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EVALUATION OF ALTERNATIVE CONCEPTS FOR PRIORITY USE OF URBAN FREEWAYS IN TEXAS

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Priority Use of Freeway Facilities

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ABSTRACT

This report presents an evaluation of priority techniques for Texas freeways, including exclusive lanes, contraflow reserved lanes, concurrent flow reserved lanes, priority entry and priority treatment on frontage roads. A literature review was conducted, and from this, characteristics of priority techniques on U. S. freeways were documented. Based on analysis of these data, an evaluation of techniques was made for Texas freeways.

Key Words: Priority Techniques, Exclusive Busway, Contraflow, Concurrent Flow, Normal Flow, Reserved Lane, Frontage Road, Signal Preemption, Metered Freeway, Carpools, Mass Transportation, Public Transportation, Urban Transportation, Transportation Planning, Diamond Lane.

SUMMARY

Priority treatment for high occupancy vehicles, buses, and carpools is a technique that increases the people moving capacity of transportation facilities. This report deals with five techniques, exclusive lane, contraflow reserved lane, concurrent flow reserved lane, priority entry, and priority use of frontage roads relative to Texas freeways.

Exclusive Lane

An exclusive lane facility is one that is physically separated from the normal freeway lanes. Exclusive lanes are the most capital intensive type facility. Although operating costs are low, a high level of potential demand should exist before exclusive lanes are considered, because exclusive lane facilities should demonstrate high usage by high occupancy vehicles. In addition, heavy traffic flows in both directions should exist so that contraflow is not a viable alternative.

The implementation of an exclusive lane facility would best be considered as part of initial freeway planning, even if an exclusive lane is not to be constructed immediately. Although right-of-way acquis is never inexpensive, it may be extremely costly, if not impossible, to obtain additional right-of-way at a future date. This type of facility will be generally less desirable in the near future in Texas, due to the low (1.2 to 1.3) auto occupancy and the low existing transit ridership base.

Contraflow Reserved Lane

Contraflow is a technique whereby a lane in the off-peak direction is used for peak direction traffic. Contraflow lanes offer potential when

the off-peak direction has relatively light volumes and the removal of a lane would not cause a drop below level of service C. Minimum peak direction splits are 64/36 for six lanes, 62/38 for eight lanes, and 60/40 for ten lanes. These minimum splits provide a simple initial screening for potential locations for contraflow.

In considering contraflow lanes, the minimum freeway cross section applicable to contraflow is a six-lane facility. This size freeway allows two lanes in the off-peak direction after implementation. Without two lanes in the off-peak direction, traffic would be unduly constrained by slow moving vehicles and accidents.

Two other geometric considerations are left-hand entrance ramps, and freeway to freeway interchanges. The presence of left-hand entrance ramps, except in isolated instances, would probably preclude contraflow. Freeway to freeway interchanges offer the possibility of constructing special lanes through the interchanges, although possibly at substantial cost.

Concurrent Flow

The concurrent flow reserved lane concept is merely the assignment of a normal flow lane, by the use of signs and markings, to high occupancy vehicles. Concurrent flow lanes should generally be considered only as part of freeway widenings, due to the underutilization of the designated lane and increased congestion on the reduced number of mixed flow lanes that would occur unless the number of lanes is increased.

A possible reason to consider designating an existing lane for priority vehicles would be in the case of an underutilized facility. If designation of a reserved lane would not reduce the level of service below level C on the mixed flow lanes, designation of a reserved lane would help to preserve the people moving capacity of the facility. The reserved lane would encourage carpools and thereby increase the people moving capacity as the level of congestion increased.

When evaluating projects that will eliminate the left shoulder to provide the added lane by restriping, serious consideration should be given to the safety aspects. This problem appears to be most significant on eight-lane or larger freeways where the reserved lane is relatively long. Enforcement also becomes difficult when long concurrent flow reserved lanes do not have a shoulder on which to stop violators. The restriping technique therefore appears most appropriate on shorter congestion bypass type projects.

The presence of left-hand entrance or exit ramps would preclude the use of concurrent flow reserved lanes, due to conflicts with entering and exiting traffic.

Priority Entry

Priority entry is a technique by which high occupancy vehicles are given access to a facility via special lanes. These special lanes might be exclusive bus ramps, bypass lanes at ramp meters, or special reserved lanes at a toll booth. This technique is applicable to older freeways where right-of-way is limited, volumes heavy and little potential exists for exclusive lanes, contraflow lanes, or concurrent flow lanes. Priority entry can be installed and operated at relatively moderate cost, and provide an increase in people moving capacity with little negative impact.

Priority Treatment on Frontage Roads

Priority treatment on frontage roads is merely an extension of priority treatment techniques used on urban arterials. The possible techniques include concurrent flow reserved lane, contraflow reserved lane, and priority treatment at traffic signals. All of these techniques, including a combination of reserved lane and priority signalization have been successfully used on arterials.

Priority treatment on frontage roads appears to be a technique of limited applicability. It appears most applicable as an alternative to concurrent flow reserved lanes as a bypass to a short length bottleneck. It also appears to be a technique for use in improving local bus service that is already using the frontage road.

Conclusions

Priority entry and contraflow are the two techniques that appear to offer the greatest short-term potential in Texas. The applicability of priority entry has the greatest potential of the two techniques because of its suitability for carpools. The operating cost of priority entry is also significantly less than for contraflow.

Concurrent flow also merits serious considerations where freeway reconstruction is necessary and right-of-way is available for an additional lane. This technique would provide greater people moving capacity in the long-term rather than the traditional technique of allowing mixed flow on widened freeways.

Although exclusive lanes do not appear to be cost-effective in the short-term, planning for new facilities should give adequate consideration to future exclusive lanes; because right-of-way purchase is never inexpensive in urban areas but is less expensive during initial construction than during reconstruction. In fact, it is likely in most cases that obtaining additional right-of-way is not feasible. The above should not be taken as a carte blanche recommendation to allocate median space for future exclusive lanes on all urban freeways. Some freeways, especially circumferential routes, have little potential for exclusive lanes. Proper evaluation is therefore needed to give consideration to the potential of future exclusive lanes.

Priority treatment on frontage roads is also a technique not to be forgotten. Although not offering potential for long haul express routes, it may have potential as a connector between freeway facilities and CBD facilities. It is therefore a tool to be used in designing complete priority systems.

IMPLEMENTATION STATEMENT

The primary purpose of this research project (Study 2-10-74-205) is to provide data and develop guidelines that will be useful to the State Department of Highways and Public Transportation as well as the various cities in Texas in designing and implementing priority treatment projects on highway facilities. Thus, the total focus of this study is aimed toward implementation.

The City of Houston has adopted a transit improvement program which emphasizes the use of buses on existing facilities. Priority treatment projects on several freeways in Houston are currently being planned under a demonstration project. The findings contained in this report have already been used in developing plans in Houston.

The City of Austin and the Dallas/Fort Worth Urban Transportation Steering Committee have also recently adopted transit improvement plans that include priority treatment for buses on certain highway facilities. Other cities in Texas will probably follow similar plans. Hence, the results of this study should have broad applicability in Texas and in other states.

I. INTRODUCTION

Problem Statement

The automobile has been the dominant form of urban transportation in recent decades. It has led to a dispersed urban form that is increasingly auto-dependent. During the 50's and 60's, the need for increased vehicle capacity was generally met by constructing new facilities. In the last few years, however, construction of new facilities has been curtailed for many reasons including cost, land availability, environmental concerns, and energy concerns.

Alternatives have therefore been sought that do not require construction of more freeway capacity. One alternative which offers promise is to better utilize existing capacity by giving priority to high occupancy vehicles. For example, a lane of buses has a people moving capacity of 40,000 to 60,000 persons per hour (50 passengers per bus) (1)* as compared to 2,600 persons per hour (1.3 persons per vehicle) for a lane of auto traffic.

Objective of Report

The objective of this report is to evaluate alternative techniques for providing priority treatment for high occupancy vehicles on existing urban freeways in Texas. The report will first describe five techniques for freeway priority:

- Exclusive Lanes
- Contraflow Reserved Lanes
- Concurrent Flow Reserved Lanes

*Denotes number of reference at end of report.

