ABC
A Better City

Surface Transportation Optimization and Bus Priority Measures

The City of Boston Context

MARCH 2013

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INTRODUCTION

The following document presents the results of the research conducted for the Boston Surface Transportation Optimization Pilot Study. VHB researched bus optimization measures to determine the current best practices employed domestically and internationally to improve bus operations. Based on this research, VHB developed a list of candidate measures that could be applied to improve travel times and reliability for buses operating in Boston.

The project hopes to build upon the good work the MBTA has started by understanding domestic and foreign best practices for bus operations within a congested urban setting. The project provides an opportunity to see how bus operations in Boston can evolve into either high quality BRT service or routes/corridors with enhanced operations. Additionally, the Project will explore the opportunity to introduce alternative fuel and low emission buses to the MBTA fleet.

The Project is funded by the Barr Foundation, the largest private foundation in Massachusetts. One of the Barr Foundation's missions is to provide financial support for projects that mitigate climate change. As such, the Project's effort to increase the quality and operational efficiency of Boston's public transportation system and to reduce greenhouse gas (GHG) emissions through the exploration of next generation fuels and fleet vehicles aligns with the Barr Foundation's vision for the Boston of tomorrow.

The first section of this document describes the current state of the MBTA including its challenges, recent initiatives and current initiatives. The document provides the current bus priority best practices and describes the treatment, presents the treatment's effectiveness (if known), and estimates the cost to implement the treatment. Finally, the document summarizes the findings and suggests which treatments may work best within Boston’s urban context.

MBTA Operations and Initiatives

VHB, along with A Better City (ABC), met with MBTA officials on July 10, 2012 to discuss current bus operation practices and to learn what operational challenges the MBTA faces. The current and next generation MBTA bus fleet was also discussed during this meeting but will not be addressed in this document.

The MBTA is the fifth largest transit authority in the nation, servicing over 1.3 million customers daily. Bus ridership represents approximately 30 percent of total transit ridership. Bus ridership has grown steadily over the past decade, approximately three to four percent per year. Ridership growth continually places a strain on the bus operations, as noted by an Urban Land Institute (ULI) report highlighting the need for additional passenger capacity due to ridership growth.

The active fleet size is approximately 1,065 vehicles. The propulsion systems vary across the fleet and include diesel, CNG, diesel/electric hybrid, diesel/trackless trolleys, and electric. A major constraint in the makeup, distribution, and operation of buses is the location of the maintenance facilities. Maintenance locations only support specific propulsion systems and these vehicles must return to the respective maintenance facility that supports its propulsion system. The MBTA has expressed concern over the mounting deferred maintenance and capacity issues at several bus maintenance facilities and how this needs to be addressed in the near future. Relocation and/or construction of new facilities in certain communities face significant challenges by neighborhood groups and representatives who do not want these facilities within or near their communities.   However, significant upgrades are needed at many facilities and all of them are currently at capacity.

Current MBTA Operational Challenges

The MBTA has several programs that work towards maintaining the existing service operations. They also have other programs that are focused on improving operations for specific routes.

Roadway Congestion and Hotspots

Within any urban environment, roadway congestion is a significant factor in vehicle speed and delay. Delays experienced by buses within a mixed traffic corridor are exacerbated given the frequency of bus stops and the challenge to re-enter the flow of traffic. Congestion on roadways also varies based on the time of day, often experiencing the worst congestion during the morning or evening peak commuting periods, depending on the direction of the major commuter traffic flow.

The MBTA monitors delay and roadway congestion on its bus routes regularly. While there are several metrics used to measure congestion and delay on bus routes, the MBTA and other public transit agencies often use average bus speeds over specific roadway segments to compare different roadway segments. For the MBTA Key Bus Routes, MBTA buses generally experience bus average bus speeds of approximately 11.4 MPH throughout the day. During the hour between 8 and 9 AM, average speed is 9.6 MPH,   during the hour between 5-6 PM the average speed is 8.4 MPH.

Using the average bus speed metric, the MBTA developed a list of 10 “hot spots” based on the lowest average speed calculated along the Key Bus routes. The following table presents the list of the top 10 hot spots.

