in the remaining general lanes.

There may be a direct relationship between the volume of traffic in the median HOV lane and safety of the vehicles traveling in the HOV lane. This relationship could result from the motorists being more keenly aware of the HOV lane due to a higher volume in the HOV lane. There may also be a direct relationship between the restriction of crossing movements and safety of the vehicles traveling in the HOV lane.

A curb bus lane project experiences two accident types not experienced by a median lane project— an accident with a parked vehicle and an accident involving a pedestrian. A vehicle parked or stopped in the curb lane forces the following vehicles to weave into the adjacent general traffic lane. A pedestrian accident may be associated with a curb HOV lane because these projects most often will be located in the downtown area where 1) pedestrian traffic is the highest, and 2) the local bus service that travels the curb lane creates additional pedestrian traffic, as well as being in close proximity to the pedestrians.

Difficult maneuvers and potential safety problems for this HOV treatment include:

- Vehicles authorized to use the curb HOV lane (HOV vehicles, taxicabs, and right-turning vehicles) will be merging into and out of the curb lane throughout the project limits. The potential safety problem is with vehicles unduly merging ahead or weaving around a slower moving bus in the curb lane.

- For vehicles turning right onto a street with a curb HOV lane, this maneuver may cause the vehicle to be in the curb lane. Once realizing the existence of the HOV restrictions, this motorist may attempt to quickly merge out of the curb lane or perhaps be trapped in the curb lane by the existing traffic congestion and come to a halt.

- Left-turns off the facility with a median HOV lane may create a safety problem by motorists 1) stopping in the "express" HOV lane to make the left turn or 2) weaving unexpectedly across the HOV lane into a left-turn bay.

- A large speed differential between the HOV lane and adjacent general lanes cause slower vehicles to merge into a high speed HOV lane or faster vehicles in the HOV lane having to decelerate rapidly to merge into the general lane. Either action could result in side-swipe or rear-end accidents.

Specific recommendations that may improve the safety of this HOV treatment include:

- Prohibit taxi-cabs and other vehicles from stopping in the curb lane to pick-up and drop-off passengers, or to make deliveries.

- Remove parked vehicles from the curb lane.

- Prohibit left-turns at selected locations, if not at all locations. Closing off of non-signalized intersections by cones or other implements should be considered to reduce crossing movements across the HOV lane.

- The speed differential between the HOV lane and general-use lanes should be controlled if necessary and possible. This may be accomplished by using variable speed control signing on the HOV lane.

- Volumes in the HOV lane should be high enough to portray the lane as an operational lane.

CHAPTER 9 — CONTRAFLOW HOV LANE ON ARTERIAL STREET

A contraflow HOV lane on an arterial street is commonly a lane in the off-peak direction reserved for HOV vehicles traveling in the peak direction. It can incorporate the median lane or the curb lane of a highway facility. A contraflow HOV lane operating in the median lane is commonly associated with express bus service operating in a through or line-haul trip. The major objective of the contraflow median HOV lane is to provide travel time advantages to the HOV vehicles by bypassing traffic congestion in the general traffic lanes and traffic queues at signalized intersections. A contraflow HOV lane operating in the curb lane occurs on a facility which otherwise serves one-way traffic. This type is commonly associated with local bus service making periodic stops for passenger loading and unloading. The major objectives of the contraflow curb HOV lane is to 1) separate the different classes of vehicles—bus and auto—in order to improve traffic flow on the facility and traffic circulation in the CBD, and 2) provide a travel-time advantage for the HOV vehicles (i.e. local buses).

The overwhelming majority of accidents involving a contraflow lane vehicle were associated with a crossing maneuver of some type by the other involved party. These crossing maneuvers may involve 1) a vehicle turning left off of the main facility, 2) a vehicle crossing or turning onto the main facility from the side street, and 3) a pedestrian crossing the main facility. The overwhelming causative factor for the occurrence of these contraflow lane accidents involving crossing maneuvers is the inability of motorists or pedestrians to recognize a facility's "wrong-way" operation. Therefore, when performing crossing movements, these individuals may scan for traffic in the general lane direction and fail to look for contraflow traffic. There tends to be a greater violation of driver expectancy for a left turn if the median contraflow lane is associated with a physically divided facility than if it is associated with an undivided facility.

