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Bus Lanes/Bus Rapid Transit Systems on Highways: Review of the Literature

Authors
Miller, Mark A.
Garefalakis, Antonios

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CALIFORNIA PATH PROGRAM
INSTITUTE OF TRANSPORTATION STUDIES
UNIVERSITY OF CALIFORNIA, BERKELEY

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Bus Rapid Transit Systems on Conventional Highways: A Review of the Literature and Practice

Mark A. Miller

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ABSTRACT

This report documents a review of the literature illustrated by examples of bus rapid transit systems practice implemented on conventional highways. By conventional highways we mean arterials, freeways and busways, which are frequently referred to, respectively, as on-street and off-street bus service options. On-street bus facilities have widespread applicability because of their relatively low costs, ease of implementation, and opportunities for incremental deployment. For on-street facilities, numerous implementation options exist depending on the placement of the bus lane (curb or median), direction of flow (normal or contra-flow), mix of traffic (buses only (dedicated bus lanes), buses and taxis, buses and goods delivery vehicles, or mixed traffic flow with automobiles), and traffic controls (turn controls, parking, loading and unloading of commercial motor vehicles, and signalization). Off-street bus rapid transit running ways, however, require higher investments in land and construction, and which commonly take the form of special bus roadways that vary by type of construction (above grade, at grade, below grade), direction of flow (concurrent or contra-flow), and treatment of stations (on- or off-line).

Key Words: bus rapid transit, bus lanes, highways, on-street, off-street

EXECUTIVE SUMMARY

The elements that comprise any rapid transit system consist of running ways, stations, vehicles, intelligent transportation systems, fare collection, service patterns, and identity and branding. Running ways are the key element of BRT systems around which the other components revolve since running ways serve as the infrastructural foundation around which the other elements function. Moreover, it is the running ways that should allow for rapid and reliable movement of buses with minimum traffic interference to provide a clear sense of presence and permanence. The types of running ways for BRT service can range between mixed traffic operation and fully grade-separated busways.

Of particular importance to consider when implementing bus rapid transit is its deployment on conventional highways including arterials, freeways, and busways because of the need to integrate BRT within an existing roadway infrastructure with specific land use patterns. Such integration may require changes including removal of peak period parking to allow for a bus-only travel lane, replacement of conventional traffic signal control systems with transit signal priority systems, or removal of an existing curbside travel lane during peak periods to allow for a bus-only travel lane. Moreover, such changes are likely to have impacts – possibly negative impacts from certain stakeholder perspectives – that need to be addressed.

Arterial bus facilities have widespread applicability because of their relatively low costs, ease of implementation, and opportunities for incremental deployment. Moreover, numerous implementation options exist for such facilities depending on the placement of the bus lane (curb or median), direction of flow (normal or contra-flow), mix of traffic (buses only (dedicated bus lanes), buses and taxis, buses and goods delivery vehicles, or mixed traffic flow with automobiles), and traffic controls (turn controls, parking, loading and unloading of commercial motor vehicles, and signalization). Off-street bus rapid transit running ways on freeways or busways, however, require higher investments in land and construction, and which commonly take the form of special bus roadways that vary by type of construction (above grade, at grade, below grade), direction of flow (concurrent or contra-flow), and treatment of stations (on- or off-line).

There are numerous examples of bus rapid transit systems in California that showcase most of the various types of these running ways, including the following:

Mixed Traffic Flow in various parts of the State:

- Los Angeles County Metropolitan Transportation Authority's Metro Rapid Lines with the first two lines implemented in 2001 on Wilshire and Ventura Boulevards.
- AC Transit's San Pablo Rapid traveling on State Route 123 (San Pablo Avenue) between San Pablo and Oakland with very
- Santa Clara Valley Transportation Authority's Rapid Line 522 along the El Camino/Santa Clara Street/Alum Rock Avenue corridor (State Route 82), which provides service along the east-west length of Santa Clara County between the Eastridge Shopping Center in San Jose and the Palo Alto Transit Center.
- Sacramento County's Regional Transit Line 50 E-Bus on the Stockton Boulevard corridor

Concurrent Flow Bus Lane in San Francisco under the operation of the San Francisco Municipal Railway (Muni):

- Sacramento and Clay Streets, which employ peak-hour curbside lanes that prohibit parking during peak periods.
- Mission Street operates curbside lanes between 7am and 7pm that dedicate a traffic lane to bus-only use, though convert to mixed flow use between 7pm and 7am.
- Third Street between Townsend and Market Streets operates a bus lane throughout the day; taxis are also allowed to travel in the lanes with buses

Contra Flow Bus Lanes:

- In San Francisco under the operation of the San Francisco Municipal Railway (Muni) on Sansome Street
- In Los Angeles under the operation of the Los Angeles County Metropolitan Transportation Authority on Spring Street.

Busways/Freeways in Los Angeles under the operation of the Los Angeles County Metropolitan Transportation Authority including:

- Metro Orange Line in the San Fernando Valley area of the county built at-grade on an abandoned rail right-of-way
- El Monte Busway in the median of the San Bernardino Freeway (I-10) east of downtown Los Angeles
- Harbor Transitway on an above-grade elevated structure above the Harbor Freeway (I-110) south of downtown Los Angeles

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1. INTRODUCTION

Bus Rapid Transit (BRT) systems have repeatedly demonstrated over at least the past thirty-five years their effectiveness through both international and U.S. deployments as an alternative public transportation mode to attract non-traditional transit riders. BRT systems have the flexibility to be integrated into the current urban environment and can be incrementally implemented in different settings including dedicated busways, freeway rights-of-way, and on city streets.

