# EVALUATION OF PRIORITY TECHNIQUES FOR HIGH OCCUPANCY VEHICLES ON ARTERIAL STREETS

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# TABLE OF CONTENTS

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## ABSTRACT

This report presents an evaluation of the priority techniques for high-occupancy vehicles (buses and carpools) relative to arterial streets. The techniques considered include contraflow lanes, concurrent flow lanes, reversible lanes and priority at traffic signals. The report is aimed at an overall evaluation of the relative merits of each of the four techniques rather than an extensive documentation of the many implemented projects.



Key Words: Priority Techniques, Contraflow, Concurrent Flow, Reserved Lane, Signal Pre-emption, Bus Priority Signal Systems, Carpools, Mass Transportation, Public Transportation, Urban Transportation, Urban Transportation Planning.

## SUMMARY

This report is concerned with priority techniques for high-occupancy vehicles (buses and carpools) as they relate to urban arterials in Texas. The report deals primarily with four techniques--contraflow lanes, concurrent flow lanes, reversible lanes, and priority at traffic signals. It is the intent of this report to evaluate the various techniques in terms of providing improved transit operation, not to provide details on the operation of all or even most implemented projects.

There are several advantages to high occupancy vehicles using contraflow lanes. Travel times are shorter and more reliable. Delays due to queues at traffic signals and from turning vehicles are reduced. In cases where two-way flow is changed to one-way flow, the need for more circuitous bus routes is eliminated. Contraflow can generally be implemented with no net loss in capacity if two-way streets are changed to one-way operation.

Contraflow lanes are respected by motorists and are, therefore, easy to enforce. This is because violators can only enter or leave the contraflow lane at a limited number of points, primarily intersections. Public acceptance of contraflow lanes appears to be good.

A problem with contraflow on streets that were originally one-way is the perception, especially by pedestrians, that the street is still one-way. Accidents have occurred when pedestrians failed to look in both directions. This problem seems to be most acute during the initial months of operation.

Contraflow, in essence, results in a modified form of two-way flow which inherently has a greater accident potential than one-way flow. Experience indicates that, initially, accidents may increase, but generally, that accident rates are at most slightly higher than one-way flow. Another problem with

contraflow is the provision for loading and unloading in central areas that do not have off-street or alley loading capabilities.

Concurrent flow lanes allow high-occupancy vehicles to bypass waiting vehicles at traffic signals or other bottlenecks. The potential advantage is an improved level-of-service for high-occupancy vehicles as the result of reduced trip time and greater reliability.

Another advantage of concurrent flow reserved lanes is that they can easily be restricted to peak periods and can revert to mixed flow traffic or, more importantly, to parking or loading areas. This may be important in a central business district if off-street loading facilities or alleys are not present.

There are several disadvantages to concurrent flow lanes. The lane is subject to frequent violations by both moving and parked vehicles. Therefore, vigorous and continual enforcement is required. Increased congestion is likely unless high-occupancy vehicles are significant in number; and if high-occupancy vehicles are significant in number, then the advantages of a reserved lane may be diminished. If a lane other than the curb lane is used as the reserved lane, it is difficult to load and unload passengers. Although this would not be a problem in an express operation, it does pose a safety problem when used in central business districts.

Reversible median lanes reduce conflicts due to access to abutting properties. The potential advantage is improved travel time. Another advantage of a reversible center lane is that it can revert to a continuous center lane for left turns during off-peak periods.

The reversible lane concept is disruptive to normal traffic flow. It requires the prohibition of left turns if a median reversible lane is used. If the reversible lane is located to the left of the left-turn lane, the

signal phasing is constrained by the need to avoid conflicts between the left-turn lane and the reversed lane. The potential for accidents is increased due to the complexity of movements through intersections. A safety problem also exists if it is necessary to load or unload passengers from a reversible lane.

Violations are also a problem similar to the case of concurrent flow. Violators can easily get into and out of the reserved lane. This can further add to the safety problem, especially if violators are using the lane in the direction opposite to the priority flow.

Priority for buses at traffic signals has the potential for reducing delays on urban arterials. Implementation is relatively easy and can be done at moderate or low cost. Passive priority techniques would generally only require engineering and support services and no capital investment, except possibly at an actuated intersection that might require a new controller to implement split phasing.

Priority at traffic signals can be implemented at locations where special lanes are either not feasible, due to limited pavement and/or right-of-way, or where designation of a reserved lane would be extremely disruptive to non-priority vehicles. Bus priority at signals may also provide improvements for non-bus traffic on the bus priority phase. There is no violation problem and enforcement requirements are, therefore, eliminated.

At high levels of demand, bus priority at traffic signals may be disruptive to other traffic. This would especially be the case if unconditional preemption did not allow enough cross-street green time to accommodate vehicles in a reasonable period of time. Conditional preemption with very heavy bus flows (e.g., less than one-minute headways) might not provide any benefit over passive priority (retiming to give more green time to the bus movement).

A preemptive system will increase traffic signal maintenance costs. In addition to the increased cost to maintain more complex equipment, calls from motorists about perceived signal malfuctions are likely to increase. Traffic signal preemption does not have potential for carpool use due to the possible disruption caused by a large number of preemptions in a short period of time.

Capital and operating costs are nominal for all techniques except priority treatment at traffic signals. Preemption is a technique that requires an initial capital investment plus a recurring maintenance cost that is higher than the other techniques, including passive priority.

Contraflow and priority treatment at signals are significantly easier to enforce than the other two measures. Contraflow is largely self-enforcing while there is no enforcement required for traffic signal priority.

An important limitation of active priority at traffic signals is its lack of applicability to carpools. It is, therefore, less flexible in terms of developing an overall traffic management plan.

Overall, the four techniques provide a low cost means of improving the people-moving capacity of existing streets. These techniques can be quickly implemented by operating agencies, often with a minimal amount of effort. They are certainly techniques worth considering in any medium or large size Texas city.

## IMPLEMENTATION STATEMENT

The primary purposes of this research project (Study 2-10-74-205) are to provide data and to 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.

This report provides basic information necessary to evaluate priority treatment projects on arterial street systems. It is likely that an increasing number of such projects will be implemented in Texas in the future.

# I. OVERVIEW

Although freeways are a significant part of the transportation system in larger urban areas, arterial streets are an important part of the street system in all urban areas. The majority of bus mass transportation in the United States takes place on urban arterials. This report, although similar to a previous Texas Transportation Institute report (1)* concerning priority techniques on freeways, is concerned with priority techniques as they relate to urban arterials in Texas.

The concept of priority techniques is to increase the people moving capacity of existing street systems by increasing the number of high-occupancy vehicles. Since peak period auto occupancy is typically about 1.2 to 1.3 persons per vehicle, a car with two or more occupants could be considered a high-occupancy vehicle. However, in order to limit the number of cars eligible for priority treatment and thereby provide favorable service, cars with three or more occupants have generally been considered high-occupancy vehicles.

Assuming a lane of a signalized arterial street can carry 500 vehicles per lane per hour, the people moving capacity is 600 persons per hour at an auto occupancy of 1.2. Assuming a minimum occupancy of 3 persons per vehicle yields an average of 3.5 passengers per vehicle, the potential of the same arterial street lane carrying 500 vehicles per hour is 1750 persons per hour.