Operations of a contraflow HOV lane project may be expected to impact safety through 1) the period of operation, 2) the vehicular volume in the contraflow HOV lane, and 3) the length of time the contraflow operation has been underway. A contraflow lane that operates for 24 hours each day can establish permanent traffic control guidance through appropriate signing and pavement markings. Motorists driving a facility with a peak period(s) operation would not be continually exposed to the contraflow lane thereby lessening the chance for total familiarity with the operations. There may be an indirect relationship between vehicular volume in the contraflow lane and the accident rate. This relationship could result from motorists being more keenly aware of the contraflow lane due to a higher volume in the contraflow lane. There may be an adjustment period of some duration for the motorists driving the facility to better comprehend the contraflow lane operation. In other words, the driver expectancy may improve with the life of contraflow lane projects. Reasonably, after a certain (but unknown) life of the project there would be a leveling off of this adjustment period where the driver expectancy no longer improves.

Difficult maneuvers and potential safety problems for this HOV treatment include:

- A variety of pedestrian and vehicular crossing movements may adversely impact safety when the crossing movement interacts with the HOV vehicle in the contraflow lane.

- A motorist, making a turning movement from a side street toward the off-peak direction of the main facility, might inadvertently turn into the contraflow HOV lane. Oftentimes, the natural turning path for this left turn would place the turning vehicle in the contraflow lane.

- A motorist traveling in the off-peak direction might inadvertently swerve into the contraflow HOV lane in order to bypass traffic, to avoid a collision in his lane or by error.

Specific recommendations that may improve the safety of this HOV treatment include:

- Prohibit left-turns at all locations along the contraflow lane operation. This prohibition should also be considered for the off-peak periods. Provide rigorous enforcement of any left-turn prohibition. Reinforce left-turn prohibitions with physical impediments where possible.

- Provide traffic control devices—signing and pavement markings—that are highly visible and frequently spaced in order to make the motorists more fully aware of any imposed restrictions.

- The contraflow lane demarcation should be a double yellow skip line indicating a reversible lane. Yellow flexible tubular delineators should be placed along the lane line. They should be reflectorized and spaced at a maximum distance of 40 foot (12 meter) intervals.

- It may be desirable to impose additional restrictions on both contraflow lane and/or opposing lane traffic. Reduction of the speed limit and spatial headways are the most common restrictions.

- In order to speed up the motorist familiarization process with the contraflow lane operation, undertake 1) an intense public education campaign, and 2) heavy enforcement of the contraflow lane restrictions from the onset of the project.

CHAPTER 10 — SIGNAL PREEMPTION SYSTEM ON ARTERIAL STREET

A signal preemption system provides buses with a capability to control the traffic signals in order to obtain preferential treatment at signalized intersections. Signal preemption produces travel time savings to buses through the provision of increased green time when the applicable vehicle is approaching the signal. Signal preemption generally has the capability to 1) extend the main street green phase and/or, 2) accelerate the side street phase in order to advance a main street green signal. In short, signal preemption provides the bus with a high probability of receiving a green signal phase upon its arrival at each equipped traffic signal. Travel time savings to the bus can be further increased by the provision of a reserved lane for the bus, thereby allowing the bus to bypass any traffic queues and congestion, especially at the traffic signals.

Signal preemption by the bus has the observed impact of producing a vehicle clustering effect, or in other words, vehicles traveling in close proximity to one another. This clustering effect is caused by 1) vehicles attempting to follow the express buses closely in order to gain the benefits of signal preemption, and 2) signal preemption producing a green signal band much like signal progression. This clustering effect with a smooth progression-like traffic flow could cause 1) an increase in side-swipe/passing accidents because of the close proximity of the vehicles, and 2) a decrease in rear-end accidents because of the higher quality of flow produced.