The elements that comprise any rapid transit system consist of:

- Running Ways;
- Stations;
- Vehicles;
- Intelligent Transportation Systems;
- Fare Collection;
- Service Patterns; and,
- Identity and Branding.

Running ways are the key element of BRT systems around which the other components revolve since running ways serve as the infrastructural foundation around which the other elements function. Moreover, it is the running ways that should allow for rapid and reliable movement of buses with minimum traffic interference to provide a clear sense of presence and permanence. The types of running ways for BRT service can range between mixed traffic operation and fully grade-separated busways (Diaz, R.B., et al., 2004), (Kittelson & Associates, Inc., et al., 2007), and (Levinson, H.S., et al., 2003).

Of particular importance to consider when implementing bus rapid transit is its deployment on conventional highways including arterials and freeways because of the need to integrate BRT within an existing roadway infrastructure with specific land use patterns. Such integration may require changes including removal of peak period parking to allow for a bus-only travel lane, replacement of conventional traffic signal control systems with transit signal priority systems, or removal of an existing curbside travel lane during peak periods to allow for a bus-only travel lane. Moreover, such changes are likely to have impacts – possibly negative impacts from certain stakeholder perspectives – that need to be examined.

A wide range of examples of BRT on conventional highways exist in California (Caltrans, 2007). For example, in Los Angeles County, of the 18 Metro Rapid Lines traveling on arterials in mixed flow traffic three BRT lines travel on state routes[1]; in the San Francisco Bay Area, the Santa Clara Valley Transportation Authority operates BRT service in mixed arterial traffic along El Camino Real, another state route[2]. Also in the Bay Area is Van Ness Avenue[3] in San Francisco which is currently preparing its BRT Draft Environmental Impact Report/Statement and is expected to begin operation in 2011. Another Bay Area BRT is AC Transit's new East Bay BRT along the E. 14th – Telegraph Avenue – International Boulevard corridor part of which runs along State Route 185. The transit agencies associated with each of these BRT examples analyze the tradeoffs among the alternatives under consideration for each of their respective transit corridors. Among the issues that can arise from implementing BRT along a conventional highway that must be considered include impacts on adjacent lanes of traffic from converting an existing travel lane to bus-only travel; impacts on businesses from removal of curbside parking during peak periods; impacts of traffic diversion to parallel streets; impacts on ridership. It is important to take a systematic approach to understand the issues that arise in these circumstances so that the best and most appropriate BRT implementation decisions may be made.

We are taking a three-stage approach to investigate the BRT implementation issues identified above. In this report we are documenting our review of the literature of bus lanes and bus rapid transit systems use of conventional highways together with a consideration of California bus rapid transit systems practice. The third stage of our research approach is performing a case study of the Lincoln Boulevard Big Blue Bus (Santa Monica) Rapid 3 Line currently running in mixed flow traffic. The case study will use corridor simulation and analytical transportation planning methods to perform a before and after type of analysis to quantify the impacts of implementing BRT in this setting consisting of traffic and ridership impacts.

[1] Lincoln Boulevard is State Route 1; Santa Monica Boulevard is State Route 2; Hawthorne Boulevard is State Route 107.
[2] El Camino Real is State Route 82.
[3] U.S. 101

2. COMMON THEMES FROM THE LITERATURE AND EXAMPLES FROM PRACTICE

A review of the literature has provided us with information that serves as input for subsequent project tasks. We highlight below those major themes from the literature that are relevant to and valuable for the research team to achieve the project objectives. These topics consist of the following:

- Running way classifications
- Bus priority treatments
- Planning and implementation guidelines

The literature on bus use of highways goes back thirty-five years to the influential works by (Levinson, H.S. et al., 1973) and (Levinson, H.S. et al., 1975), which conducted a state of the art review of ongoing and completed research at the time and reflects the experience of over 200 bus priority treatments in the United States. Treatments especially relevant to our proposal include those relating to arterials and freeways. For example, bus priority treatments included reserved bus lanes on downtown city streets, busways and shoulder use on freeways.

2.1 Running Way Classifications

Tables 1 and 2 show two classifications of running ways, according to the degree of access control/traffic separation and facility type, respectively (Levinson, H.S., et al., 2003) together with examples. An existing mixed flow lane on an arterial represents the most basic form of running way. BRT vehicles can operate with no separation from other vehicle traffic on virtually any arterial street or highway. Increasing levels of segregation beginning with operations in mixed arterial traffic, through exclusive arterial lanes (curbside or median), contra-flow freeway bus lanes, normal-flow freeway HOV lanes, grade-separated lanes or exclusive transitways on separate rights-of-way and bus tunnels add increasing levels of travel time savings and reliability improvement for the operation of BRT services. Fully grade-separated, segregated BRT transitways have the highest cost and highest level of speed, safety and reliability of any BRT running way type.

TABLE 1 Running Ways Classified by Extent of Access Control

Classification Scheme	Access Control	Facility Type
I	Uninterrupted flow – full control of access	• Bus tunnel • Grade-separated busway • Reserved freeway lanes
II	Partial control of access	• At-grade busway
III	Physically separated lanes within street rights-of-way	• Arterial median busway • Bus streets
IV	Exclusive / semi-exclusive lanes	• Concurrent and contra-flow bus lanes
V	Mixed traffic operations	

Source: (Levinson, H.S., et al., 2003)