An even more significant type of high-occupancy vehicle is a bus. Although data on bus capacities on arterial streets are limited, capacities of 120 buses per lane per hour have been experienced on urban streets with signalized intersections. Assuming 50 seat buses with an 80 percent load factor (seats-for-all policy), the carrying capacity of an arterial bus lane is 4800 passengers per hour. The capacity on an arterial with limited stops is obviously higher; nevertheless, even at 120 buses per hour, the capacity is nearly

*Denotes number of reference listed at end of report.

three times that of what extensive carpooling can provide and eight times capacity at present auto occupancies.

The remainder of this report will deal with priority techniques on arterial streets for high-occupancy vehicles (both buses and carpools). The techniques to be considered in this report are:

1. Exclusive Facilities,
2. Contraflow Lanes,
3. Concurrent Flow Lanes,
4. Reversible Lanes, and
5. Priority at Traffic Signals.

# II. CHARACTERISTICS OF ARTERIAL TREATMENTS

More than 40 arterial priority projects have been identified (2, 3), and, without a doubt, there are other projects that were not identified. Table 1 presents a chronology of some of the more significant arterial priority projects. It is the intent of this report to evaluate the various techniques in terms of providing improved transit operation, not to provide details on the operation of all or even most of the implemented projects. Emphasis will also be on projects related to long haul trips rather than projects related more to internal circulation in central business districts.

Table 1: Selected Arterial Priority Projects

| DATE | LOCATION | NAME | TYPE | CARPOOLS |
|---|---|---|---|---|
| 1939 | Chicago, IL | N. Sheridan Road | Contraflow | No |
| 1948 | Providence, RI | East Side Tunnel | Exclusive | No |
| 1956 | Newark, NJ | Market Street | Concurrent | No |
| 1958 | Dallas, TX | Elm and Commerce Streets | Concurrent | No |
| | Cambridge, MA | Harvard Square | Exclusive | No |
| | Harrisburg, PA | Market Street | Contraflow | No |
| 1963 | New York, NY | | Concurrent | No |
| 1968 | Minneapolis, MN | Nicollett Mall | Exclusive | No |
| | San Antonio, TX | Alamo Plaza | Contraflow | No |
| 1969 | Indianapolis, IN | College Avenue | Contraflow | No |
| 1971 | Honolulu, HI | Kalakaua Avenue | Contraflow | No |
| | Houston, TX | Main Street | Concurrent | No |
| | San Juan, PR | Fernandez Juncos<br>Ponce de Leon | Contraflow | No |
| | Louisville, KY | 2nd and 3rd Streets | Contraflow<br>Signals | No |
| 1972 | Washington, D.C. | UTCS/BPS | Signals | No |
| 1974 | Miami, FL | N.W. 7th Avenue | Concurrent<br>Signals | No |
| | Miami, FL | S. Dixie Highway | Contraflow<br>Concurrent | No<br>Yes |
| | Denver, CO | 16th and 17th Streets<br>Lawrence and Larimer | Concurrent<br>Concurrent | No<br>Yes |
| | Arlington, VA | Wilson and Arlington | Concurrent<br>Signals | No |
| | Dallas, TX | Ft. Worth and Harry Hines | Concurrent | No |

Source: Reference (2), (3), and (4)

## Exclusive Facilities

Bus streets and bus tunnels are the types of treatments that are categorized as exclusive facilities. Three projects are listed in Table 1 as exclusive facilities. These facilities are limited in scope and primarily relate to internal circulation. Exclusive facilities will not be considered further in this report, although the reader may wish to consult References (2), (3), and (5) for detailed information.

## Contraflow

Contraflow is a concept whereby high-occupancy vehicles travel on an arterial in the direction opposite the normal flow. Contraflow facilities have developed in three ways. Typically, contraflow has been added to existing one-way arterials. Contraflow lanes have also been implemented when two-way streets were converted to one-way flow and high-occupancy vehicles continued to use the street in the contraflow direction. Finally, contraflow lanes have been added to divided arterials by using an off-peak direction lane (left side of median) for peak direction buses.

Although no contraflow lanes to date have allowed carpools, it should be noted that the safety problems that exist in freeway applications do not exist on undivided arterials. On undivided arterials, contraflow operations are just a restricted form of two-way flow. This is not to say that problems with carpools using contraflow lanes would not exist, only that carpool use of contraflow facilities should not be ruled out of consideration in facility evaluations.

## Advantages

There are several advantages to high-occupancy vehicles using contraflow lanes. Travel times are shorter and more reliable. Delays due to queues at traffic signals and from turning vehicles are reduced. In cases where two-way flow is changed to one-way flow, the need for more circuitous bus routes is eliminated. Contraflow can generally be implemented with no net loss in capacity if two-way streets are changed to one-way operation. Streets with left-turn prohibitions and without left-turn lanes would result in a loss in capacity of non-priority lanes.

Contraflow lanes are respected by motorists and are therefore easy to enforce. This is because violators can only enter or leave the contraflow lane at a limited number of points, primarily intersections. Public acceptance of contraflow lanes appears to be good.

## Disadvantages

A problem with contraflow is the perception, especially by pedestrians, that the street is one-way. Accidents have occurred when pedestrians failed to look in both directions. This problem seems to be most acute during initial months of operation. Special signing should be installed (see Figure 1 for example of signing in the United Kingdom) to alert pedestrians to the bus lane.

Contraflow, in essence, results in a modified form of two-way flow which inherently has a greater accident potential than one-way flow. Experience indicates that, initially, accidents may increase; but generally, accident rates are at most slightly higher than one-way flow.

Another problem with contraflow is the provision for loading and unloading in central areas that do not have off-street or alley loading capability. This has been handled in Paris (5) by providing loading areas either between the contraflow lane and the sidewalk or between the contraflow lane and the