- Priority Entry
- Priority Treatment on Frontage Roads

A review of available data will be presented to document significant characteristics of implemented projects throughout the U.S. Finally, priority techniques for high occupancy vehicles will be evaluated as they relate to Texas freeways.

II. FREEWAY PRIORITY TECHNIQUES

Five techniques for providing priority to high occupancy vehicles on freeways will be discussed. A high occupancy vehicle, unless otherwise indicated, is a bus or an auto with 3 or more occupants. The rationale for selecting 3 or more occupants will be discussed later in the report.

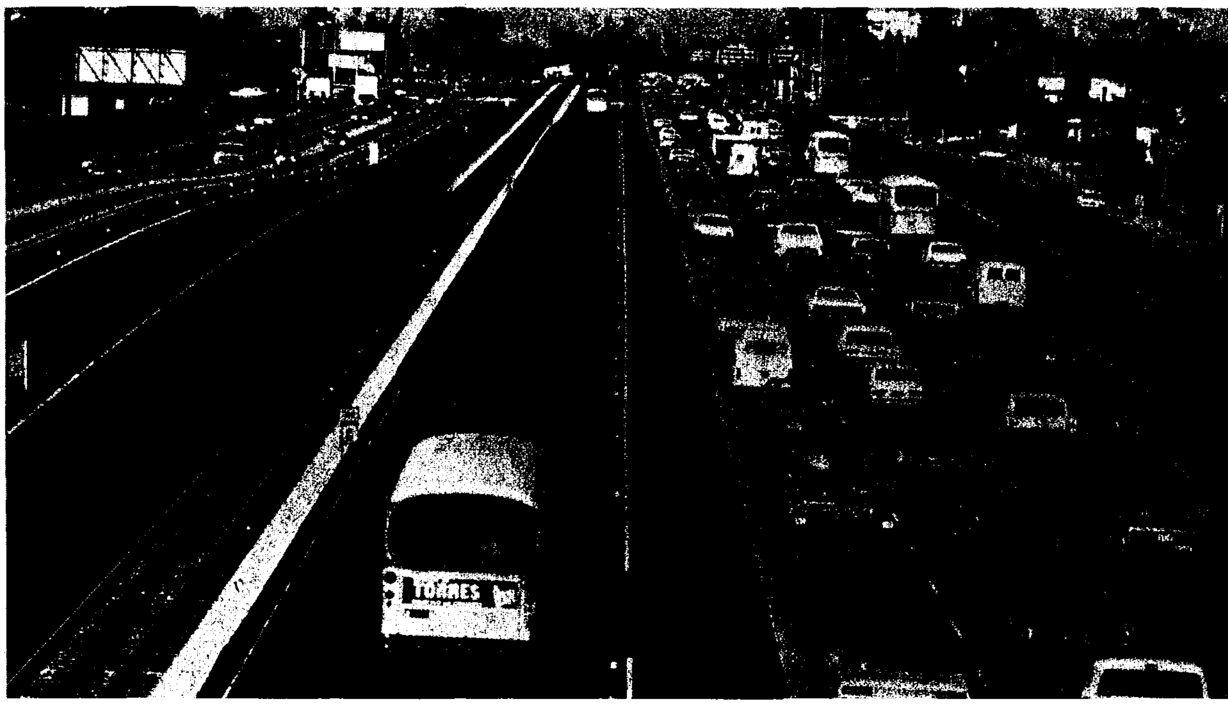
Four of the five techniques to be discussed--Exclusive Lane, Concurrent Flow Reserved Lane, Contraflow Reserved Lane, and Priority Entry--have been implemented in more than one city, as shown in Table 1. The fifth technique, Priority Treatment on Frontage Roads, is a concept that appears to have application in Texas due to the presence of continuous or nearly continuous frontage roads along many Texas freeways.

Exclusive Lanes

An exclusive lane facility is one that is physically separated from the normal freeway lanes. Access is limited to special ramps, so that opportunities for violators to enter are limited. Possible locations for exclusive lanes are the median, adjacent to normal lanes within the right-of-way, and on an exclusive right-of-way.

As shown in Table 2, two exclusive facilities have been constructed in the U. S. The first exclusive lane facility was constructed in the median of Shirley Highway (I-95) in suburban Washington, D. C. in 1969, as a two-lane reversible roadway for buses only. The reversible lanes were opened to carpools with four or more occupants in December 1973. The second project, on the San Bernadino Freeway (I-10), was constructed as a two-lane, two-way roadway with parts of the facility in the median* and part adjacent

*The seven-mile median portion is not physically separated, although a barrier could be installed in the shoulder area between lanes.



Exclusive lanes are physically separated from the normal mixed flow lanes. Although portions of the San Bernadino Freeway busway (top) in Los Angeles are only separated by plastic stanchions, the Shirley Highway (bottom) busway in Virginia and other portions of the San Bernadino busway are separated from mixed flow traffic by a median type barrier.

Table 1: Chronology of Priority Treatments for High Occupancy Vehicles on U. S. Freeways

Date	Location	Name	Type*	Carpools
1969	Northern Virginia	I-95 Shirley Highway	EXC	Yes
1970	Seattle	I-5 Blue Streak	PE	No
	New Jersey	I-495 Approach to Lincoln Tunnel	CTF	No
	Oakland	Oakland Bay Bridge	CFR	Yes
1971	Los Angeles	San Diego Freeway and other Ramps	PE	Yes
	Boston	State Highway 3 Southeast Expressway	CTF	No
	New York	Long Island Expressway	CTR	No
	Pittsburgh	Braddock Avenue Parkway East	PE	No
1972	Marin County, California	Redwood Highway US 101	CTF	No
1973	Los Angeles	I-10 San Bernadino Expressway	EXC	Yes
1974	Honolulu	Moanalua Freeway	CFR	Yes
	Minneapolis	I-35 W	PE	No
	Marin County, California	Redwood Highway	CFR	Yes
1975	Miami	I-95	CFR	Yes
	Portland	I-80 N Banfield Freeway	CFR	Yes
	San Francisco	I-280 Southern Freeway	CFR	Yes
1976	Los Angeles	I-10 Santa Monica** Freeway	CFR	Yes
	Dallas	US 75 North Central Expressway	PE	No

* EXC = Exclusive Lane
PE = Priority Entry
CTF = Contraflow Lane
CFR = Concurrent Flow Reserved Lane

** Closed August 1976

Table 2: Selected Characteristics of Exclusive Lane Projects

Location:	Los Angeles, CA	N. Virginia - Washington, D.C.
Name:	San Bernadino Expwy.	Shirley Highway
Date Started:	1973	1969
Type:	Bus and Carpool	Bus and Carpool
Length, miles (km.)	11 (17.7)	11 (17.7)
No. Lanes:	One each direction	Two reversible
Construction Cost:	$64 million	$43 million (estimate)
Operation/Maintenance Cost:	Routine only	$25,000 per year (estimate)
Usage:		
# Bus	400 daily (80 peak hour) January 1977	357 AM* Nov. 1974
# Carpools	800** January 1977	1050 AM* Nov. 1974
Bus Passengers	16,000 Daily January 1977	16,106 AM* Nov. 1974
Car Passengers	3000 (estimate)	4630 AM* Nov. 1974
Time Savings	2-10 minutes	10-20 minutes
Time Operated	24 hours	6:00 - 9:00 a.m. 4:00 - 7:00 p.m.
Violations***	3-16%	N.A.

* 6:30 - 9:00 AM
** On 7 miles only
*** Percent of legal carpools

References (2), (3), (4)

to the freeway. The lanes were opened to carpools of three or more during the bus strike of 1973 and during and after the bus strike of 1976.

Ridership

The growth in express bus ridership in the Shirley corridor relative to total people movement is shown in Figure 1. Until about 1972, increases in bus service occurred concurrently with decreases in autos on the Shirley Highway. Two events may explain the increase in Shirley auto traffic subsequent to March 1973: 1) the energy crisis coupled with the opening of the reversible lanes to carpools; and 2) completion of the construction of an interchange near the CBD which significantly reduced congestion. The increase in carpools is indicated by an increase of auto occupancy from 1.35 to 1.61 on Shirley Highway and from 1.32 to 1.40 on adjacent arterials.

Trends in carpool usage on Shirley Highway are shown in Table 3.