Exhibit 1 Top 10 “Problem Spots” on MBTA Key Bus Routes

	Route	Segment	Period	Average Speed
1	1	Massachusetts Avenue station to Hynes Station	PM Peak	3.5 MPH
2	66	Brigham Circle to Roxbury Crossing	PM Peak	3.6 MPH
3	66	Union Square to Harvard/Commonwealth Ave	PM Peak	4.2 MPH
4	39	Heath Street to Brigham Circle	AM Peak	4.6 MPH
5	28*	Roxbury Crossing to Dudley	PM Peak	4.7 MPH
6	1	MIT to Central Square	PM Peak	4.8 MPH
7	66	North Harvard/Western to Harvard Square	AM Peak	4.8 MPH
8	66	Brookline Village to Brigham Circle	All Day	4.8 MPH
9	66	Harvard/ Commonwealth Ave to Union Square	PM Peak	4.8 MPH
10	39	Huntington/Longwood to Brigham Circle	PM Peak	4.9 MPH

** Other routes on this segment experience similar average speeds*

Source: MBTA, e-mail message to author, 08/10/12

As shown in Exhibit 1, the average speed experienced at a top 10 hot spots on the MBTA’s Key Bus Routes ranged from 3.5 MPH and 4.9 MPH. All but three of these hot spots occur in the evening peak period. There are four routes featured on this list.

Route 66 appears on the list five times, while Routes 1 and 39 each appear twice, and Route 28 appears once. It should be noted that the routes and hot spots presented in Exhibit 1 do not include factors for the number of bus stops or the number of boardings/alightings at each stop. While these are important factors in determining dwell time and delay, the values still present some of the most congested areas along MBTA routes.

The *MBTA Bus Deployment Needs Study* evaluated the reduction in travel speed by route using the CTPS Travel Demand Model. The model predicts the changes in the transportation system given anticipated changes in the demographics and infrastructure or system changes. The reduction in travel speed is likely due to the anticipated change in vehicular volumes on roadways bus routes follow and the vehicular volumes along roads that cross bus routes. The following table from the report presents the anticipated percentage reduction in travel speed by route.

Exhibit 2Percentage Reduction in Travel Speed by Route, 2005-2015

Increase	Route Name	Route #
-17%	Harvard-Dudley	1
-11%	Harvard-Waverly	73
-11%	Kenmore-Watertown	57
-11%	Harvard-Arlington Heights	77
-10%	Harvard-Dudley	66
-10%	Central-Waltham	70
-10%	Maverick-Chelsea	114/116/117
-8%	Ruggles-Dorchester	15
-8%	Haymarket-Chelsea	111
-8%	Ruggles-Mattapan	28
-7%	Ruggles-Ashmont	22
-7%	Back Bay-Forest Hills	39
-7%	Ruggles-Ashmont	23
-6%	Harvard-Watertown	71
-6%	Sullivan-Reservoir	86
-6%	Forest Hills-Hyde Park	32

Source: (MBTA, 2008)

Travel speeds along key bus route corridors are anticipated to decrease between 6 and 17 percent between 2005 and 2015. Without significant changes to the volume of vehicles travelling along the route or providing transit vehicles an advantage through bus priority measures the travel times may decrease significantly along these corridors.

Dwell Time

Research shows there are several factors which contribute significantly to dwell time at bus stops. These factors include:

- The number of doors available for boarding and alighting
- The number passengers boarding and alighting
- The fare payment method
- The crowdedness of the bus (e.g., number of passengers standing in the aisle)

On-board fare collection is a significant contributor to high dwell times on MBTA bus routes. Currently, individuals waiting to ride the bus are required to enter at the front door of the bus pay their fare using cash, Charlie Ticket or Charlie Card. The fare payment queue that develops at the front of the bus, particularly at busier stops, significantly contributes to increased dwell time.