TABLE 2 Running Ways Grouped by Facility Type

Facility Type	Classification Scheme	Examples
Busways • Bus tunnel • Grade-separated running way • At-grade busway	 • I • I • II	 • Boston, Seattle • Ottawa, Pittsburgh • Miami, Hartford
Freeway lanes • Reserved concurrent flow lanes • Reserved contra flow lanes • Bus-only or priority ramps	 • I • I • I	 • Ottawa • New Jersey approach to Lincoln Tunnel • Los Angeles
Arterial streets • Median arterial busway • Curb bus lane • Dual curb lanes • Interior bus lane • Median bus lane • Contra flow bus lane • Bus-only street • Mixed traffic flow	 • III • IV • IV • IV • IV • IV • IV • V	 • Curitiba, Vancouver • Rouen, Vancouver • Madison Av., NYC • Boston • Cleveland • Los Angeles, Pittsburgh • Portland • Los Angeles

Source: (Levinson, H.S., et al., 2003)

2.2 Bus Priority Treatments

Bus priority treatments on running ways may be grouped by level of access control and by facility type (Tables 1 and 2). Generally, arterial running ways are also referred to as on-street running ways and BRT running ways on busways or freeways are commonly referred to as off-street running ways. The focus in this section is on arterial or on-street BRT running ways.

On-street bus facilities have widespread applicability because of their relatively low costs, ease of implementation, and opportunities for incremental deployment. For on-street facilities, numerous implementation options exist depending on the following characteristics (Wilbur Smith and Associates, 1975):

- Placement of bus lane (curb or median)
- Direction of flow (normal or contra-flow)
- Mix of traffic (buses only (dedicated bus lanes), buses and taxis, buses and goods delivery vehicles, or mixed traffic flow with automobiles)
- Traffic controls (turn controls, parking, loading and unloading of commercial motor vehicles, and signalization)

2.2.1 Arterial-Related Bus Priority Treatments

There are several types of arterial-related bus priority treatments for BRT running ways, as follows:

- Mixed traffic flow
- Concurrent flow curb bus lanes
- Concurrent flow inside curb bus lanes
- Contra-flow curb bus lanes
- Median bus lanes
- Bus-only streets

Mixed Traffic Flow

Bus rapid transit systems operate in mixed traffic flow when physical, traffic, and/or environmental factors preclude bus lanes or busways from being implemented. There are tradeoffs with implementing BRT in mixed traffic flow; advantages include low costs and fast implementation with a minimum of construction; however, mixed traffic flow operations can limit bus speeds and service reliability due to the BRT vehicle having to travel in this environment *with other vehicles*; system identity can also suffer without specific actions taken to equip either or both the BRT vehicle and the BRT stop/station with a single unified BRT brand identity.

There are several examples of BRT systems implemented in California that currently operate in mixed traffic flow all of which having a distinctively unique brand identity associated with their buses and bus stops, as follows:

- Los Angeles County Metropolitan Transportation Authority's Metro Rapid Lines with the first two lines implemented in 2001 on Wilshire and Ventura Boulevards.
- AC Transit's San Pablo Rapid traveling on State Route 123 (San Pablo Avenue) between San Pablo and Oakland
- Santa Clara Valley Transportation Authority's Rapid Line 522 along the El Camino/Santa Clara Street/Alum Rock Avenue corridor (State Route 82), which provides service along the east-west length of Santa Clara County between the Eastridge Shopping Center in San Jose and the Palo Alto Transit Center.
- Sacramento County's Regional Transit Line 50 E-Bus on the Stockton Boulevard corridor

Buses will also benefit from customary street and traffic improvements that reduce overall travel delay. The range of transit-related traffic improvements can include grade separations to bypass points of delay; street expansions to improve traffic distribution or to provide bus routing continuity; traffic signal improvements including signal coordination and bus transit signal priority. Other transit-focused enhancements include turn controls that exempt buses, bus stop lengthening, effective enforcement of parking restrictions, and bus stop design improvements.

Concurrent (Normal) Flow Curb Bus Lanes

Of bus lane and bus street priority treatments, normal flow curb bus lanes are the most common; they are generally considered when it is not practical to install other on-street bus service options. They are appropriate for implementation under the following conditions:

- No parking or stopping along the curbs during the time periods that the bus lanes would be in effect
- At least two other moving general traffic lanes in the same direction except in cases on two-way four-lane streets where left turns are not permitted during peak period traffic time periods.
- Curb access for other services to adjacent properties can be readily prohibited during the time periods of bus lane operation; such services can include loading, unloading, deliveries

They are the easiest to implement, have the lowest installation costs because they normally involve only pavement markings and street signs, and have minimum impact on intersecting driveways and street routings. Customarily, such bus lanes have been used to facilitate bus movements in Central Business District by separating buses from other traffic; however, such bus lanes are also used along outlying arterials.

Experience in the U.S., however, has shown that they are least effective in terms of travel time saved, image and brand identity, ability to be enforced, and that they may impact curb access requirements such as deliveries. Another disadvantage is that right-hand turns, when allowed may conflict with bus flow; thus efforts should be made to either totally eliminate or at least restrict right-turning movements that would impede BRT service.

Concurrent flow bus lanes can operate at all times or only during peak period times. On one-way and two-way streets, an 11- to 13-foot bus lane should be provided along the curb. When street width and circulation patterns permit and peak bus volumes exceed 90 to 100 buses per peak period hour, dual bus lanes should be considered. Figure 1 depicts four typical concurrent flow bus lane designs for two-way streets. The four designs vary by number of non-bus traffic lanes (one or two) and whether left turns are allowed. For design numbers 1 and 3, no left turns are allowed. Designs 1 and 2 each have a single non-bus traffic lane; designs 3 and 4 each have two non-bus traffic lanes. The width ranges of the right-of-way for each of the four designs are provided at the top of the figure adjacent to each design. Right turns from the bus lane may be prohibited or permitted.