Table 3: Trends in Carpool Usage On Shirley Highway
Reversible Lane AM Peak Period (6:30 - 9:00)

Date	Carpools	Carpool Persons	Occupancy
March 1974	698	3133	4.49
June 1974	757	3472	4.59
November 1974	1050	4630	4.41

Source: Reference (2).

Although the data for Shirley carpools are limited, it is worthwhile to look at total people movement in the corridor and on Shirley Highway. Table 4 summarizes person movement and appears to indicate that Shirley

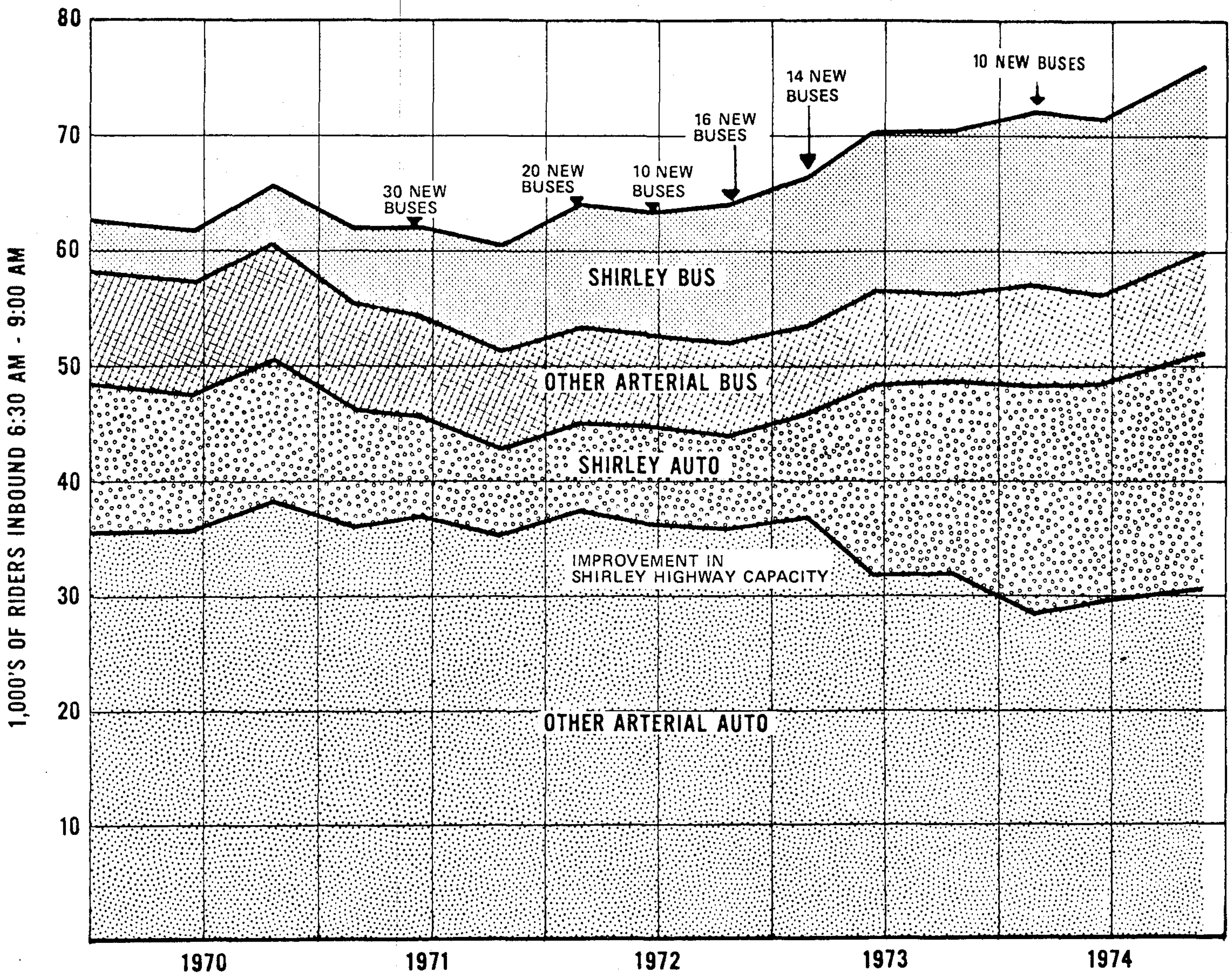


Figure 1: Trends in People Movement in Shirley Corridor Inbound A.M. Peak Hours

Source: Reference (4).

Table 4: Trends in People Movement on Shirley Highway During AM Peak Period (6:30 - 9:00)

Date	Total Persons				Percent of Total Corridor Person Trips			Percent of Total Shirley Person Trips	
	All Corridor Arterials	Shirley Highway	Shirley Bus	Shirley Carpool*	Shirley Highway Total	Shirley Bus	Shirley Carpool*	Shirley Bus	Shirley Carpool*
April 70	62,533	16,936	4,407	-	27.1	7.05	-	26.0	-
Oct. 70	65,341	17,083	4,873	-	26.5	7.46	-	28.5	-
Oct. 71	60,504	16,647	9,093	-	27.5	15.0	-	54.6	-
Oct. 72	64,222	20,205	12,105	-	31.5	18.8	-	59.9	-
Oct. 73	70,581	30,562	14,042	-	43.3	19.9	-	45.9	-
Mar. 74	72,023	34,562	15,092	3,133	48.0	21.0	4.35	43.7	9.06
June 74	71,466	33,492	14,839	3,472	46.9	20.8	4.86	44.3	10.4
Nov. 74	76,338	36,848	16,106	4,630	48.3	21.1	6.06	43.7	12.6

Source: Reference (2)

* on reserved lane (4 or more occupants).

Highway bus person trips during the AM period may be stabilizing in terms of percentage of total corridor person movement. Carpool ridership data is too limited to draw any conclusions.

Travel Time

An obvious reason for constructing exclusive lane facilities is to reduce travel time for exclusive lane users. Travel time savings for buses on the San Bernadino exclusive lanes of up to 10 minutes were experienced. Caltrans concludes (3), however, that net user savings is zero because of the time lost by those taking the bus to El Monte Station.

Figure 2 shows travel time for buses on the Shirley Highway exclusive lanes as compared to autos on the main roadway. The addition of carpools to the reversible lanes did not lower bus operating speeds and therefore provided the same time savings to carpools.