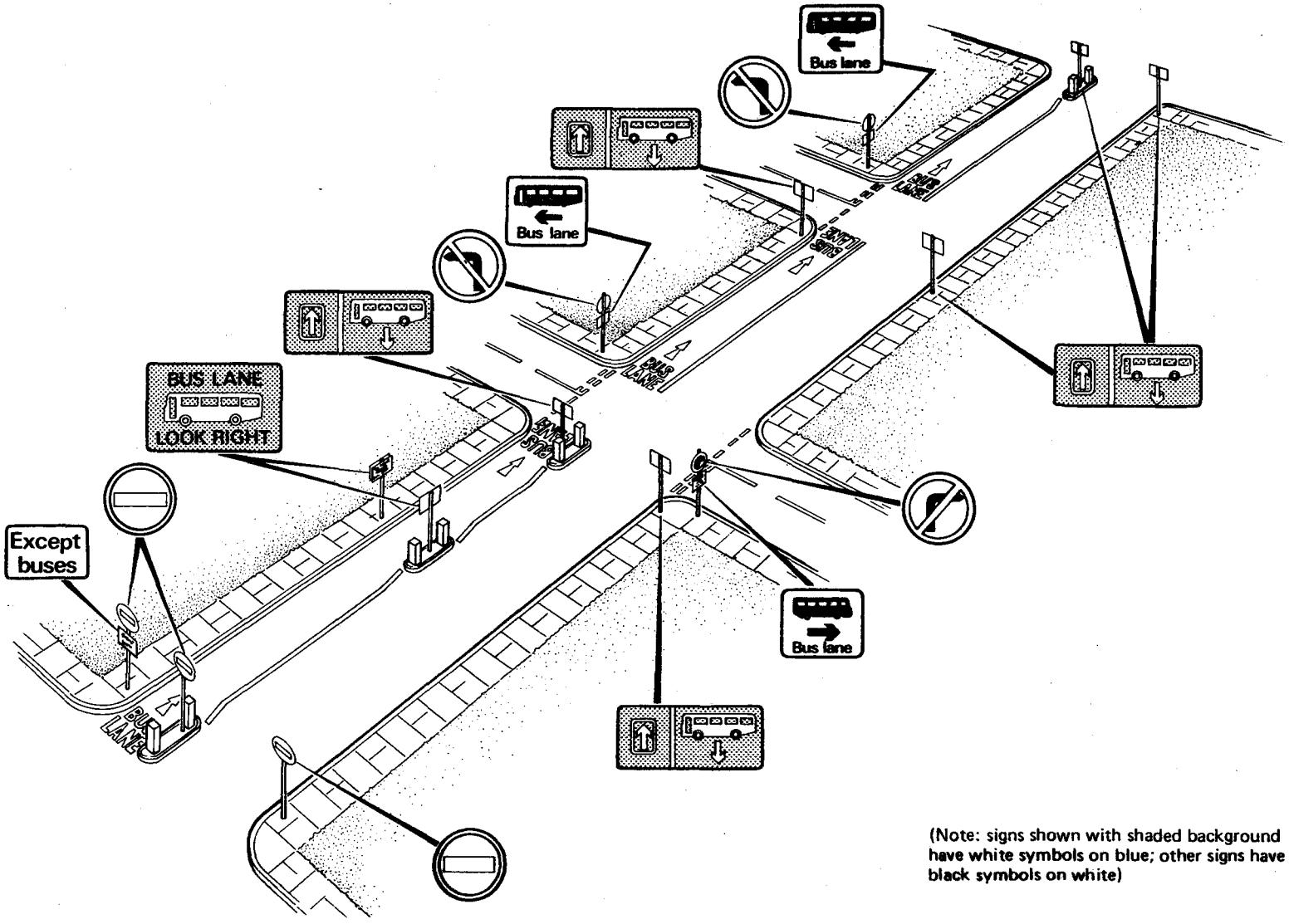



Figure 1: Example of Contraflow Lane Signing in United Kingdom

Source: Reference (4).

normal flow lanes. In suburban areas, the problem of loading is less likely to be of significant concern.

Case Study (3, 4)

The longest and perhaps most significant contraflow project on an arterial street is in San Juan, Puerto Rico. The contraflow lane (see Figure 2) is 17.6 kilometers (10.9 miles) long on two arterials, Ponce de Leon and Fernandez Juncos.

The two boulevards each have three lanes for normal flow traffic and one lane for contraflow. The bus lanes operate 24 hours per day and handle 1300 to 1500 bus trips per day in each direction.

Although the lanes have little in the way of signing and marking, violations have been negligible. Enforcement efforts are minimal, although both the police and highway authority separately maintain trucks to tow away illegally parked vehicles.

The number of accidents that occurred initially was large and included one fatality. Accidents have apparently declined below rates experienced prior to the opening of the contraflow lane.

Implementation costs were approximately $100,000 for signing, marking, some right-of-way acquisition, minor paving, some minor construction, publicity, and administration. The value of staff time contributed to the project was approximately $50,000.

Substantial time savings are claimed for the contraflow lane. The before scheduled time was 55 minutes one-way, but actual times were closer to 80 minutes. After implementation of the bus lanes, actual trip time was 50 minutes, a reduction of about 35 percent. In terms of speed, the average one-way trip increased from 8.6 km/hr (5.3 mph) to 14 km/hr (8.7 mph). Run times

at different times of the day indicated little difference between peak and off-peak periods.

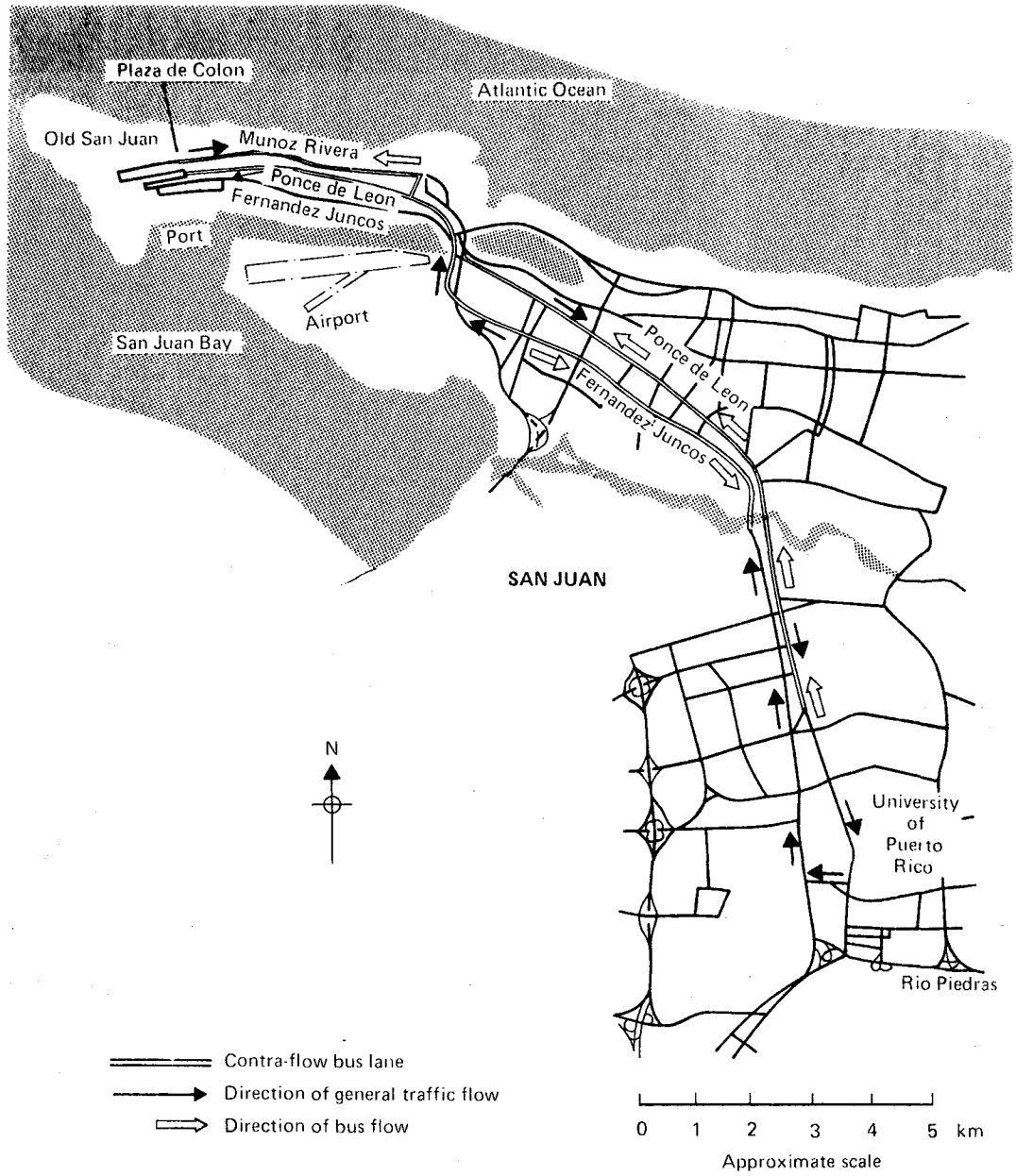



Figure 2: Plan of San Juan, Puerto Rico, Showing Locations of the Two Contraflow Bus Lanes