The primary example of a concurrent flow bus lane in California is in San Francisco under the operation of the San Francisco Municipal Railway (Muni) on various streets within the city including (Kiesling, M. and M. Ridgway, 2006):

- Sacramento and Clay Streets, which employ peak-hour curbside lanes that prohibit parking during peak periods.
- Mission Street operates curbside lanes between 7am and 7pm that dedicate a traffic lane to bus-only use, though convert to mixed flow use between 7pm and 7am.
- Third Street between Townsend and Market Streets operates a bus lane throughout the day; taxis are also allowed to travel in the lanes with buses

Concurrent Flow Inside Bus Lanes

These bus lanes can be provided adjacent to parking lanes on both one-way and two-way streets. Examples of these lanes are located in the CBD of Ottawa, Canada and along Washington Street in Boston where they serve the Silver Line BRT. No examples were identified for concurrent flow inside bus lanes in California. The concurrent flow *inside* bus lanes remove buses from most curbside conflicts from illegally parked vehicles and they do not impact left turn access. Right turns may be allowed from the bus lane or provided in the curb lane by prohibiting curbside parking at intersection approaches. For such lanes, customarily 60 to 70 foot wide streets are required, with and without left turn lanes, respectively. Lanes should be a minimum of 11-feet wide and clearly marked on the pavement. Effective enforcement is essential because the lanes are not self-enforcing such as contra-flow lanes are. The disadvantage of concurrent flow interior bus lanes is that if parking is allowed such as in the off-peak period, there may be conflicts with parking and/or idling vehicles.

1 **2** **3** **4**

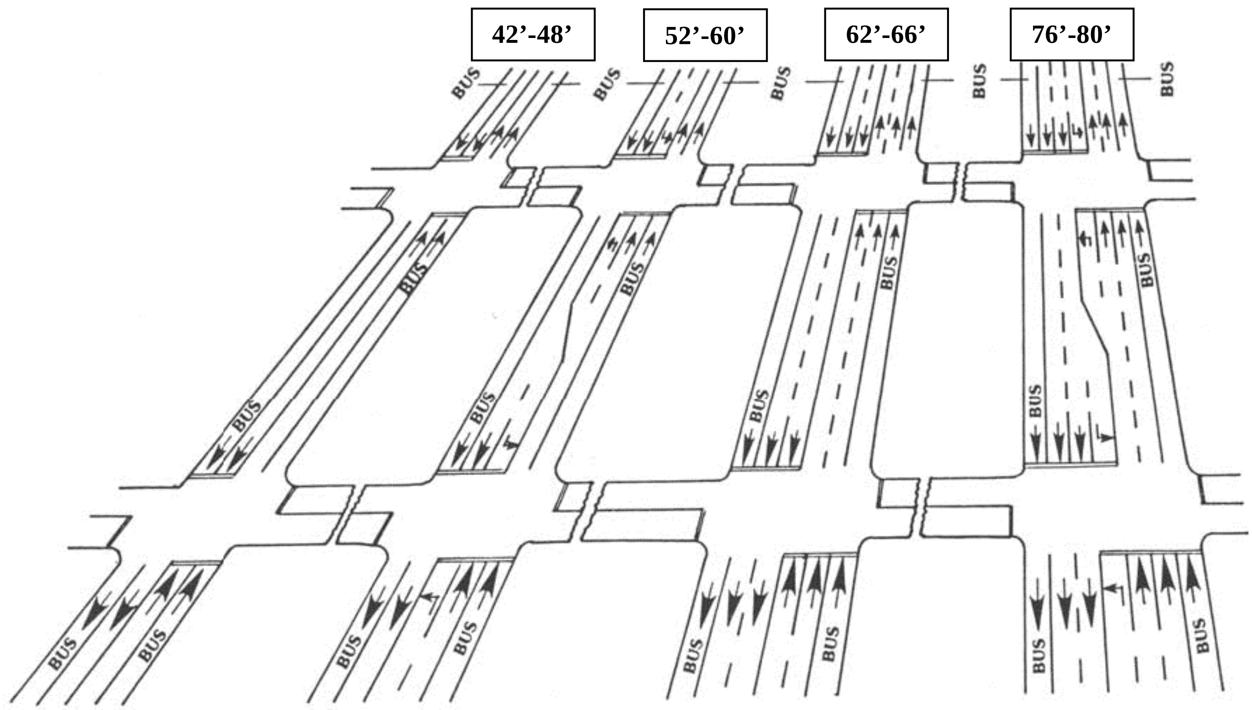

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FIGURE 1 Typical Concurrent Flow Lane Designs for Two-Way Streets

Contra Flow Curb Bus Lanes

Contra-flow bus lanes enable buses to operate opposite to the normal traffic flow on one-way streets. They may, however, be used for a single block on two-way streets to enable buses to reverse direction and normally operate at all times. They are generally appropriate for BRT implementation under the following conditions:

- Curb parking and stopping is prohibited during the hours that the bus lanes are in effect
- If street patterns permit installing a pair of contra-flow lanes on adjacent one-way streets
- If street patterns do not permit installing a pair of such lanes, then a contra-flow lane in one direction may have to be paired with a concurrent flow curb bus lane on the same street
- There are, at a minimum, two lanes remaining for traffic in the concurrent flow direction. An exception may be made for short segments of contra-flow bus lanes of less than two or three blocks that provide bus turn-around movement service

Figure 2 depicts four typical contra flow bus lane designs. Design 1 has a 32-foot wide minimum right-of-way with two non-bus traffic lanes and no left turns allowed; design 2 has a 45-foot wide minimum right-of-way with three non-bus traffic lanes and no left turns allowed; design 3 has a 55-foot wide minimum right-of-way with three non-bus traffic lanes and left turn lane; design 4 has a 60-foot wide minimum right-of-way and left-turn lane and a continuous off-peak loading zone.