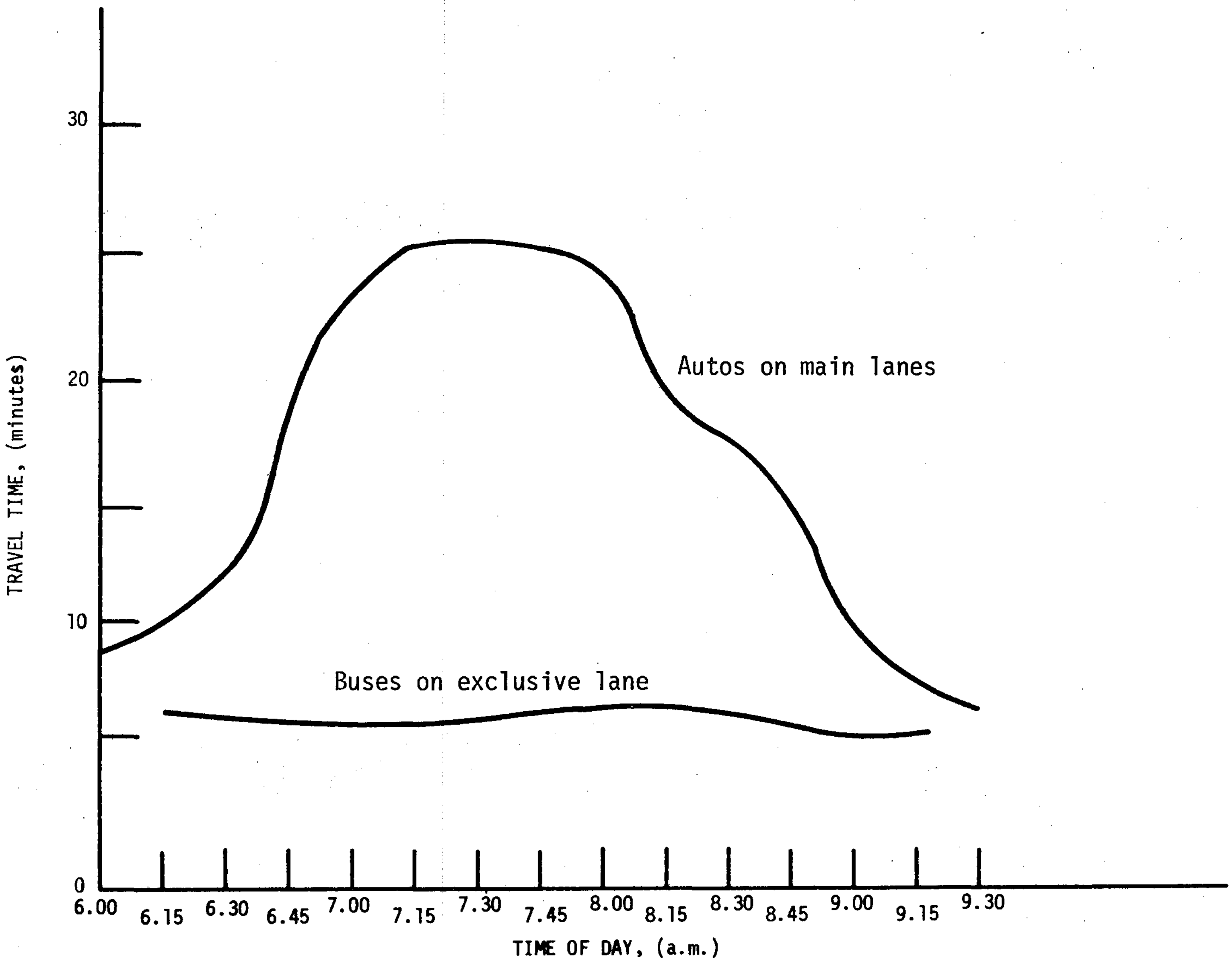


Figure 2: Mean Travel Times on Shirley Highway Inbound Between Turkeycock and Washington Boulevard Ramps (6.3 miles) (10.1 km)

Source: Reference (2).

Accidents

A possible concern in mixed bus and carpool operations might be the potential for accidents. The only reported accidents on Shirley Highway during the first year were 4 sideswipe accidents that did not involve injuries. It should be noted that, unlike the San Bernadino exclusive lanes, Shirley Highway provides two lanes per direction. There is presently no accident experience for carpools and buses on the San Bernadino exclusive lanes.

Violations/Enforcement

It would be expected the exclusive lanes would be somewhat self-enforcing, since access is limited. The San Bernadino experience with carpools was 5.4 percent violations during the 1974 bus strike with regular enforcement by the California Highway Patrol. In 1976 violations ranged from 2.8 to 16.3 percent during peak periods. Violations for bus-only operations are not reported and are presumed to be insignificant.

Former Mode

It is helpful to know the former mode of exclusive lane users to obtain information on the possible effects on auto use. Carpools on the San Bernadino exclusive lanes during the 1974 bus strike indicated the following previous mode:

857 former bus users,

735 already carpooling,

145 who had been driving alone.

Contraflow Reserved Lanes

The concept of contraflow lanes on freeways is the result of extending the technique of contraflow lanes on one-way arterials to freeways. It is a technique whereby an off-peak direction lane is used for peak direction traffic. The basic reasons for considering contraflow lanes on freeways are to better utilize available capacity and to provide priority treatment to high-occupancy vehicles. To date, the concept has been limited to use by professional bus drivers, although consideration is also being given to other vehicles such as trucks, taxis and even carpools. Table 5 summarizes basic characteristics of four contraflow facilities in the U.S.

Accidents

A basic issue in considering contraflow facilities on freeways is accident potential. Freeways, as a class of facility, are the safest type of highway, due to their limited access and divided cross section. Except for the U.S. 101 facility in Marin County which uses an empty buffer lane, contraflow has been provided adjacent to normal flow lanes. Traffic control has consisted of signs and plastic lane delineators for all projects.

Table 6 compares a limited base of accident data for the four projects. The circumstances surrounding the three fatalities on contraflow projects is worth noting. The Long Island Expressway fatality in New York was the driver of a taxicab that skidded on wet pavement. The first fatality on the Southeast Expressway in Boston was a maintenance man who was killed when a truck veered into a maintenance vehicle which was parked in a coned-off area past the contraflow lane. The second fatality in Boston was a pedestrian that had crossed to the median and then jumped from the median

Contraflow is the use of an off-peak direction lane for peak direction flow. The buses on the I-495 contraflow lane in New Jersey (top) are directly adjacent to vehicles travelling in the opposite direction, while the Marin County, California (bottom) contraflow lanes are separated by a buffer lane from the off-peak direction traffic.

Table 5: Selected Characteristics of Contraflow Projects

Location	New Jersey	New York	Marin County	Boston
Name	I-495 Approach to Lincoln Tunnel	Long Island Expressway	U.S. 101, Redwood Hwy.	Southeast Expressway
Date Initiated	1970	1971	1972	1971
Length	2.5 miles (4.0 km)	2 miles (3.2 km)	3.9** (6.3 km)	8.4 miles (13.5 km)
Access Via	Special Ramp	Median Crossover	Median Crossover	Median Crossover
# Lanes of Facility	6	6	8	6
# Contraflow Lanes	1	1	2***	1
End Treatment	Toll Plaza Lincoln Tunnel	Toll Plaza Queens - Midtown Tunnel	Median Crossover to Reserved Lane	Median Cross-over merge with traffic
Construction Cost	$700,000	$ 50,000	$205,000	$ 33,700
Operation/Maintenance Cost/Yr.	$200,000	$125,000	$ 80,400	$150,000
Peak Period Usage				
# Buses	724-852	180	125	90 am period
# Passengers	35,000	6500	5000	3000
Peak Periods Operated	7:30-9:30 am	7:00-9:00 am	4:00-7:00 pm	7:00-9:00 am 4:00-7:00 pm
Time Savings (Minutes)	10-25	up to 15	0****	4-14

*Operated only during summer
**Total facility 7.7 miles (12.4 km)--3.8 miles (6.1 km) concurrent flow reserve lane
***1 contraflow lane--1 buffer lane
****3-20 minutes prior to downstream widening

Source: References (5), (6), (7), (8)

Table 6: Accident Comparison for Contraflow Lanes

Location	Period	Accidents	Injuries	Fatalities	Bus Miles (Bus Km.)	Accidents/ 1M Vehicle Miles (1M Vehicle Km.)
I-495 Approach to Lincoln Tunnel	9/71 thru 1972	3	3	0	1.24 M (2.00 M)	2.42 (3.87)
Long Island Expressway	10/71 thru 9/73	2	2	1	0.22 M (0.35 M)	9.1 (14.6)
Southeast Expressway	Summers 1971 thru 76	2	1	2	N.A.	-
U.S. 101 Marin Co.	9/72 thru 1974	0	0	0	0.30 M (0.48 M)	0 (0)
City Bus						55 (88)
Intercity Bus						7 (11)
Passenger Cars						15 (24)

Source: Reference (9).

barrier in front of an oncoming bus.

The contraflow lane in Marin County also resulted in approximately a 100 percent increase in accidents in the remaining normal flow lanes during the first year after implementation. After the first year, accidents returned to normal on the freeway. The initial accident increase was possibly the result of the unusual type of operation.

Two tentative conclusions regarding contraflow accidents that appear reasonable are 1) the accident rates are as good as normal flow, and 2) the severity of accidents is high. Overall accident experience does not appear unreasonable, although extreme care is warranted in designing any such facility.

Ridership

The end result in terms of total bus ridership is clear. Bus patronage increased 50 percent in 16 months in California, increased 14 percent in Boston, and increased 5 percent in New Jersey. What is unclear is the effect of the reserved lanes as opposed to service improvements, because a survey in California indicated that of the 5000 riders on the Marin contraflow lanes, only 40 switched from autos. Of the 40, half were previously members of carpools. In addition, speed was only a minor reason for riding the bus, trailing well behind comfort, cost, driving tension, and parking problems (1).

Time Savings

Time savings can be substantial if congestion is severe. A significant factor in bus schedule reliability is the general elimination of long delays (up to 30 minutes or more) due to accidents or other traffic incidents on the main lanes.