Source: Reference (4).

## Concurrent Flow Lanes

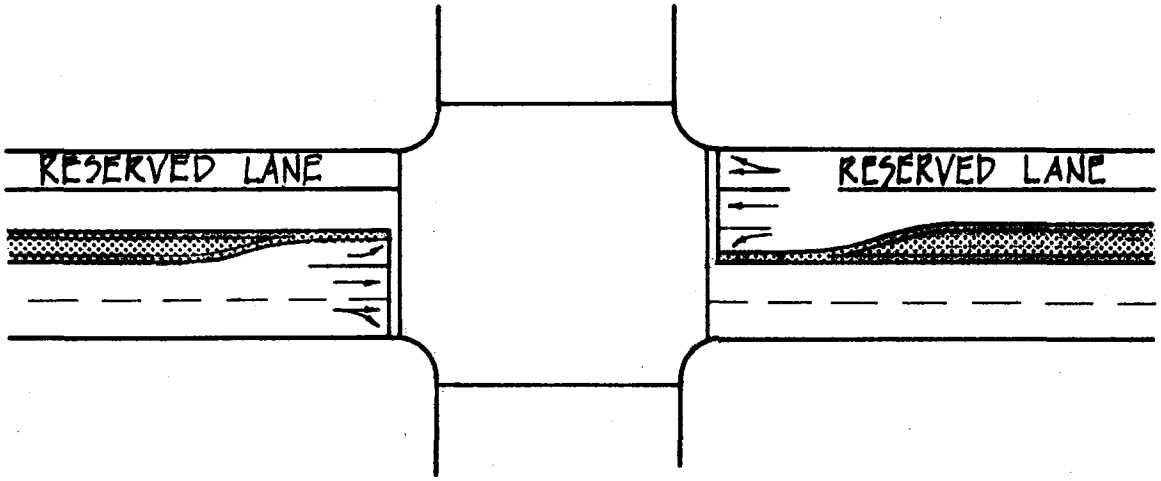
Concurrent flow lanes are traffic lanes reserved for high-occupancy vehicles in the same direction as the normal traffic flow and are also the most common form of priority lanes. Although the curb lane is normally used, lanes adjacent to the median or in the area previously used by streetcars are sometimes used (see Figure 3).

By far the most common form of concurrent flow lanes are reserved curb lanes in central business districts. Some of the more significant concurrent flow projects in recent years have been on radial arterials. Another possible application is at bottlenecks, such as river crossings. The bottlenecks result in the concentration of traffic, and there is more likely to exist a concentration of buses sufficient to warrant reserved lanes.

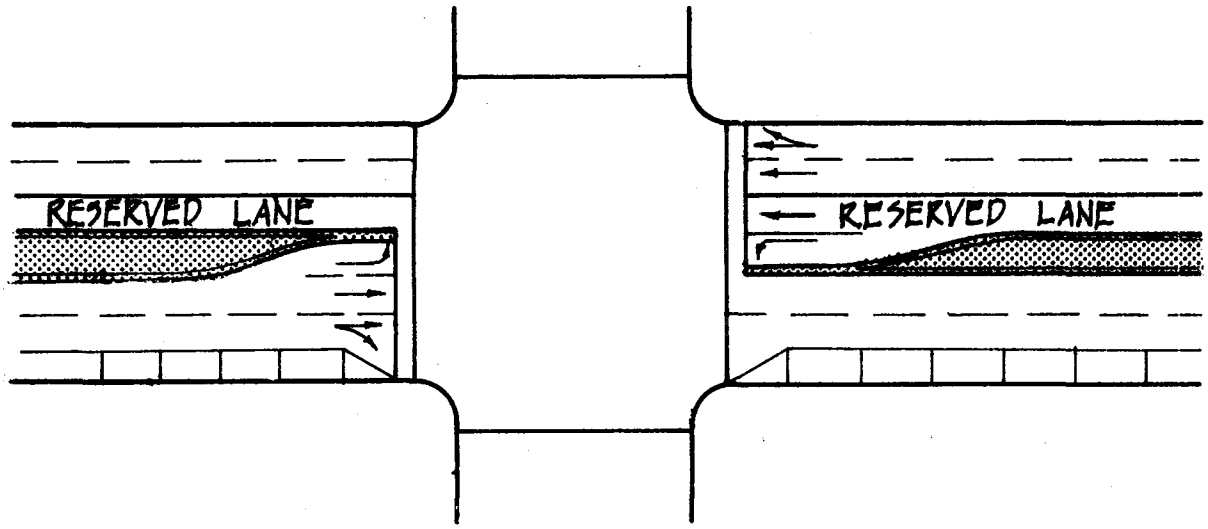
### Advantages

Concurrent flow lanes allow high-occupancy vehicles to bypass waiting vehicles at traffic signals or other bottlenecks and act essentially as queue bypassing devices. The potential advantage is an improved level-of-service for high-occupancy vehicles, because of reduced trip time and greater reliability.

Another advantage of concurrent flow reserved lanes is that they can easily be restricted to peak periods and can revert to mixed flow traffic or, more importantly, to parking or loading. This may be important in a central business district if off-street loading facilities or alleys are not present.




Curb Concurrent Flow Lane with Right Turns
Permitted from Lane at Intersection




Median Concurrent Flow Lane

Figure 3: Examples of Concurrent Flow Lanes

## Disadvantages

There are several disadvantages to concurrent flow lanes. The lane is subject to frequent violations by both moving and parked vehicles. Therefore, vigorous and continual enforcement is required for success. Increased congestion is also likely unless high-occupancy vehicles are significant in number, and if high-occupancy vehicles are significant in number, then the advantages of a reserved lane may be diminished. In addition, if other than curb lane is used as the reserved lane, it is difficult to load and unload passengers. Although this would not be a problem in an express operation, it does pose a safety problem when used in central business districts.

## Results

There have been too many projects to attempt to summarize results. Table 2 presents the results of several selected projects in the U.S. to indicate the effect of concurrent flow bus lanes.