Examples of contra-flow bus lanes in California consist of the following:

- In San Francisco under the operation of the San Francisco Municipal Railway (Muni) on Sansome Street
- In Los Angeles under the operation of the Los Angeles County Metropolitan Transportation Authority on Spring Street.

1 2 3 4

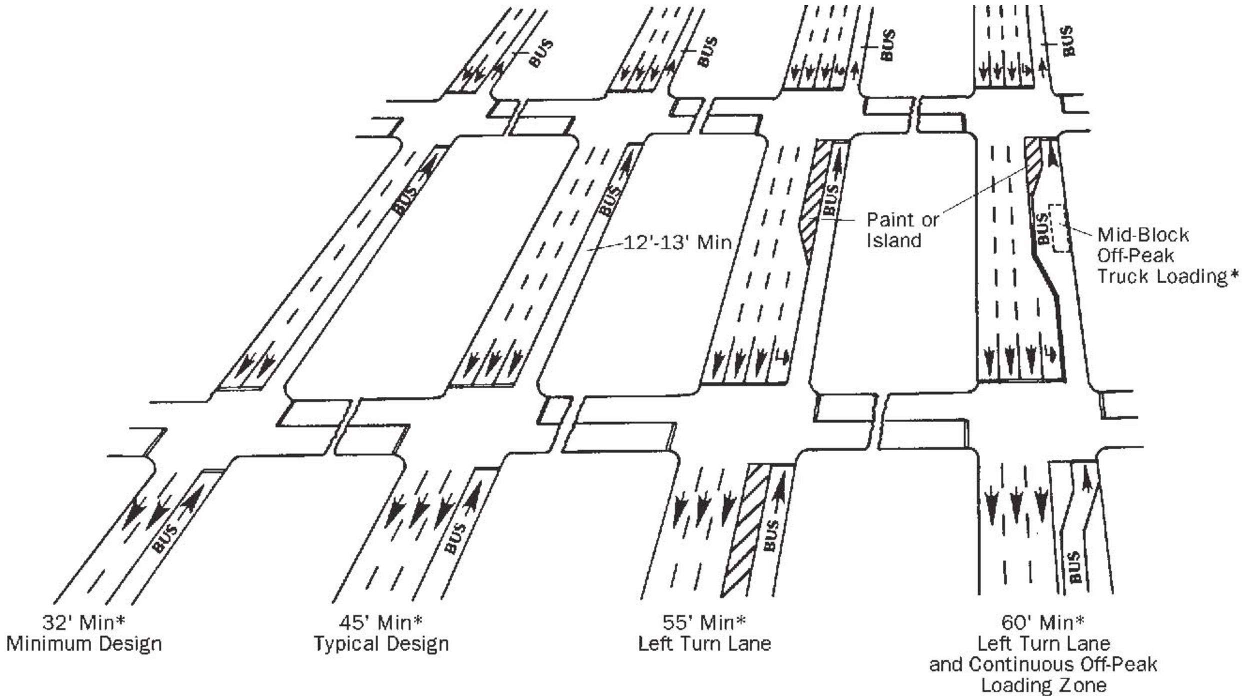

FIGURE 2 Typical Contra-Flow Lane Designs

From the perspective of bus rapid transit systems implementation, contra-flow lanes have definite disadvantages, as follows:

- Tend to disperse buses onto two different streets thereby reducing notions of BRT identity
- Passing stopped or disabled BRT vehicles is difficult unless dual bus lanes are provided
- Buses run counter to the conventional traffic signal progression; however, this can be at least partially offset.

An example of evaluating bus use of highways may be found in (Berg, W.D, et al., 1979), which documents in a with-and-without type of treatment scenario of a contra flow arterial bus lane. The field operational test evaluation was performed over the course of 90 days in which the contra flow arterial bus lane was closed and all buses were rerouted into mixed traffic lanes on a parallel arterial. Measures of effectiveness included traffic performance, safety, transit revenue, ridership, and environmental impacts. Overall findings indicate that the contra flow arterial bus lane was safer and environmentally friendlier than the alternative of having buses sharing travel lanes in mixed traffic.

Median Bus Lanes

Median bus lanes are located in the center of a roadway for exclusive bus use. They may operate in one-way or two-way directions depending on the street travel environment. Median bus lanes have continuous access, thus making enforcement difficult, but providing routes around disabled buses, for example, returning into mixed flow traffic. Currently in the planning stage is the Van Ness Avenue median bus lane BRT system in San Francisco; also is AC Transit's East Bay BRT system along E. 14th – Telegraph Avenue – International Boulevard BRT system, which will have a median component along part of its corridor alignment.

Bus-only Streets

Bus-only streets or malls may be warranted where high bus volumes traverse narrow streets or as part of downtown revitalization programs. Bus streets or malls may include the last block of an arterial street, a dead-end street at the end of several bus routes, a "bus loop" to change directions at major bus terminals, downtown bus malls, and bus circulation through automobile-free bus zones.

Bus streets identify transit routes and are easy to enforce. They increase walking space for pedestrians and waiting space at bus stops. Bus streets should incorporate curb loading zones for off-peak service vehicles where the necessary service cannot be provided from intersecting streets or off-street; where other options are unavailable or impractical, pickups and deliveries may be allowed from the bus streets when bus traffic is low such as during night hours.

In Table 3, we present guidelines for the planning for and implementation of on-street bus running ways. These guidelines were initially formulated in (Levinson, et al, 1975) and subsequently updated in (Levinson, et al, 2003), and (Levinson, 2003). They correspond to classification schemes III, IV, and V from Table 1 and arterial street (or on-street) entries from Table 2.