Photo Credit: MBTA

Riders are also permitted to reload their CharlieCards at fare boxes on all bus and green line vehicles. Adding value to CharlieCards on board buses significantly increases transaction time and can contribute significantly to bus dwell time. In addition, allowing riders to add value to their cards lets them avoid the premium levied to riders that do not pay by CharlieCard. Currently, riders who pay by CharlieCard pay $1.50 per ride on a local bus, $3.50 on an inner express bus and $5.00 on an outer express bus. If riders pay by CharlieTicket or cash, the fares increase to $2.00, $4.50, and $6.50 respectively. So by enabling riders to add value to their CharlieCards at fare boxes, dwell times are increased significantly and the MBTA loses out on additional revenue from alternative fare payments that the rider would have paid in lieu of adding value and paying with their CharlieCard.

There are currently only a handful of wayside bus fare media validators at a limited number of locations around the transit network which allow customers to validate their fare, receive a validated ticket, and board at rear doors when permitted. This technology is intended to confirm payment, increase the rate at which customers board, thus decreasing dwell time. However, employment of validators requires staffing and MBTA staff is not always available to cover all locations where this technology is in use. According to the MBTA, there are currently not enough inspectors or MBTA transit police to validate fares at all locations.

Due to the lack of inspectors, the MBTA has taken other action to deter fare evasion. Fare evasion can occur when buses allow rear door boarding in order to decrease dwell time. Boarders enter the rear doors without coming to the front to validate their passes or pay their fare. As of July 1st, 2012, fare evasion citations were increased to $50 per violation. Currently, MBTA inspectors and transit police officers are allowed to write citations to fare-evaders; however, inspectors are not permitted to ask for identification from the evader. As such, the evader can state a false name and this fare will most likely not be paid since the evader's true identification is unknown. In order to provide inspectors with the ability to request identification, a change in state legislation would be required. Currently, if fines are not paid by violators providing accurate identification, the RMV places a hold on license or vehicle registration renewal. Many MBTA riders do not have a license or motor vehicle so in many cases an RMV hold may not be a significant deterrent.

Seasonal Challenges

In addition to routine and typical maintenance requirements, inclement weather during the winter creates significant issues for fleet operations. The 60' articulated buses the MBTA employs face significant traction and stability issues and run the risk of jack-knifing when turning. As such, the MBTA needs to take these buses off-line when there is significant snow fall and replace them with 40' buses. This requires the MBTA to have enough 40' buses on reserve to service all routes that typically use 60' articulated buses. Based on our understanding, there are currently no American manufacturers that are able to resolve this issue for articulated buses.

Current Capacity Challenges and Accommodating Growth

According to the recent report, "Hub and Spoke: Core Transit Congestion and the Future of Transit and Development in Greater Boston", MBTA ridership has risen at an average rate of 1.2% per year and this growth has accelerated in the past 5 years to 2.9% per year.

The MBTA uses several metrics to help determine the quality and efficiency of bus routes and publishes standards for these metrics in the Service Delivery Policy. Within these standards, the MBTA includes a standard for "Loading", a metric to estimate how crowded buses are. According to the standard "In order to pass, the following standards must be met: During peak periods the standard is <140% of seated load (meaning there should be less than one person standing for every two people sitting). At non-peak periods, the standard is <100% of seated load - every passenger should have their own seat." The MBTA publishes route performance indicators (RPI), a report which presents whether bus routes meet the service delivery policy standards for all of its bus routes. According to published RPI data available on the MBTA website, approximately half of all routes do not meet the loading standards during weekday service. In other words, about half of the routes operate over capacity. All of the MBTA Key Bus routes operate over capacity. This is an indicator of high demand and strong ridership numbers. Additional funding would typically be needed to improve performance for this indicator.

The *MBTA Bus Deployment Needs Study* evaluated the increase in ridership by route using the CTPS Travel Demand Model. The following table from the report presents the anticipated increase in ridership for key and other bus routes between 2005-2015.