Table 2: Effect of Concurrent Flow Bus Lanes

| LOCATION | LENGTH meters (feet) | BUS VOLUMES buses/hr | EFFECT ON BUSES | EFFECT ON OTHER ROAD USERS |
|---|---|---|---|---|
| First Avenue, New York 34th - 72nd Street | 3,060 (10,037) | 110 | 27% reduction in bus travel time | |
| Newark, New Jersey Market Street | 550 (1,804) | 100 | 7 minute time saving | |
| Birmingham, Alabama Third Avenue | 1,290 (4,231) | 44 | 27% decrease in bus travel time | 29% decrease in car travel time |
| Louisville, Kentucky 3rd Street between Breckinridge and Avery | 2,410 (7,905) | 12 | 25% reduction in travel time | |

Source: Reference (5).

## Reversible Lanes

Reversible lanes utilize the same lane for both the A.M. peak period and the P.M. peak period. This type of facility could conceptually be considered a form of concurrent flow or a combination of concurrent flow and contraflow, depending on the configuration.

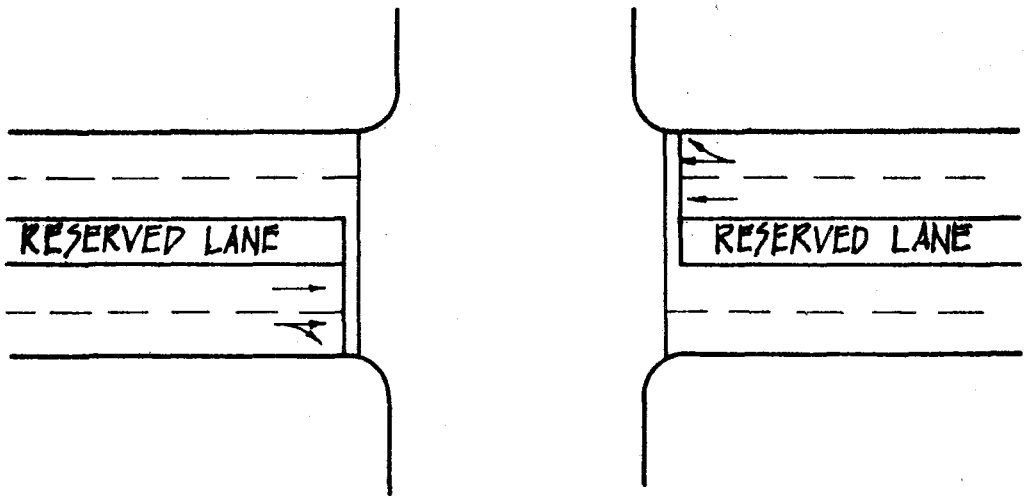
The only reported reversible lane project was on NW 7th Avenue in Miami, Florida (6). This project utilized two different reversible lane configurations (see Figure 4). One configuration used a center reversible lane with left turns prohibited. The center reversible lane was also used as a continuous center lane for left turns only during the off-peak periods. The other reversible cross section involved a reversible lane to the left of the left-turn lane. Special traffic signal phasing was required to prevent conflicts between the reserved lane and left turning traffic.

### Advantages

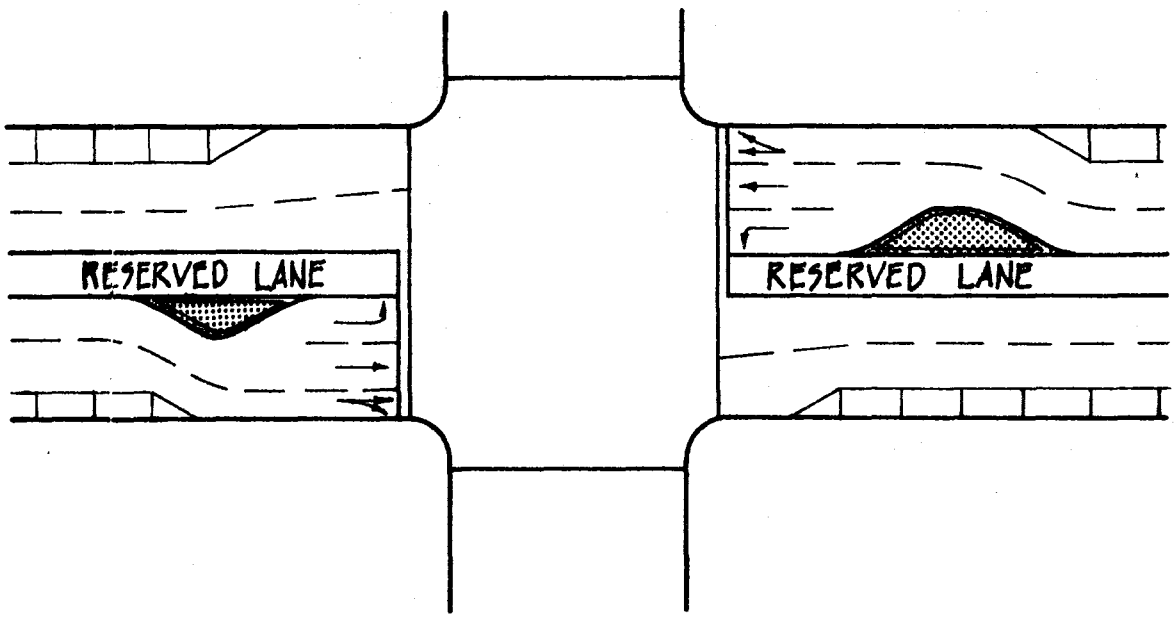
The two reversible lane configurations reduce the conflicts due to access to abutting properties. The potential advantage is improved travel time as compared to curb lanes. An advantage only of the reversible center lane configuration is that it can revert to a continuous center lane for left turns during off-peak periods.

### Disadvantages

The reversible lane concept is disruptive to normal traffic flows. It requires the prohibition of left turns if a reversible center lane is used. If the reversible lane is located to the left of the left-turn lane, the




Reversible Center Lane




Reversible Lane Left of Left-Turn Lane

Figure 4: Examples of Reversible Lanes

signal phasing is constrained by the need to avoid conflicts between the left-turn lane and the reserved lane.

The potential for accidents is increased due to the complexity of movements through intersections. A safety problem also exists if it is necessary to load or unload passengers from a reversible lane.

Violations are also a problem similar to the case of concurrent flow. Violators can easily get into and out of the reserved lane. This can further add to the safety problem, especially if violators are using the lane in the direction opposite to the priority flow.

### Results

The NW 7th Avenue project in Miami tested several different concepts and operational schemes including reserved lanes and traffic signal priority. Due to the configuration of the project, it is not possible to distinguish the effects of the reversible lanes. It does appear, however, that reversible lanes are equally as effective as concurrent flow lanes.

## Priority at Traffic Signals

A significant amount of delay in urban areas is the result of traffic signals. Even if reserved lanes allow vehicles to bypass queues at traffic signals, priority vehicles will still have to wait up to one complete traffic signal cycle for the green signal. The result has been a variety of schemes to give certain vehicles priority at traffic signals. It should be noted that this technique is limited to buses and emergency vehicles because a large number of vehicles interacting with the traffic signals would be very disruptive. The remainder of this section deals with methods designed to reduce

bus delay at traffic signals.