TABLE 3 Planning and Implementation Guidelines for Arterial-Related Bus Running Ways

Guidelines	Remarks/Comments
1. General traffic improvements and road geometric design should be coordinated with BRT service to improve the overall efficiency of street use	Improvements typically include • Prohibiting curb parking • Adding turning lanes • Prohibiting right turns • Modifying traffic signal timing • Providing bus queue bypasses
2. Curb parking generally should be prohibited before (curb) bus lanes are established, at least during peak hours	Prohibition • Provides a bus lane without reducing street capacity for other traffic • Reduces delays resulting from parking maneuvers • Gives buses easier access to stops
3. Bus routes should be restructured as necessary to make effective use of bus lanes and bus streets	• When BRT vehicles exceed 40 buses/hour, they should have exclusive us of the running way • With less frequent service, consider operating running way with local buses but without bus-bus congestion or pedestrian inconvenience
4. Bus priority treatments should reduce both the mean and variability of average trip times	A 10%-15% decrease in bus running time is desirable
5. Extended bus lanes are necessary to enable BRT schedule speeds to achieve significant time savings, better service, reliability, and increased ridership	A time savings of 1 minute per mile could produce a 5 to 6 minute time savings, if achieved over the entire length of a typical 5-mile bus trip
6. Emergency service vehicles should be allowed to use bus lanes and bus streets	
7. Design and operation of bus lanes must accommodate the service requirements of adjacent land uses	Deliveries should be prohibited from curb bus lanes during the hours that the lanes operate; deliveries can be provided from the opposite side of the street, from side streets, or from off-street facilities.
8. Access to major parking garages should be maintained	May require limited local automobile circulation in blocks adjacent to the garages
9. Taxi loading areas should be removed from bus lanes where they would interfere	On one-way streets, taxi loading areas should be placed on the opposite side of the street

Guidelines	Remarks/Comments
	from the bus lane
10. Pedestrian access to bus stops and stations should be convenient and safe	Curbside stops should allow sufficient space for amenities within the stop or in the adjacent sidewalk; crosswalks to reach median bus lanes and busways should be placed at signalized locations wherever possible and should be designed to discourage errant crossings
11. Running way design should reflect available street widths and traffic requirements	Bus lanes should be provided without reducing the lanes available to through traffic in the heavy flow direction, which may entail removing parking or reducing lane widths to provide additional travel lanes, eliminating left-turn lanes, and or providing reversible lane operation
12. When buses preempt moving traffic lanes, the number of lanes taken should be kept to a minimum	The exception is when parallel streets can accommodate the displaced traffic
13. Bus lanes and streets should provide a strong sense of identity	Can be achieved by using colored pavement wherever buses have exclusive use of lanes; such treatments are especially important for curb bus lanes when the lanes operate at all times
14. Effective enforcement and maintenance of bus lanes and bus streets is essential	Fines for unauthorized vehicles should be sufficiently large to discourage illegal use
15. BRT bus lanes (and streets) should operate all day	Will give passengers a clear sense of bus-lane identity and make use of specially colored pavements easier
16. Far-side bus stops generally should be provided	Essential when there are traffic signal priorities for buses and along median arterial busways where left-turn lanes are located near side; far-side bus stops are desirable where curb lanes are used by moving traffic and at locations with heavy right-turn traffic
17. Reserving lanes and/or bus streets for buses must be perceived as reasonable by users, public agencies, and the general public	An exclusive bus lane should carry more people than it would if the lane were used by general traffic

Sources: (Levinson, H.S., et al., 1975), (Levinson, H.S., 2003), and (Levinson, H.S., et al, 2003)

These guidelines are meant to be examined and, where applicable, followed by transit agencies when planning for on-street arterial bus running ways as part of implementing a bus rapid transit system. Moreover, the research team will examine those guidelines that overlap with its scope of work, which focuses on the traffic and ridership impacts of implementing a bus only curbside lane during peak periods along the Lincoln Boulevard corridor between Pico and Washington Boulevards.

A succinct summary of the strengths and weaknesses associated with the various on-street BRT running ways is provided in Table 4 (Levinson, H.S., et al., 2003).

TABLE 4 Arterial-Related Running Ways: Strengths and Weaknesses

On-Street Bus Priority Treatment	Strengths	Weaknesses
Operations in mixed traffic flow	• Quick implementation • Minimum cost	• Buses subject to traffic delays • Little if any sense of identity
Concurrent flow curb bus lanes	• Ease of installation • Low cost • Minimize street space devoted to BRT	• Difficult to enforce • Least effective in reducing BRT travel time • Added delay for buses due to conflicts between right-turning traffic and pedestrians
Contra flow curb bus lanes	• Enables two-way bus operation on one-way streets • May increase number of curb faces available for passenger stops • Completely separate BRT from general traffic flow • Self enforcing	• May disperse BRT onto several streets and reduce passenger convenience • Limits passing opportunities around stopped or disabled buses unless multiple lanes are provided • Can create conflict with opposing left turns • May create safety problems for pedestrians
Concurrent flow interior bus lanes	• Remove BRT from curbside frictions • Allow curb parking to be	• Require curb-to-curb street widths of 60 to 70 feet • Curb parking maneuvers