Difficult maneuvers and potential safety problems for this HOV treatment include:

- Bus operators driving with the expectation that he is guaranteed a green signal at the equipped traffic signals and running the yellow or red phase.

- Automobiles clustering around the bus in order to receive the benefits of signal preemption.

- Motorists and pedestrians may be accustomed to certain signal timing and be unaware that signal preemption could disrupt it. This could result in uncertain and hazardous movements especially on the cross streets where signal preemption may reduce the cross street green phase.

Specific recommendations that may improve the safety of this HOV treatment include:

- Bus speeds should be reduced if the bus drivers with signal preemption are able to drive faster than the posted speed limit. A lower bus speed should reduce the clustering effect.

- The drivers of the buses utilizing signal preemption should be permanent drivers regularly assigned to these bus trips. A comprehensive driver training program should be conducted.

- The signal preemption strategy and timing package should be carefully designed to provide minimum phase lengths that will insure pedestrian clearance and/or driver expectation intervals.

CHAPTER 11 — LEGAL ISSUES OF HOV PRIORITY TECHNIQUES

Priority techniques for high-occupancy vehicles present two basic legal issues: First, whether or not the particular agency has the authority to conduct an HOV project, and, second, what risks of legal liability are faced by the agency when traffic accidents occur causing damages and injury.

It is impossible to prepare an answer that is universally applicable to questions such as these. The law varies from state to state so far as the details of governmental authority and governmental liability are concerned. For this reason, any particular project should be reviewed by the proponents of the project as a part of the development of that specific proposal. Nevertheless, it is entirely feasible to make some generalized statement as to the procedure for approaching these issues and for the probable result if they are approached correctly.

In respect to the question of authority to conduct an HOV project, it can be stated without trepidation that the legislature in any state has the power to authorize such projects. As a general matter, it cannot be denied that these projects fall within the typical police powers of the state. It is quite another matter, however, as to whether a particular agency has had delegated to it by the legislature the authority to conduct such a project. Determining this would require examining the basic legislation establishing the agency in question and also, any specific legislation that may have been enacted to authorize an HOV project. If the implementing agency is a municipality, an affirmative answer to the question would be less likely than if the agency is a state authority such as a department of transportation. The amount of power inherent in municipalities to conduct innovative programs is generally restricted, but varies greatly from state to state, depending upon the amount of home rule authorized in the basic law of the state. Moreover, just as a state agency might be specifically authorized to carry out such a program, so also a municipality might be authorized by the legislature to do so. Hence, in making any meaningful statements about the authority question, one needs to know what state and what agency are to be involved.

The scope of tort liability is the second major legal issue to be addressed. Under the present state of the law, if there is to be liability imposed upon an agency in respect to an HOV project, it would be under that branch of the law known to lawyers as the law of negligence. A second aspect of the liability question involves an analysis of the doctrine of sovereign immunity. Traditionally, in this country, governmental agencies were not held accountable for negligent acts on the theory that the government was immune to suit. That theory has broken down to some extent in almost every state, if not every state, and has been completely abrogated in some states.

The decision to employ an HOV project is a discretionary function. Hence few, if any, courts are likely to entertain a tort lawsuit alleging that the basic decision to try an HOV project was not a reasonable one. On the other hand, the design of the elements of an HOV project is ministerial. The designers simply are carrying out the policy decision already made. Hence, where immunity has been waived, one would expect the function of designing specific elements no longer to be protected.

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FEDERALLY COORDINATED PROGRAM OF HIGHWAY RESEARCH AND DEVELOPMENT (FCP)

The Offices of Research and Development of the Federal Highway Administration are responsible for a broad program of research with resources including its own staff, contract programs, and a Federal-Aid program which is conducted by or through the State highway departments and which also finances the National Cooperative Highway Research Program managed by the Transportation Research Board. The Federally Coordinated Program of Highway Research and Development (FCP) is a carefully selected group of projects aimed at urgent, national problems, which concentrates these resources on these problems to obtain timely solutions. Virtually all of the available funds and staff resources are a part of the FCP, together with as much of the Federal-aid research funds of the States and the NCHRP resources as the States agree to devote to these projects.*

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