It is first desirable to develop some definitions and categories for discussing bus priority schemes. Two types of priority will be defined. Passive priority only acknowledges the presence of a bus in terms of the timing pattern, but the predetermined timing pattern is not affected by the presence or absence of buses. Active priority or preemption of traffic signals occurs when a signal from a bus overrides the existing pattern and substitutes a new signal pattern to benefit buses.

Preemption can be further divided into two subsets, unconditional and conditional preemption. Unconditional preemption results if preemption is granted whenever a bus requests it, subject only to clearance intervals (pedestrian and vehicle) required for safety. On the other hand, conditional preemption results if other factors (e.g., progression, or time since last preemption) are also considered to determine when or if a preemption will be granted.

## Passive Priority

The signal timing plan for an intersection or group of intersections can be changed in several ways to favor buses. Four possible ways of favoring buses are:

1. Adjusting cycle length,
2. Splitting phases,
3. Giving priority to buses in area-wide timing plans, or
4. Metering vehicles.

*Adjustment of Cycle Length*

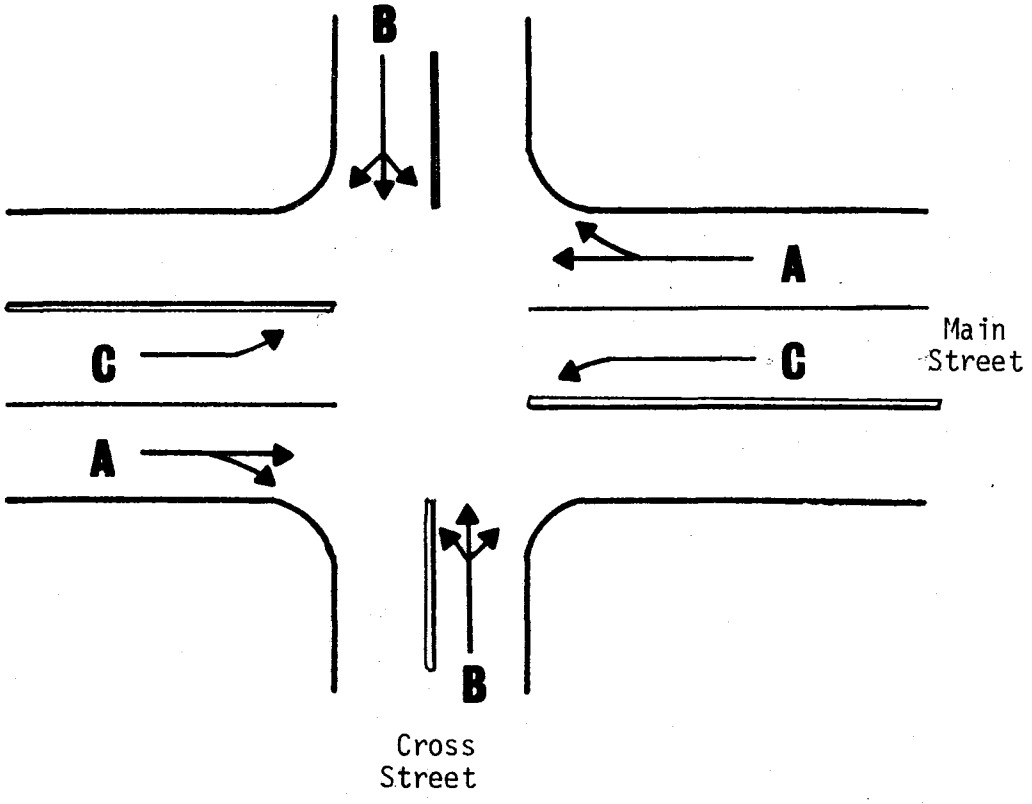
Delay at traffic signals is directly related to cycle length. As the cycle length is increased, so is the delay. Therefore, even if queue bypassing is provided by reserved lanes, delay can be long because of long cycle lengths. Reduction in cycle lengths will therefore generally benefit buses. Reduction in cycle length is not without danger, because as cycle lengths decrease, so does capacity. If reduced cycle lengths increase congestion to the point of affecting bus operation, this measure will be counterproductive.

*Phase Splitting*

Phase splitting is a way of reducing the effective cycle length for buses without necessarily changing the overall cycle length. This technique requires a minimum of either two non-bus traffic signal phases (movements) for each bus phase or a three-phase operation with buses on only one of the phases.

As an example, take a simple three-phase operation (refer to Figure 5) with a leading concurrent left-turn phase on Main Street (Phase C), a through and right movement on Main Street (Phase A), and a Cross Street movement (Phase B). The bus movements are through on Main Street. The normal phasing for leading turns would be ABC. If the bus arrived at the end of Phase A, it would have to wait for the total time of Phase B and Phase C.

If, however, Phase A is split into two parts, placing half between Phase B and Phase C and the other half between Phases C and B, the result would be and ABAC phasing. Buses would generally not have to wait longer than either Phase B or Phase C, rather than the sum of Phase B plus Phase C in the original phasing. The net result is a reduction in cycle length for vehicles on Phase A.




Normal Phasing - Leading Turns


Split Phasing

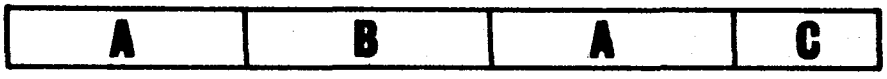



Figure 5: Example of Split Phasing to Reduce Bus Delay

*Area-Wide Traffic Timing*

Two schemes are possible for giving buses priority in area-wide traffic control timing plans. Buses can be converted to auto equivalents in order to give more green time to phases being used by buses. Alternatively, the timing can give preferential progression to bus movements.

Several off-line optimization techniques such as SIGOP and TRANSYT are increasingly being used to generate area-wide timing plans which minimize vehicle delay. By considering passenger delay, rather than vehicle delay, these techniques can be used to give priority to buses. In fact, a modification of TRANSYT, called BUS TRANSYT (7), has been developed. Indications are that it offers an inexpensive way of achieving improved bus travel times (5).

A less sophisticated method of giving priority to buses is to manually or graphically make allowances in the traffic signal progression for the travel time of buses through a coordinated network of signals. Although this method may be difficult, it can be used effectively in a grid of one-way streets. One-way streets simplify the calculation of timing patterns because of the need to progress traffic in only one direction. This is not to say that a reasonable solution is easy in a closed network, but it does simplify adjustments to provide priority to buses. The case of a contraflow lane would be a good example of where timing patterns could be adjusted to aid buses. Of course, the degredation of normal flow traffic would also need to be considered.

A specific limitation to the ability to provide progression to buses is the problem of stops for loading and unloading. In express operations, travel times can be calculated with reasonable accuracy. However, in local type operations, the variability of stop times may make bus progression ineffective.

*Metering*

Metering is a form of traffic control that regulates the flow of traffic through an intersection from one or more directions. It is analogous to freeway ramp metering and can be used to the same advantage for buses as for priority vehicles on freeways [see Reference (1)].