On-Street Bus Priority Treatment	Strengths	Weaknesses
	retained • Provide far-side bus "bulbs" at stops for passenger convenience	could delay buses
Median arterial busways	• Physically separates BRT running ways from general traffic • Provides a strong sense of BRT identity • Eliminates conflicts between buses and right-turning automobiles • Can enable busways to be grade separated at major intersections	• Require prohibiting left turns from the parallel roadways or providing special lanes and signal phases for these turns • Require wide streets, generally more than 80 feet from curb to curb • Costs can be high
Bus-only streets	• Remove BRT from general traffic • Increase walking space for pedestrians and waiting space at stops/stations • Improves BRT identity • Improves the ambience of surrounding areas	• Require nearby parallel streets for displaced traffic, provisions for goods delivery and service access from cross streets or off-street facilities • Generally limited to a few city blocks

Source: (Levinson, H.S., et al., 2003)

Research into bus use of highways from the operational perspective is found in (St. Jacques, K. and H. S. Levinson, 1997), which analyzes the operation of buses along arterial street bus lanes, focusing on operating conditions in which buses have full or partial use of adjacent lanes, exploring the impacts of adjacent lanes on bus speeds and capacities. Three types of bus lanes were analyzed:

1. A curb bus lane where passing is impossible or prohibited and where right turns are either permitted or prohibited. The lane may operate in the same direction as other traffic or may operate contra flow.
2. A curb bus lane where buses can use the adjacent mixed-traffic lane for overtaking around stopped buses. Right turns by non-bus traffic may or may not be prohibited from the curb bus lane.
3. Dual bus lanes with non-bus right turns prohibited.

The analyses focus on bus lanes along downtown streets, where passenger boardings generally are the heaviest, traffic signals are the most frequent, and most bus lanes are located. The procedures and parameters also apply to bus lanes on major radial arterials. The research addressed the impacts of bus flow on arterial lanes but did not include assessing the capacity and level of service of the arterial.

An analysis of bus rapid transit running ways is documented in (Levinson, H., et al., 2003), (Diaz, Roderick B., et al., 2004), and (Kittelson & Associates, Inc. et al, 2007). Most existing and proposed BRT lines operate on city streets for all or a portion of their routes. They may run in mixed traffic, normal or contra flow curb bus lanes, and/or arterial median busways. (Levinson, H.S., 2003) describes the design, operations, and effectiveness of each, and identifies the key issues and tradeoffs. It also gives illustrative examples of usage, costs and benefits. It shows that with proper design, BRT can improve bus speeds, reliability and identity, while minimizing adverse impacts to street traffic, pedestrians and property access.

2.2.2 Non-Arterial Bus Priority Treatments

Off-street bus rapid transit running ways, unlike on-street treatments, require higher investments in land and construction, which commonly take the form of special bus roadways that vary by

- Type of construction
  - Above grade
  - At grade
  - Below grade
    - Cut-and-cover
    - Deep-bore subways
- Direction of flow
  - Normal or concurrent
  - Contra
- Treatment of stations
  - On-line
  - Off-line

Such facilities are planned and designed as permanent long-range facilities; however, they can permit for future conversion to rail or other fixed guideways. They are desirable in line-haul BRT operations to permit high speeds and to minimize traffic interferences. Busways may be built on separate rights-of-way, alongside freeways, or within freeway medians.

The primary examples of busways in California are in Los Angeles under the operation of the Los Angeles County Metropolitan Transportation Authority including:

- Metro Orange Line in the San Fernando Valley area of the county built at-grade on an abandoned rail right-of-way
- El Monte Busway in the median of the San Bernardino Freeway (I-10) east of downtown Los Angeles
- Harbor Transitway on an above-grade elevated structure above the Harbor Freeway (I-110) south of downtown Los Angeles

Another example of off-street bus running ways in California is the *bus use of shoulders* Demonstration Project on SR 52 in San Diego (Martin, P.C., 2006). This one-year demonstration project has allowed the Metropolitan Transit System (MTS) route 960 to drive on the freeway shoulder from I-805 and Nobel Drive to SR 52 and Kearny Villa Road during morning and evening peak periods. Other U.S. examples of bus shoulder applications are in

- Falls Church, Virginia
- Miami, Florida, and
- Minneapolis-St. Paul, Minnesota

In Table 5, we present guidelines for the planning for and implementation of off-street bus running ways. These guidelines were initially formulated in (Levinson, et al, 1975) and subsequently updated in (Levinson, et al, 2003). They correspond to classification schemes I and II from Table 1 and off-street (busways and freeways) entries from Table 2.

TABLE 5 Planning and Implementation Guidelines for Non-Arterial Bus Running Ways

Guidelines	Remarks/Comments
1. Rapid and reliable BRT service is best achieved when buses operate in dedicated	Busways have the advantages of better market penetration, closer relationship of stations to

Guidelines	Remarks/Comments
busways or reserved lanes in freeway rights-of-way	surrounding areas, better opportunities for transit-oriented development, and a stronger sense of identity
2. BRT access to freeways benefit from bus-only ramps and/or metered ramps with bus bypass lanes	Such ramps have the dual benefits of reducing bus delays and/or improving mainline flow
3. Busways should be located on their own rights-of-way whenever possible	Locations in order of desirability are • Separate right-of-way • One side of a freeway right-of-way • Within freeway medians
4. Freeway rights-of-way offer opportunities for relatively easy land acquisitions and low development costs	Such right-of-way availability needs to be balanced with its proximity and access to key transit markets
5. Busways should enable express BRT services to pass around stopped buses at stations	Increases service flexibility, reliability, and capacity; would result in cross sections of about 50 to 80 feet at stations
6. Busways could be designed to allow for possible future conversion to rail or other fixed guideway transit	A 60-foot, mid-station right-of-way width and an 80-foot width at station can allow BRT service during the conversion period
7. Busway stations should be accessible by foot, automobile, and/or bus	Should be placed at major traffic generators and at intersecting bus lines; park-and-ride facilities should be provided in outlying areas where most access is by automobile
8. Busways may operate normal flow (with shoulders provided whenever possible), special flow (with a central shoulder or passing lane), or contra flow (with a central shoulder passing lane)	Normal flow designs are the simplest, safest, and most common. Contra-flow configurations permit common center-island station platforms that minimize station stairways, supervision, and maintenance requirements; however they require crossovers at beginning and end points if buses doors on only one side are used
9. Car pools and van pools may sometimes share bus-only lanes and busways along freeways	Should happen only when bus volumes are low, there are no or few stations, and the HOVs do not impede bus movements; generally bus-only facilities are preferable from the perspective of service reliability and identity
10. Special BRT facilities along freeways are essential whenever congestion is prevalent	Identification of major overload points along freeways is an important first step in identifying where special BRT facilities should be provided
11. Bus lanes generally should extend at least 5	Principal exceptions are queue bypass lanes,