Concurrent Flow Reserved Lanes

The concurrent flow reserved lane concept (also called normal flow or with flow) for freeways is an extension of the reserved lane concept on arterials. The concurrent flow reserved lane concept is merely the assignment of a normal flow lane using signs and markings for use by designated vehicles. Whereas the curb lane is normally used on arterials to facilitate bus loading, the median lane is generally used on freeways to reduce conflict with the ramp traffic.

This report will provide an overview of operational projects and an evaluation relative to other priority techniques. A separate report on

Concurrent flow reserved lanes are designated adjacent to the median using signs and markings. The Santa Monica Freeway (top) in Los Angeles utilized an existing lane while the I-95 (bottom) concurrent flow lane in Miami was added to the freeway.

concurrent flow is also being published by TTI (10).

Before looking at selected operational data from the six projects summarized in Table 7, it is important to point out a major difference between the Santa Monica Freeway project which has been terminated and the other five projects. The following analysis will generally treat these two groups of projects separately.

Table 7: Summary of Concurrent Flow Reserved Lane Projects

Location	Honolulu, HI	Marin County, CA	Portland, OR	Miami, FL	Los Angeles, CA	San Francisco, CA
Name	Moanalua Frwy.	Redwood Hwy. (U.S. 101)	Banfield Frwy. (I-80N)	North-South Frwy. (I-95)	Santa Monica Frwy. (I-10)	Southern Frwy. (I-280)
Date Initiated	October 1974	December 1974	December 1975	December 1975	March 1976*	Spring, 1976
Length, Miles (km)	2.7 (4.3) IN 1.4 (2.3) OUT	4 (6.4)	3.3 (5.3) W.B. 1.7 (2.7) E.B.	7.5 (12.0)	12.5 (20.1)	2 (3.2) S.B. only
Construction Cost	-	-	$1.8 million including median barrier.	$18.5 million total construction.	$3.1 million including buses & parking lot.	-
Carpools	3+ Occupants	3+ Occupants	3+ Occupants	3+ Occupants	3+ Occupants	3+ Carpools
Number of Users	11 buses and 1500 carpools A.M. peak period.	96 buses and 475 carpools peak hour	33 buses peak period, 183 carpools peak hour.	40 buses peak period, 334 carpools peak hour.	170 buses and 4592 carpools daily	15 buses and 200 carpools peak hour
Time Savings (Minutes)	10 inbound	3-6 initially, none presently.	1.2 westbound 0.5 eastbound	7-10	2.5 - 4 eastbound 5 - 6.5 westbound	None
Hours Operated	24 hours	6-9 A.M. 4-7 P.M.	6:30 - 9:30 A.M. 3:30 - 6:30 P.M.	6:30 - 10:00 A.M. 3:00 - 7:00 P.M.	6:30 - 9:30 A.M. 3:00 - 7:00 P.M.	24 hours

*Terminated August 1976.

Source: Reference (10).

Santa Monica Reserved Lanes

The Santa Monica diamond lanes are the only concurrent flow project where an existing lane was taken away from mixed flow traffic and assigned to high occupancy vehicles. Given the prior heavy utilization and prior auto occupancy, it is easy to see that the people moving capacity is reduced in the short-term. In the case of this project, the short-term problems effectively killed the project.

The Santa Monica Freeway was an eight- to ten-lane freeway carrying 109,000 vehicles during the eight peak hours prior to implementation. Auto occupancy was a rather typical 1.20. The number of preproject carpools with 3 or more occupants, based on a 7 hour count, was 8925 per week or less than 2 percent of the vehicles. Therefore, less than 2 percent of the vehicles were assigned 20 to 25 percent of the available lanes. Although carpool ridership nearly tripled in 21 weeks, the utilization of the reserved lane was still significantly low as compared to its capacity. At the same time, the mixed flow lanes were congested.

Violations during the project were approximately 15 percent of the reserved lane traffic. Only a moderate level of enforcement was required to limit the number of violations. It should be noted that left shoulders were available for use by the highway patrol in stopping violators.

There was a substantial increase in accidents that occurred during the project. There were 512 accidents during the 21-week period compared to 179 during a similar before period. There did, however, appear to be a downward trend after a very high initial accident rate.

Other Concurrent Flow Projects

The five projects other than Santa Monica Freeway are similar in that they designated a reserved lane at the same time that they added a lane to an existing freeway. The added lane was provided either by widening or by restriping and using a portion of the shoulder. The following discussion is relative to the five projects.

Violations/Enforcement

Concurrent flow projects are inherently easy to violate because vehicles can enter and leave at any point. Also, enforcement is more difficult in some projects due to the use of the shoulder to provide the added lane.

Consequently, violators must often be followed to the end of the lane or forced across several congested mixed flow lanes to the right shoulder.

Figure 3 summarizes violations over the first several months of operation of four projects. After increased enforcement in Los Angeles and Portland, a violation rate of 10 to 20 percent was experienced.

Carpool Usage/Bus Ridership

Tables 8 and 9 show estimated increases in carpool and bus ridership during the first four to six months of operation of several projects. Carpool increases were large while bus increases were relatively small, except for a dramatic bus ridership increase in Los Angeles. The increase in Los Angeles occurred concurrently with a manyfold increase in bus service.

Table 10 shows the utilization of the Moanalua Freeway concurrent flow reserved lanes. Carpool volumes have continued to increase even with a decrease in total vehicle volume on Moanalua Freeway. The decrease is due to the opening of a nearby freeway.

Table 8: Estimated Peak-Hour Carpools (3+ Occupants) on Concurrent Flow Projects

	Before Project Opened	After 4-6 Months	Percent Increase
Portland	58	183	215
Miami	125	330	164
Los Angeles	300	800	167
Marin County	150	475	217

Source: Reference (10)