By controlling the flow of traffic into a link in the network or into a control area, the flow at a critical intersection downstream or in the control area in general will be improved. All that is necessary to give priority is to give buses a means to go around the metered signal phases. This can be accomplished with reserved lanes (with a special signal phase if required), by rerouting buses to non-metered phases, or with some type of bus actuated signals (to be discussed in the next section).

This technique is somewhat limited to the morning peak where vehicles can be queued up at intersections on the periphery of the central area in the city. In the evening, perimeter signals could only control through traffic. In the central area, it would be necessary to meter vehicles at the parking areas in order to limit the number of vehicles entering the control area.

It should also be noted that the technique is most applicable to area-wide control because vehicles could often bypass an isolated intersection if flow rates were metered. This technique would therefore be most applicable to area-wide control where central computer control exists. Detectors in the system could monitor the volume of traffic in the system and control green times at the perimeter and limit volumes to less than congestion levels. Furthermore, like freeway ramp metering (1), sophisticated control equipment is not required. Pretimed signals can limit flows to acceptable maximum rates based on time of day.

## Active Priority or Preemption

Active priority or preemption occurs when a signal from a bus results in overriding an existing traffic signal pattern and substituting a traffic signal pattern beneficial to buses. As previously mentioned, two types of preemption, conditional and unconditional, can occur.

### *Unconditional Preemption*

Unconditional preemption results if preemption occurs whenever a bus requests it. Safety considerations dictate that vehicle and pedestrian clearance intervals not be shortened or omitted and that a minimum safe green be given to any preempted movement. The net result is the provision of a green indication on the bus phase in the shortest safe time if the bus phase is red (red truncation), or extension of the bus phase green (green extension) past its normal termination if necessary.

Computer simulations by the Mitre Corporation (8) of unconditional preemption including various bus headways (one-half to four minutes), near and for bus stops, and single versus multiple routes lead to the following conclusions:

(a) Preemption provided substantial benefits to buses regardless of headway or bus stop location;
(b) Non-bus traffic benefitted on streets having preemption;
(c) Preemption penalized cross street traffic; and
(d) The greatest penalty to cross street traffic occurred with short headways and near side bus stops.

In Louisville, Kentucky (9) an unconditional preemption system at eight

isolated intersections resulted in time saving of 9 to 17 percent over express buses without preemption. Normal traffic also benefitted from the preemption. This was apparently due to the poor operation of the signals prior to implementation of bus priority. Inadequate green time on the major movement had caused unnecessary congestion.

*Conditional Preemption*

Conditional preemption results if other factors, such as side street queues, time since last preemption, or coordination constraints are also considered in determining when or if preemption will be granted. This type of preemption is likely to require some form of computerized control to evaluate the constraints imposed upon the preemption process.

This type of system appears to be necessary if active priority is to be given within a network of closely spaced traffic signals. In a network of closely spaced signals there is an interaction between queues of vehicles at adjacent traffic signals. If preemption at one location is not constrained, disruption may occur at other locations. The benefit to priority vehicles at preempted locations may then be lost due to system-wide disruption.

It should be noted that experience is generally lacking concerning preemption in coordinated networks of closely spaced intersections. Due to the perceived problems, most bus priority systems have avoided preemption at closely spaced intersections.

Another type of conditional preemption that can be accomplished without extensive controller logic is green truncation. If the point of detection (bus zone) is far from the intersection, due to a large cross street green requirement, it may be desirable to terminate the bus green phase upon detection of a bus. This strategy will reduce cross street delay by providing for

a cross street movement prior to the arrival of a bus. If green extension is used, the result would be a large cross street delay.

*Hardware*

In order to operate an active priority system, it is necessary for a bus to communicate with the traffic signal controller and for the traffic signal controller to respond in a manner to improve bus operations. A short overview of the required equipment is provided in this section. For a more detailed treatment on communications equipment, refer to Appendix A.

In order for a traffic signal controller to give priority to a bus, it must receive an impulse that a bus is present. Furthermore, depending upon the circumstances and control algorithm, it may be necessary for the impulse to indicate where the bus is and where the bus is going. This information allows the controller to compensate for travel time of the bus to the intersection on different traffic phases.

Changing the sequence of the traffic signal controller may be easy or difficult depending on the existing control hardware and algorithm under which buses receive priority. If unconditional preemption is to be provided, it is only necessary to provide the necessary clearance intervals and then provide the appropriate bus movement. This can generally be provided by a "black box" that externally removes control from the controller and takes over control of the signal. The amount of external logic and control required on a modern, digital, solid-state actuated controller may be small compared to other controllers.

Conditional priority inherently implies a contingency form of control that is more complex than unconditional preemption. The logic required suggests some form of computer control, although the "black box" approach can be used

for the green truncation strategy. A control algorithm would be required to evaluate the inputs and effect a timing sequence for more sophisticated strategies.

## Advantages

Priority for buses at traffic signals has the potential for reducing one of the largest causes of delays on urban arterials. Implementation is relatively easy and can be done at moderate or low cost. Passive priority techniques would usually only require engineering and support services and no capital investment, except possibly at an actuated intersection that might require a new controller to implement split phasing.

Priority at traffic signals can be implemented at locations where special lanes are either not feasible, due to limited pavement and/or right-of-way, or where designation of a reserved lane would be extremely disruptive to non-priority vehicles. Bus priority at signals may also provide improvements on non-bus traffic on the bus priority phase. There is no violation problem and enforcement requirements are therefore eliminated.

## Disadvantages

At high levels of demand, bus priority may be disruptive to other traffic. This would especially be the case if unconditional preemption did not allow enough cross street green time to accommodate vehicles in a reasonable period of time. Conditional preemption with very heavy bus flows (e.g., less than one-minute headways) might not provide any benefit over passive priority (retiming to give more green time to the bus movement).

A preemptive system will increase traffic signal maintenance costs. In

addition to the increased cost to maintain more complex equipment, calls from motorists about perceived signal malfunctions are likely to increase.

Traffic signal preemption does not have potential for carpool use due to the possible disruption caused by a large number of preemptions in a short period of time.

## Results

The NW 7th Avenue priority project in Miami is indicative of the results that can be expected from bus priority at traffic signals. Table 3 summarizes travel time and delay during various stages. The reduction in travel time for an unconditional preemption system ranged from 19 to 26 percent during the A.M. and P.M. peaks respectively. The corresponding reduction in delay ranged from 69 to 74 percent.

Passive priority (progression) in conjunction with the reserved lane produced a 24 percent reduction in A.M. peak travel time and a 27 percent reduction in the P.M. peak. The corresponding reductions in delays were 66 and 67 percent.

Unconditional preemption in conjunction with a reserved lane reduces travel time 30 to 32 percent during the morning and evening peak respectively. The corresponding reduction in delays were 90 and 86 percent.

One other result is worthy of note. An evaluation of schedule reliability indicated that the overall reliability was reduced with preemption (6). There was not a sufficient data base to ascertain the cause, but it was hypothesized that the greater flexibility in bus speeds allowed by preemption actually reduced schedule reliability. Although further study is warranted, the problem is not serious enough to outweigh the benefits of preemption.