Guidelines	Remarks/Comments
miles to allow buses to run non-stop	which are common on certain approaches
12. Existing freeway lanes in the heavy direction of travel should not be converted to bus lanes	It is better to provide additional lanes for this purpose so as not to make general traffic congestion worse
13. Standardization of freeway entrance and exit ramps to the right of the through traffic lanes permits use of median lanes by buses either in concurrent or contra flows	Special bus entry and exit ramps to and from the median lanes should be provided as needed so buses do not have to weave across the main travel lanes
14. When a BRT commuter express service operates on an HOV facility, it is essential that the BRT service have its own access/egress ramps to off-line transit stations and/or to its park-and-ride facility	Residential off-line collection should be done without requiring vehicles to weave across general traffic lanes to enter and leave the facility
15. Running ways should be wide enough to enable buses to pass stalled or disabled vehicles without encroaching on opposing lanes	

Sources: (Levinson, H.S., et al., 1975), (Levinson, H.S., 2003), and (Levinson, H.S., et al, 2003)

A succinct summary of the strengths and weaknesses associated with the various off-street BRT running ways is provided in Table 6.

TABLE 6 Non-Arterial Running Ways: Strengths and Weaknesses

Off-Street Bus Priority Treatment	Strengths	Weaknesses
Concurrent flow reserved freeway lanes	• High speeds • Minimize traffic interferences • Easier to develop as rights-of-way are already available	• Poor pedestrian access to stations if in median • Difficult to integrate into surrounding area for transit-oriented development
Contra flow reserved freeway lanes	• High speeds • Minimize traffic interferences • Easier to develop as rights-of-way are already available	• Poor pedestrian access to stations if in median • Difficult to integrate into surrounding area for transit-oriented development

Off-Street Bus Priority Treatment	Strengths	Weaknesses
Bus tunnel	• High speeds • Minimize traffic conflicts	• High capital cost • Extended construction periods with disruptions to residential and commercial areas
Grade-separated running way	• High speeds • Minimize traffic conflicts	• High capital cost • Extended construction periods with disruptions to residential and commercial areas
At-grade busway	• High speeds • Minimize traffic conflicts	• Extended construction periods with disruptions to residential and commercial areas

3. NEXT STEPS

This section describes the activities for the next primary task of the project that will involve performing a case study of the Lincoln Boulevard Big Blue Bus (Santa Monica) Rapid 3 Line currently running in mixed flow traffic. The case study will use corridor simulation and analytical transportation planning methods to perform a before and after type of analysis to quantify the impacts of implementing BRT in this setting including traffic impacts and ridership impacts.

4. REFERENCES

Berg, W.D., R.L. Smith, T.W. Walsh, and T.N. Notbohm, “Evaluation of a Contra-Flow Arterial Bus Lane”, *Transportation Research Record, Number 798*, Transportation Research Board, Washington D.C., 1981.

California Department of Transportation (Caltrans), *Bus Rapid Transit – A Handbook for Partners*, February 2007.

Diaz, Roderick B., et al., *Characteristics of Bus Rapid Transit for Decision-Making*, Federal Transit Administration, U. S. Department of Transportation, Washington, D.C., 2004.

Kiesling, M. and M. Ridgway, “Effective Bus-Only Lanes”, *ITE Journal*, Institute of Transportation Engineers, July 2006.

Kittelson & Associates, Inc. et al, *Bus Rapid Transit Practitioner's Guide*, Transit Cooperative Research Program, Report 118, Transportation Research Board, Washington D.C., 2007.

Levinson, H.S., et al., *Bus Rapid Transit, Volume 2: Implementation Guidelines*, Transit Cooperative Research Program, Report 90, Transportation Research Board, Washington, D.C., 2003.

Levinson, H.S. et al., *Bus Use of Highways: State of the Art*, National Highway Cooperative Research Program, Report 143, Transportation Research Board, Washington D.C., 1973.

Levinson, H.S. et al., *Bus Use of Highways: Planning and Design Guidelines*, National Highway Cooperative Research Program, Report 155, Transportation Research Board, Washington D.C., 1975.

Levinson, H.S., *Bus Rapid Transit on City Streets: How Does it Work?*, 2nd Urban Street Symposium: Uptown, Downtown, or Small Town: Designing Urban Streets that Work, Anaheim, California, 2003.

Martin, P.C., *Bus Use of Shoulders*, Transit Cooperative Research Program, Synthesis 64, Transportation Research Board, Washington D.C., 2006.

St. Jacques, K. and H. S. Levinson, *Operational Analysis of Bus Lanes on Arterials*, Transit Cooperative Research Program, Report 26, Transportation Research Board, Washington D.C. 1997.

Wilbur Smith and Associates, *Bus Rapid Transit Options in Densely Developed Areas*, U.S. Department of Transportation, February, 1975.