Exhibit 3Percentage Increase in Ridership by Route, 2005-2015

Projected % Increase	Route Name	Route #
28%	Harvard-Dudley	66
20%	Ruggles-Dorchester	15
20%	Harvard-Watertown	71
19%	Harvard-Dudley	1
18%	Central-Waltham	70
17%	Sullivan-Reservoir	86
17%	Maverick-Chelsea	114/116/117
17%	Ruggles-Ashmont	22
17%	Back Bay-Forest Hills	39
16%	Harvard-Waverly	73
15%	Kenmore-Watertown	57
15%	Ruggles-Ashmont	23
15%	Harvard-Arlington Heights	77
14%	Haymarket-Chelsea	111
13%	Forest Hills-Hyde Park	32
13%	Ruggles-Mattapan	28

Source: (MBTA, 2008)

As shown, there are significant increases in ridership for the key bus routes. Since the key bus routes currently operate over capacity, based on the service delivery policy standards, accommodating an increase in the number of riders during the peak hour will provide a significant challenge. Since bus crowding is a factor that contributes to dwell time, increasing the ridership on routes that are already crowded may exacerbate dwell times at busy bus stops.

Available Right-of-Way

Similar to most urban environments, Boston's roadway network has a limited amount of right-of-way available for transportation use. While some streets have a wide enough right-of-way to accommodate bus lanes or other bus priority measures, installing these amenities may come at the sacrifice of accommodations for other transportation modes or require the widening of right-of-way to accommodate all transportation users.

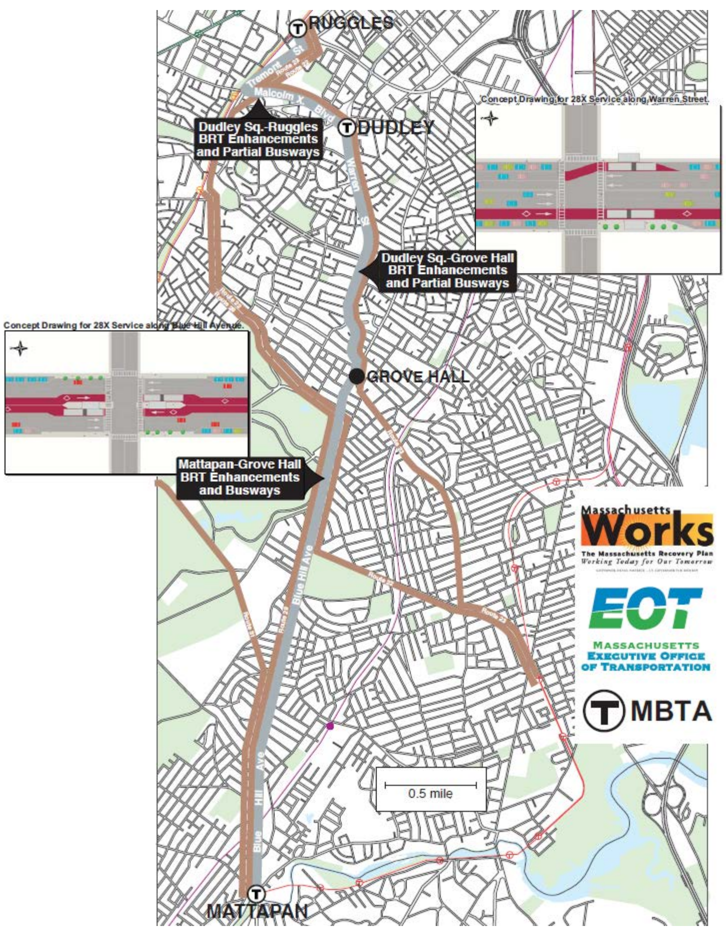
Fiscal Constraints

According to Metropolitan Area Planning Council, the MBTA will be operating at a $161 Million operating deficit in 2013. According to the MBTA, "the inability to finance billions of dollars worth of critical state of good repair projects, the MBTA's financial condition is perhaps not sustainable at current levels of operating and capital commitments. As a result, the Capital Investment Program is at a crossroads." With the inability to fund "state of good repair" capital improvement projects the ability to fund infrastructure or service enhancements poses a significant challenge. According to the Capital Improvement Plan, only 0.2% or $7 Million of a $4.2 Billion capital improvement plan is allocated to bus system enhancements over a 5-year period (FY 2013-2017).