Table 3: Travel Time and Delay on NW 7th Avenue Project

| | Stage 0 | Stage 1 | Stage 2 | Stage 3 |
|---|---|---|---|---|
| A.M. Travel Time | 26.3 | 21.2 | 18.5 | 20.1 |
| A.M. Delay | 4.05 | 1.24 | 0.42 | 1.38 |
| P.M. Travel Time | 29.8 | 21.9 | 20.4 | 21.7 |
| P.M. Delay | 6.45 | 1.65 | 0.89 | 2.16 |

Stage 0 Before--no priority systems.

Stage 1 Unconditional preemption in mixed traffic.

Stage 2 Unconditional preemption with reserved lane.

Stage 3 Passive priority with reserved lane.

Source: Reference (6).

# III. CONCLUSIONS

Table 4 summarizes some of the characteristics of the four techniques--contraflow, concurrent flow, reversible lanes, and priority treatment at traffic signals -- that were evaluated in this report. Although the relative differences between techniques are small, a few points are worth noting.

Capital and operating cost are nominal for all techniques except priority treatment at traffic signals. Preemption is a technique that requires an initial capital investment plus a recurring maintenance cost that is higher than the other techniques and also higher than passive priority.

Table 4: Evaluation of Alternative Priority Techniques

| | Capital Costs | Operating Costs | Time to Implement | Time Savings | Enforcement Requirements | Applicable to carpools |
|---|---|---|---|---|---|---|
| Contraflow Lanes | Low | Low | Short | Moderate | Small | Yes |
| Concurrent Flow Lanes | Low | Low | Short | Moderate | Large | Yes |
| Reversible Lanes | Low | Low | Short | Moderate | Large | Yes |
| Priority at Signals | Low to Moderate | Low to Moderate | Low to Moderate | Moderate | None | No* |

*Passive priority would be applicable to carpools in a reserved lane.

Contraflow and priority treatment at signals are significantly easier to enforce than the other two measures. Contraflow is largely self-enforcing while there is no enforcement required for traffic signal prioritization.

An important limitation of active priority at traffic signals is its lack of applicability to carpools. It is therefore less flexible in terms of developing an overall traffic management plan.

Overall, the four techniques provide a low cost means of improving the

people-moving capacity of existing streets. These techniques can be quickly implemented by operating agencies, often with a minimal amount of effort. They are certainly techniques worthy of consideration in any Texas city of medium or larger size.

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# APPENDIX A

## Bus Detection

Active priority requires that buses be identified from other vehicular traffic. If a bus is in an exclusive lane, ordinary detection equipment might be adequate if the possibility of actuation by other vehicles is low. It is likely, however, that other vehicles will encroach upon the exclusive lane. A special bus detector is therefore desirable to identify buses authorized for priority treatment.

Two off-the-shelf products are presently available for buses to communicate to traffic signals. Both products have been successfully used in bus priority and other applications. The two products are OPTICOM, manufactured by the 3M Company, and the PRIORITY DETECTOR, manufactured by Sarasota Engineering Company. The original development of both products was for other than bus priority applications. OPTICOM was originally developed for fire preemption while the PRIORITY DETECTOR was originally developed to allow authorized vehicles to actuate gates at the entrance of parking facilities without the need to take a parking ticket. A third product that does not appear to offer potential is a radio based system. The serious drawback to such a problem is the requirement that the driver must indicate the direction from which the vehicle is approaching.

The OPTICOM system uses an emitter mounted on the bus and a detector mounted on or near the traffic signal. The emitter flashes a high intensity light in the near infrared and visible spectrum. The detector is designed to receive the light message from the emitter. The OPTICOM system has a line-of-sight range up to 1800 feet. Up to four detectors can be used together to provide additional coverage where line-of-sight is obstructed. The cost of

the OPTICOM emitter is approximately $900 and the cost of a detector is approximately $250.

The PRIORITY DETECTOR system uses a self-contained transmitter mounted on the undercarriage of the vehicle. The transmitter inductively couples a signal to a standard roadway loop of the type normally used to detect traffic. The system has two channels such that a different course of action could be taken for two different types of vehicles such as buses and fire trucks. The cost of the PRIORITY DETECTOR system transmitter is approximately $400 and the cost of a receiver is approximately $100. Additional costs for a complete installation include the installation of the roadway loop and the necessary underground or overhead wire between the roadway loop and the control box.

## Comparison of Characteristics

The two systems are different in concept and method of operation. The OPTICOM system provides a continuous signal from point of detection to the intersection. The point of detection is variable from a few hundred feet to 1800 hundred feet from the receiver. More than one detector may be within range of a bus. This could be an asset if it is desirable to clear stopped traffic at more than one closely spaced signal at a time.

The PRIORITY DETECTOR only provides a signal while the bus is over the detector. If it is necessary or desirable to confirm passage of a bus through an intersection, it would generally require two separate detectors. One detector would be located prior to the maximum expected queue and another near the intersection. The PRIORITY DETECTOR does have an advantage over the OPTICOM system if different buses depart from an intersection approach on different signal phases.

Take, for example, a four-way intersection with one bus route turning left from the main street to the cross street and another bus route going in both directions on the main street. Two separate PRIORITY DETECTORS can be located so as to distinguish between buses going straight and buses turning left onto the cross street. The OPTICOM system would necessitate priority on both the left and through movements regardless of which way the bus was going. Besides being inefficient for general traffic, a bus in the opposing through movement could not obtain priority even though its movement is compatible with a through bus in the opposite direction. The PRIORITY DETECTOR eliminates this problem by allowing separate detection for buses in the left-turn lane and buses in the through lane on the same approach. It should be noted that separate detection would require separate lanes or utilization of both detector channels. Utilization of separate detection channels would be undesirable because it would mean that transmitters would have to be set for the proper route either by bus assignment or by operator action. Both alternatives are less than desirable due to possible errors.

Another consideration relative to the OPTICOM system is the visual effect of the system. The flashing white light is readily apparent and can be used to emphasize the priority being given to buses. If it is desired for legal or other reasons not to advertise the priority being given to the buses, 3M offers a device to filter the visible light.

## Cost Analysis

A generalized analysis of costs is difficult due to the numerous variables that must be considered. Rather than present a detailed analysis of a "typical" installation, some of the more significant variables and their effects will

be enumerated.

The most significant factor in computing costs concerns the communication cable required for the PRIORITY DETECTOR. It is necessary to install either an underground or overhead cable between the roadway loop and the control box. This cost is quite variable depending on existing conditions and local construction practices. Another additional cost for the priority detector system is the installation of the roadway loop itself.

The economics of a particular system will therefore be a function of the number of detectors required, the cost of cable installation, the cost of loop detector installation, and the number of transmitters required.

## Other Considerations

The 3M Company markets their product as a complete system whereas Sarasota is only in the detection business. The OPTICOM system can be provided with the necessary "black box" to interact with the traffic controller. The "black box" (phase selector) provides the necessary logic to provide green extension, red truncation, or green truncation as required. The alternative is to have someone else provide the "black box" functions required for bus priority. The 3M Company has been providing their phase selector for approximately $3300 per intersection on system of 10 to 20 intersections.