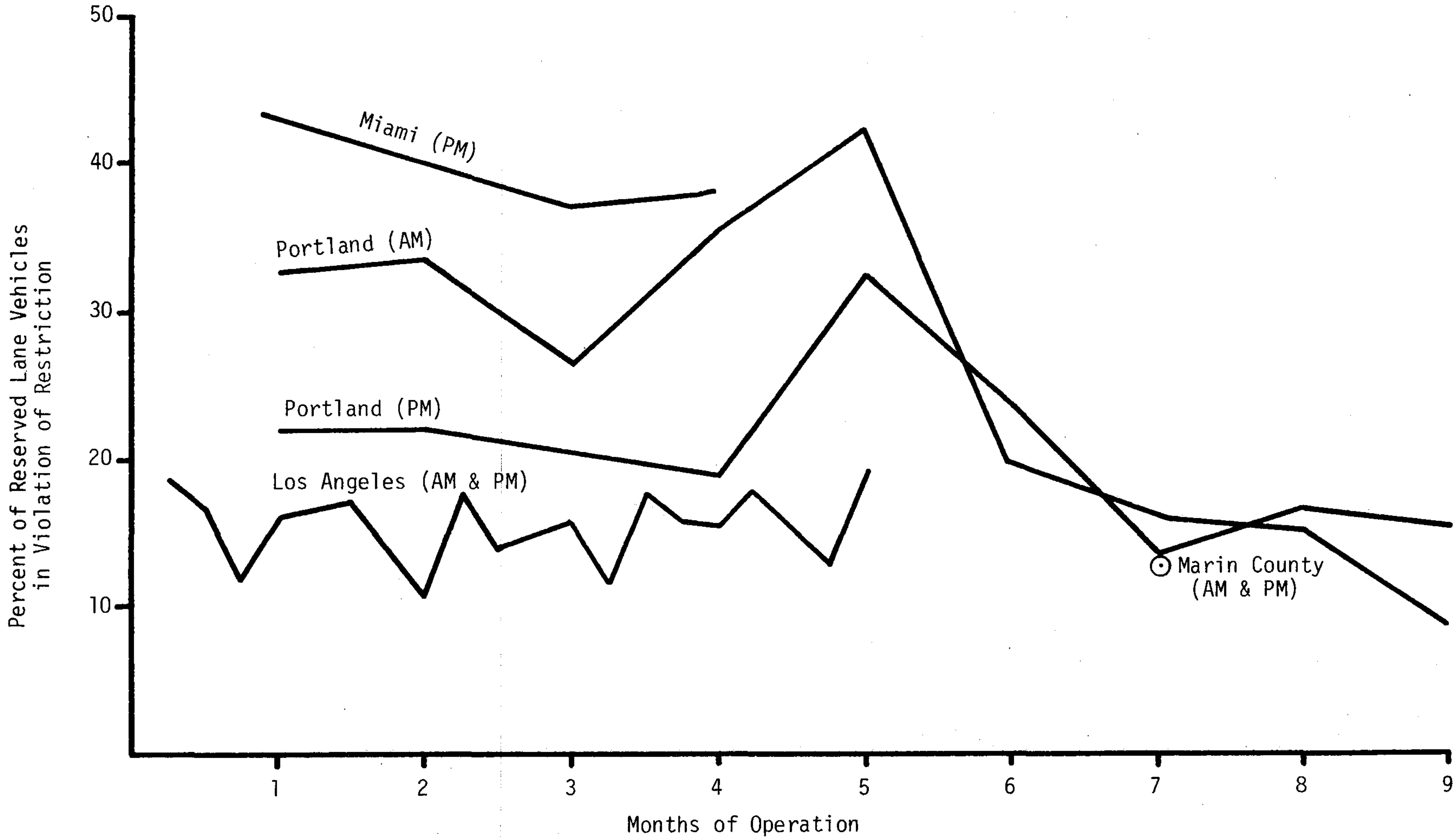


Figure 3: Violations at Selected Concurrent Flow Reserved Lane Projects.

Source: Reference (10).

Table 9: Estimated Peak-Hour Bus Ridership on Concurrent Flow Projects

Location	First Count Available	After 4-6 Months	Percent Increase
Portland	586 (Initially)	643	10
Miami	370 (Before)	400	8
Los Angeles	210 (Before)	650	209
Marin County	3468 (Before)	3922	13

Source: Reference (10).

Table 10: Utilization of Moanalua Freeway Concurrent Flow Reserved Lane

Inbound Reserved Lane Volume (6-8 a.m.)

Date	Total Volume	Carpools	Buses	Violation Rate
October, 1974	6000	525	11	∿20%
After 2 weeks	6000	1000	11	
January, 1975	9000	1500	11	9%
March, 1976	7500	1600	11	

Source: Mr. Tanaka, Hawaii Department of Transportation.

Accidents

Accidents have generally increased immediately after implementation of a concurrent lane project. The initial increase was subsequently followed by a decline in accidents. The limited data base, plus other factors such as concurrent construction makes analysis difficult. Available accident experience is presented in the TTI report on "Operational Experience with Concurrent Flow Reserved Lanes" (10).

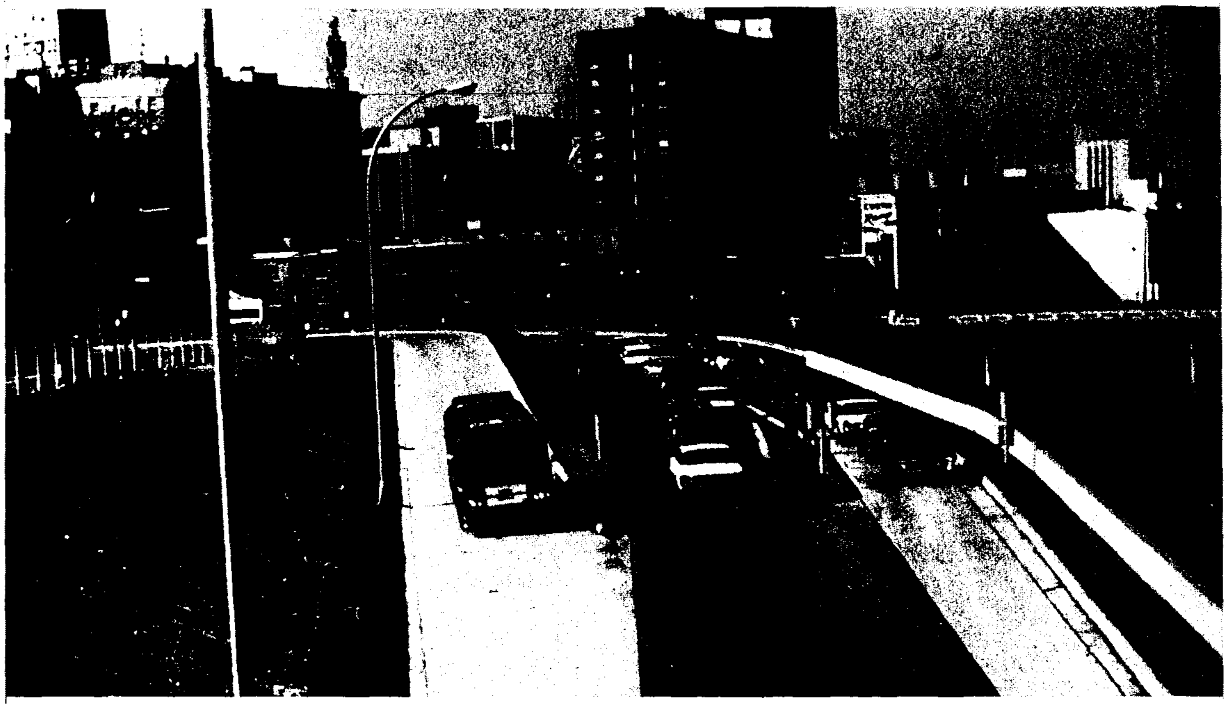
Priority Entry

Priority entry is a technique by which high occupancy vehicles are given access to a facility via special lanes. Special lanes include exclusive bus ramps, bypass lanes at ramp meters, and special reserved lanes at toll booths. Priority entry lanes have been provided for both buses and carpools. The majority of techniques summarized in Table 11 involve priority entry on metered freeways. California now has more than 15 bypass lanes on metered ramps. The remainder of the discussion will only be concerned with priority entry at metered ramps.

It should be noted that ramp metering requires neither freeway surveillance nor central computerized control. Metering can be provided using preset metering rates or localized detection and control. The California experience indicates that priority entry should be implemented after initiating ramp metering so as to reduce the confusion associated with two new operational techniques.

Usage

California has had extensive experience with carpool bypass lanes on metered ramps. An important point relative to the California projects is the definition of a carpool on ramp bypasses as a vehicle with 2 or more occupants. The California rationale is that an increase in auto occupancy



Priority entry provides a special lane for buses and/or carpools. In Minneapolis (top), buses enter the freeway ahead of vehicles queued at a ramp signal, while carpools enter the Santa Monica Freeway (bottom) in Los Angeles via a lane that bypasses cars waiting at a ramp signal.

Table 11: Summary of Selected Priority Entry Projects

Location	Oakland, CA	Seattle, WA	Minneapolis, MN	Los Angeles, CA	San Diego, CA	Dallas, TX
Name	San Francisco - Oakland Bay Bridge	Seattle Frwy. (I-5)	I-35 W	San Diego Frwy. (I-405) Lakewood Ramp	Cabrillo Frwy. (Route 163) Washington Ramp	Central Expwy. (U.S. 75) Mockingbird Ramp
Date Initiated	April 1970	September 1970	Fall 1971	June 1973	June 1973	1975
Type	Exclusive Lanes at Toll Booth	Reversible Ramp	Priority Ramp or Lane on Metered Frwy.	Ramp Meter Bypass Lane	Ramp Meter Bypass Lane	Ramp Meter Bypass Lane
No. of Priority	1 Bus 2 Carpool	1 Bus	1 Bus	1 Carpool	1 Carpool	1 Bus
Construction Cost	$398,000	N.A.	$2.8 million*	Minimal	Minimal	$22,000
Operating Cost	$2300/mo.	Routine Maintenance	$0.3 million**	Routine Maintenance	Routine Maintenance	Routine Maintenance
Daily Usage Peak Period	550 Buses 2000 Carpools A.M.	171 Buses and 4356 Passengers P.M.	7100 Passengers Daily	Up to 425 2+ Occupant Carpools	2+ Occupant Carpools	16 Buses 7-9 A.M.
Time Savings (Minutes)	5	7 during A.M. 5 during P.M.	Up to 8	Up to 8	Few	1
Violators per peak period	8%	N.A.	< 1%	6 - 12%	3%	1%
Time Operated (Local Time)	6:00-9:00 A.M.	7:00 A.M. - 7:00 P.M.	6:30-9:00 A.M. 3:30-6:30 P.M.	3:00-6:00 P.M.	7:00-8:00 A.M.	7:00-9:00 A.M. 4:15-6:15 P.M.