Recent MBTA Initiatives

Silver Line

The Silver Line represents Boston's first Bus Rapid Transit (BRT) system. The Silver Line has four branches totaling 7.1 miles and 20 stations/stops. The total project costs were $1.5 Billion. Future planned expansion includes extension of the lines to connect at South Station which would enable a single-seat ride from Dudley Square to Logan Airport and an extension of the route into Chelsea. The Silver Line was the first bus route to employ transit signal priority (TSP). There are four intersections along Washington Street in Boston which are outfitted with TSP capabilities. A wayside kiosk is located at each of these intersections. The approaching buses communicate with the kiosks through interactions with the operations control center which sends requests to truncate the side street green phase or extend the green phase for the transit vehicle depending on the current conditions. The Silver Line was also the first route to incorporate improved data/supervision technology (e.g., dynamic dispatching, CAD/AVL) in Boston. It also has the only routes which run on dedicated bus lanes in Boston. As a result of the implementation of the Silver Line, service quality and customer satisfaction increased when comparing the Silver Line with its predecessor, Bus Route 49. In addition, significant economic development has occurred along the corridor.



28X

The 28X project was a proposed BRT route for Warren Street and Blue Hill Avenue that was rejected during the public planning process. The project would have introduced new stations, partial right of way separation for running ways, traffic signal & operations improvements, and streetscape enhancements to the corridor. It is speculated that the project did not proceed because the plans were not developed with sufficient public outreach despite the merits of the plan. Some technical issues were the removal of on-street parking, safety at crossings, and intersection operations.

Current MBTA Initiatives

The MBTA is always looking for ways to improve their operations to better service their customers. The primary concern of the MBTA is reliability, ensuring that routes operate to their published schedules and headways. In order to work toward the goal of reliable service, the MBTA has implemented or is working on the following initiatives.

Data Collection

Currently all MBTA buses are equipped with Computer-Aided Dispatch/Automatic Vehicle Location (CAD/AVL) units. CAD/AVL units enable the MBTA to dynamically dispatch vehicles to change the timing and/or routing of a bus if the situation calls for it. The MBTA has also begun making real-time vehicle location data information public for web/smart phone application use. While the MBTA has the capability to dynamically dispatch its vehicles, there is no standard “playbook” for dispatchers and inspectors to consistently and uniformly use to make decisions as to which corrective action to execute.

The MBTA has also installed automated passenger counters (APCs) on about ten percent of the fleet. These APCs enable the MBTA to count the boardings and alightings on buses and estimate passenger loads. The buses outfitted with APCs are distributed across various routes and rotated frequently to help determine passenger loads across the system.

Transit Signal Priority

The MBTA and the City of Boston are working jointly to connect the City’s central Traffic Management Center and the MBTA’s Operations Control Center. The two systems will communicate with each other to determine the need for signal priority intervention for transit vehicles based on whether they are running early or late relative to their schedule. The system operates in a similar fashion to the wayside control boxes in that phases are extended or truncated to the advantage of the transit vehicle but does not require a physical control box to be located adjacent to the intersection. The system uses real-time CAD/AVL signals to determine the location of the buses relative to the intersections it is requesting phase extensions/truncations from. The impetus for the coordination of systems is to increase reliability and not to minimize travel time. Once linked into the City of Boston’s network, real-time TSP could be incorporated into the control, improving intersection operations for all users, without the purchase and installation of additional equipment at intersections or on buses.

Key Routes

The MBTA identified fifteen “Key Bus Routes” based on their frequency, schedule of operation, and ridership. Although these routes only represent ten percent of the bus operations, they carry more than a third of all bus ridership. $10 million dollars of funding was obtained through the American Recovery and Reinvestment Act to fund this project. The goals of the program are to improve the overall quality of service to customers on these routes by reducing trip times, enhancing customer comfort, convenience, and safety, and provide more reliable and cost-effective service. Some of the strategies for improvement include:

- Bus stop consolidation
- Improved amenities – shelters, benches, trash receptacles
- Improved accessibility at and around bus stops
- Better pavement marking at existing bus stops
- Traffic signal improvements and upgrades

The MBTA is currently in the design process for about half of these routes and in the planning/public outreach process in the rest. Many researched topics could be integrated into the design of these Key Routes to further enhance the operation of the busiest MBTA bus routes.