* Includes surveillance and control system and ramp construction.
** 1976 Budget.

Source: References (1), (6), (11), (12), (13) during the peak period to 1.5 or 1.6 would be a major accomplishment in Los Angeles where auto occupancy is 1.2, and 85 to 90 percent of the vehicles carry only the driver (11).

In the Los Angeles area (8) in 1976, an estimated 3600 2+ carpools and 141 buses used the 16 priority entry ramps daily. The increase in carpool usage has ranged from about 100 to 150 percent within a few weeks after implementation. Fifty percent of the increase were new carpools while 50 percent were diverted from other travel routes.

Evaluation of bus ridership relative to priority entry in Minneapolis is difficult. This difficulty in analysis is the result of a substantial service increase during the project. The express bus ridership in Minneapolis increased from 5 percent to 15 percent after implementation of surveillance, ramp control and improved express bus service.

Violations/Enforcement

Violations have not been a signficant problem as was shown in Table 11. Violations have been held to about 7 percent in California with reasonable enforcement, while violations in Minneapolis have been less than 1 percent with no special enforcement.

Priority Treatment on Frontage Roads

Priority treatment on frontage roads along freeways is a concept that appears to offer a very large potential because of the widespread use of frontage roads in Texas. The fact that frontage roads often carried 40,000 to 50,000 vehicles per day prior to construction of the main freeway lanes, and are only carrying 3,000 to 5,000 vehicles per day after construction seems to indicate unused roadway capacity. Further study indicates that major discontinuities exist in most freeway frontage roads due to the omission of frontage roads at many rivers, railroads and freeway-to-freeway interchanges. However, a potential for priority treatment still exists because frontage roads are presently used by transit and many discontinuities could be eliminated through expensive construction projects.

Priority treatment on frontage roads is merely an extension of priority treatment techniques used on urban arterials. The possible techniques include concurrent flow reserved lane, contraflow reserved lane, and priority treatment at traffic signals. All of these techniques, including a combination of reserved lane and priority signalization have been successfully used on arterials.

Several typical characteristics are pertinent in evaluating priority techniques on frontage roads. Typically, the frontage road is a two-lane, one-way roadway with turning lanes at intersections. Access from the right is unlimited with numerous drives and intersecting streets. Ramp metering may be present on entrance ramps, and traffic signalization does not generally consider frontage road progression.

Concurrent flow on arterials is typically in the form of a reserved curb lane for buses and right turns only. However, the numerous access points may seriously reduce the effectiveness of a reserved right lane. Reservation of the left lane would be equally difficult due to the weaving movements to and from the ramps. Contraflow would have even more conflict problems with ramp terminals, due to the additional problems associated with two-way flow. The degredation of frontage road flow might also have a carry-over effect onto the freeway. The presence of ramp metering would make contraflow difficult, if not impossible, due to the queueing at entrance ramps. In terms of bus movement, however, contraflow would be effective, except in the presence of ramp metering, in reducing bus travel time by reducing the presence of vehicles in the lane and the impedance of queued vehicles at traffic signals.

Two types of traffic signal priority have been used. Local preemption results in the changing of the sequence of a light after a bus gives an identifiable indication of its presence. Alternately, priority timing of a progressive system of traffic signals either gives favorable consideration to buses in the signal timing plan or adjusts the amount of green time on the bus approach upon receiving an identifiable indication from a bus.

Although preemption has been used on both pre-timed and traffic responsive traffic signal controllers, only traffic responsive traffic signal controllers have the capability to recover from preemption by adjusting the green time based on demand. Preemption inherently requires some means of telling the controller of the presence of a bus. This subject will be covered in more detail in a subsequent report on priority treatment for arterial streets.

Two methods of priority timing can be used while still maintaining the coordination of traffic signals. The simplest technique is to provide a timing pattern that favors buses. If the roadway between two traffic signals included a bus stop, the timing pattern would then include travel time plus average stopped time. This passive technique would require interconnection of signals along the frontage road. A more costly and more responsive method of providing priority on pre-timed controllers would be to adjust the green time based on a signal from a bus. The green phase for the bus approach would begin early or be extended in order to reduce the probability of stopping a bus. This technique requires computerization and sophisticated control algorithms, in addition to a means by which the bus actively communicates to the controller.

In terms of cost, priority timing for buses would be the least expensive technique. The costs involved would be for interconnection, if it was not present, plus the engineering time and support necessary to develop the timing plans. Preemption would be more costly because of the need for communication between bus and the traffic signal controller, plus the local intersection hardware to override local intersection control. The most expensive technique would be computerization to monitor and control intersections while still maintaining progression.

Table 12 presents some empirically derived guidelines for priority signalization. It is suggested that if peak-hour headways are greater than fifteen minutes, bus movement is too low to warrant any priority treatment. Furthermore, because of the cost, computer control should not be considered for less than 12-15 buses during the peak hour because local preemption would likely be less costly. There does not appear to be any maximum number of buses under which priority timing or computer control would be appropriate. However, local preemption would appear limited to demands of no more than 12-15 buses per hour due to the more disruptive nature of preemption.

Table 12: Guidelines for Frontage Road Signal Prioritization for Buses

Technique	Peak Hour Minimum No. Buses	Peak Hour Maximum No. Buses
Priority Timing (Passive)	4	None
Local Preemption	4	12-15
Priority Timing with Computer Control	12-15	None

III. EVALUATION OF PRIORITY TECHNIQUES AS THEY RELATE TO TEXAS FREEWAYS

Table 13 summarizes the five priority techniques relative to eight parameters; as can be seen by the table, no technique has a clear overall superiority. Those techniques having least cost generally have a smaller positive effect, while those with the greatest advantage have the largest cost and lead time.

Table 13: Evaluation of Priority Techniques for Texas Freeways

Technique	Capital Cost	Operating Cost	Time to Implement	Time Savings	Enforcement Requirements	Applicable to Carpools	Congestion Peak Dir.	Congestion Off-Peak Dir.
Exclusive Lane	High	Low	Long	Large	Low	Yes	Possible Large Reduction	No Effect
Contraflow Lane	Low to Moderate	High	Moderate	Large	Low	No	Possible Large Reduction	Possible Large Increase
Concurrent Flow Lane	Low to High	Low	Short to Long	Moderate	High	Yes	Possible Large Increase	No Effect
Priority at Ramps	Low to Moderate	Low to Moderate	Moderate	Small to Moderate	Moderate	Yes	Possible Small to Moderate Reduction	No Effect
Priority on Frontage Road	Low to Moderate	Low to Moderate	Short to Moderate	Small to Moderate	None	No	Possible Small to Moderate Reduction	No Effect

Exclusive Lanes

Exclusive lanes are the most capital intensive type facility. Although operating costs are low, a high level of potential demand would be warranted before one should consider exclusive lanes. Exclusive lane facilities should demonstrate high usage by high occupancy vehicles. Heavy traffic flows in both directions should exist so that contraflow is not a viable alternative.

The implementation of an exclusive lane facility would best be considered as part of a freeway construction or reconstruction, because available right-of-way is generally lacking and costs are very high. This type of facility will generally be less desirable in the near term in Texas, due to the low (1.2 to 1.3) occupancy and the low existing transit ridership base.

Contraflow Reserved Lanes

Contraflow lanes offer potential when the off-peak direction has relatively light volumes and the removal of a lane would not cause a drop below level of service C. Table 14 suggests guidelines relative to flow rates for consideration of contraflow.

Translating Table 14 into minimum peak direction splits yields 64/36 for six lanes, 62/38 for eight lanes, and 60/40 for ten lanes. These minimum splits provide a simple initial screening for potential locations for contraflow.

Table 14: Flow Rates for Consideration of Contraflow Lanes

Vehicles Per Lane During Peak Hour	
Primary Direction	Reverse Direction
Minimum number of vehicles in each lane BEFORE implementing contraflow. 1800 vehicles per hour	Maximum number of vehicles in each lane AFTER implementing contraflow. 1500 vehicles per hour

In considering contraflow lanes, the minimum freeway cross section where contraflow is applicable is a six-lane facility. This size freeway allows two lanes in the off-peak direction after implementation. Without two lanes in the off-peak direction, operation would be unduly constrained by slow moving vehicles and accidents.

Two other geometric considerations are left-hand entrance ramps, and freeway to freeway interchanges. The presence of left-hand entrance ramps, except in isolated instances, would probably preclude contraflow. Freeway to freeway interchanges offer the possibility of constructing special lanes through the interchanges, although possibly at substantial cost.

Concurrent Flow Reserved Lanes

Concurrent flow reserved lanes should not generally be considered without the addition of a lane through restriping or reconstruction. The reason for not reserving an existing mixed flow lane under congested conditions is that the disbenefits to mixed flow are great compared to the advantages to carpools and buses.

Tables 15 and 16 show vehicle occupancies for implemented projects (both before and after), and for existing conditions on some Texas freeways. The number of 3+ occupant carpools is in the range of 2 to 7 percent while the range of 2+ occupant carpools is 13 to 27 percent. The approximately per-lane capacity of a 6- to 8-lane freeway is 20 to 25 percent of peak direction volume. Therefore, designation of a lane for 3+ occupant carpools results in underutilization of the reserved lane and increased congestion in the mixed flow lanes. On the other hand, designation of a reserved lane for 2+ occupant carpools provides little advantage to carpools. It has, therefore, been typical to designate reserved lanes for 3+ occupant carpools on most reserved lane projects.

A possible reason to consider designating an existing lane for priority vehicles would be in the case of an underutilized facility. If designation of a reserved lane would not reduce level-of-service below Level C on the mixed flow lanes, designation of a reserved lane would help to preserve the people moving capacity of the facility. The reserved lane would encourage

Table 15: Summary of Selected Concurrent Flow Reserved Lane Project Vehicle Occupancy

Location	Percent of 1 Occupant Vehicles	Percent of 2 Occupant Vehicles	Percent of 3 Occupant Vehicles
Portland-Banfield Frwy.			
BEFORE (Nov. - Dec. 1975)	77	21	2
AFTER (Jan. - Sept. 1976)	76	18	6
Los Angeles-Santa Monica Frwy.			
BEFORE (March 1975)	-	-	2
AFTER (June - July 1976)	-	-	5-6
Nationwide (1969-1970)			
WORK TRIPS	75	18	7

Source: Reference (10)

carpools and limit the growth of low occupancy vehicles.

The same arguments for designating a reserved lane on underutilized facilities would be valid when adding a lane to an existing congested facility. The restricted lane would encourage carpools, limit growth of low occupancy vehicles, and would not worsen and would possibly improve slightly the conditions on the mixed flow traffic lanes.

When evaluating projects that will eliminate the left shoulder to provide the added lane by restriping, serious consideration should be given to the safety aspects. This problem appears to be most significant on 8-lane or larger freeways where the reserved lane is relatively long. Enforcement also becomes difficult when long concurrent flow reserved lanes do not have a shoulder on which to stop violators. The restriping technique therefore appears most appropriate on shorter congestion bypass type projects.

Table 16: Summary of Dallas-Ft. Worth Vehicle Occupancy Percentages*

	Percent of 1 Occupant Vehicles	Percent of 2 Occupant Vehicles	Percent of 3+ Occupant Vehicles	Percent Total
<u>Dallas</u>				
I.H. 35E	87	11	2	100
	80	16	4	100
I.H. 30	80	17	3	100
U.S. 75	82	15	3	100
	73	21	6	100
Dallas North Tollway	86	13	1	100
<u>Ft. Worth</u>				
I.H. 35W	78	18	4	100
I.H. 30	82	16	2	100
U.S. 377	77	18	5	100
U.S. 287	80	17	3	100
S.H. 199	80	17	3	100
S.H. 121	84	13	3	100
Lancaster Blvd.	83	13	4	100
Averages	81	16	3	100

*Percentages based upon peak-flow direction, 7:00-9:00 A.M. during 1976.

Source: Reference (<u>10</u>)

The logical lane to reserve for a concurrent flow project is the left-hand lane (nearest the median). Any other lane would require a provision to permit non-qualified vehicles to merge through the reserved lane in order to use the remaining lanes of the freeway. Not only would this merging operation seriously detract from the benefits of the reserved lanes, but it would also present an untenable enforcement situation. For these same reasons, the presence of left-lane entry and exit ramps along a freeway will prohibit the use of a concurrent flow reserved lane on that freeway.

Priority Entry

Priority entry is a technique that is applicable to older freeways where right-of-way is limited, traffic volumes are heavy and little potential exists for exclusive lanes, contraflow lanes and concurrent flow lanes. This technique is worthy of immediate consideration at locations where ramp metering already exists.

This technique, combined with concurrent flow, appears to have the greatest short-term potential for increasing car occupancy. Priority entry can be installed and operated at relatively moderate costs, and provide an increase in people-moving capacity with little negative impact.

If ramp metering is not present, two conditions are required for successful implementation. First, adequate storage is required to install ramp metering without serious negative effects on the adjacent street system. Second, alternate routes in the form of continuous frontage roads or parallel arterials should exist. It is also worth repeating that ramp metering does not require expensive freeway surveillance for implementation.

Priority Treatment on Frontage Roads

Priority treatment on frontage roads appears to be a technique of limited applicability. It appears most applicable as an alternative technique to concurrent flow reserved lanes as a bypass around a short length bottleneck. It also appears to be a technique for use in improving local bus service that is already using the frontage road.

The biggest deterrent to express use of frontage roads is the side friction caused by local access and frontage roads. A technique to provide good express service on frontage roads would be to install contraflow bus lanes. The severe negative effects of extensive use of contraflow on frontage roads suggests that contraflow only be considered for short distances on frontage roads.

IV. CONCLUSIONS

Priority entry and contraflow are the two techniques that appear to offer the greatest short-term potential in Texas. The applicability of priority entry has the greatest potential of the two techniques because of its suitability for carpools. The operating cost of priority entry is also significantly less than contraflow.

A problem with priority entry is inbound peak flow. Inbound congestion results from concentration of demand as the central business district is approached. In order to make priority entry effective, an extensive control network is required to limit demand. This is not the case on outbound trips where demand is initially concentrated. A limited number of metering points can effectively control outbound demand and give substantial benefits to high occupancy vehicles.

The difference between inbound and outbound flows suggests that a combination of techniques would be appropriate. A hypothetical example might suggest contraflow in the morning when off-peak flow is low and priority entry in the evening when inbound flow is too heavy to allow contraflow. Alternatively, in order to provide for carpools, a concurrent flow lane might be constructed past a congestion bottleneck for inbound traffic, while priority entry might be more cost effective for outbound traffic.

Concurrent flow also merits serious consideration where freeway reconstruction is necessary and right-of-way is available for an additional lane. This technique would provide greater people-moving capacity in the long-term compared to the traditional technique of allowing mixed flow on widened freeways.

Although exclusive lanes do not appear to be cost-effective in the short-term, planning for new facilities should give adequate consideration to future exclusive lanes. Although right-of-way purchase is never inexpensive in urban areas, it is less expensive during initial construction than during reconstruction. In fact, it is likely in most cases that obtaining additional right-of-way is not feasible. The above should not be taken as a carte blanche recommendation to allocate median space for future exclusive lanes on all urban freeways. On some freeways, especially circumferential routes, exclusive lanes have little potential for improving people-moving capacity. Therefore, consideration should be given to the potential of exclusive lanes in the analysis of freeway construction or reconstruction projects.

Priority treatment on frontage roads is also a technique not to be forgotten. Although not offering potential for long-haul express routes, it may have potential as a connector between freeway facilities and CBD facilities. It is, therefore, a tool to be used in designing complete priority systems.

In summation, all five techniques are likely to be used in Texas over the long-term. Priority entry and contraflow seem to have the greatest short-term potential. Concurrent flow and priority use of frontage roads have the greatest potential for congestion bypasses. Concurrent flow also has the potential to increase people-moving capacity in freeway-widening projects. Finally, exclusive lanes have the least short-term potential and the greatest long-term potential. Although it is unlikely that exclusive lanes will be constructed in the near future, adequate consideration should be given to exclusive lanes in planning new facilities.

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