EXHIBIT 4MBTA SYSTEM WITH KEY BUS ROUTES

Photo Credit: MBTA

Next-generation Fare Payment

Fare collection is a major obstacle in providing reliable, consistent service as bus travel times vary greatly depending on the length of on-board fare collection. The MBTA is continuing to examine the possibility of incorporating new on-board technology or off-board fare collection/proof of purchase to speed up dwell times at stops.

The current fare collection system used by MBTA bus and transit lines, the CharlieCard, is a contactless, stored-value smart card system that was introduced in December 2006. Changes to this system are not anticipated in the near future.

The MBTA will launch the country's first ticketless smartphone ticketing system in the near future. This system allows passengers on the MBTA commuter rail to purchase, manage and display proof of payment for their commuter rail fare tickets on their smartphones (iPhone, Android, Blackberry).

Greenhouse Gas Reporting

The MBTA completed a fleet emission study approximately 5-6 years ago. In addition, the MBTA has a sophisticated mobile infrared emission detector which can be placed at any entry/exit point at a maintenance facility and measure the emissions from any vehicle. These detectors can determine if a bus is running at its peak efficiency and emitting the least amount of harmful emissions as possible. Each bus is tested approximately four times per year and these tests identify which buses require additional inspection and service.

Bus Priority Best Practices

VHB researched both domestic and international bus transit best practices. The research focused on measures, technologies, and tools that could be implemented to improve the MBTA's bus operations along the running way, at intersections and bus stops, and on-board through fare collection. A summary of these findings is below and in a summary matrix attached to this report. It should be noted that many of the cost and treatment impact estimates were drawn from *TCRP Synthesis 83: Bus and Rail Transit Preferential Treatments in Mixed Traffic*.

Running Way

Running way treatments can often be the most beneficial operationally, while often having the highest cost and being the most challenging treatment to implement. Running way is defined as the roadway between intersections. Running way treatments are classified into three main categories:

- Exclusive
- Restricted
- Mixed-use

The MBTA currently employs all three segment classifications in their bus network, although exclusive and restricted segments are limited to just potions of the Silver Line.

Exhibit 5 Running Way Treatment Considerations

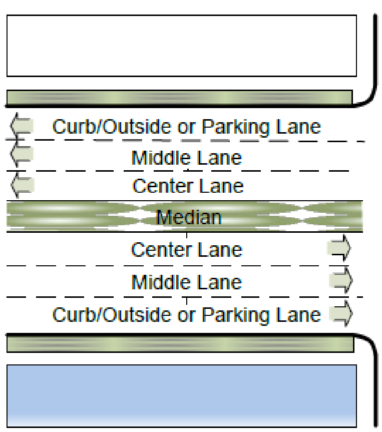
Type	Applicability	Potential Benefits	Potential Impacts	Consideration
Exclusive	High volume streets operating at levels of service A, B or C	Improved bus schedule reliability, higher bus speeds	Reduction of private vehicle capacity or increased congestion of remaining mixed traffic lanes, elimination of curb parking spaces	Traffic impacts, reduction of parking capacity, turning movements
Restricted Lanes	High volume streets operating at levels, of service A, B, or C	Improved bus schedule reliability, slightly higher bus speeds, HOV capacity	Less reduction of private vehicle capacity but risk of bus delays by HOV's, elimination of curb lane parking	Untrained drivers use of lane, signage, enforcement, safety and turning movements
Unrestricted lanes	High volume streets operating at levels of service E or F	Designated stop space, potential to provide a bus shelter and paved landing pad	Little to no improvement in bus operations	Unchanged operational environment for buses

Source: (Vanasse Hangen Brustlin, 2011)

An exclusive transit way is only traversed by transit vehicles. They can be located on-street, in the median of the streets (with bus stops in the middle of the right-of-way rather than on the sidewalk), or in an exclusive right of way, such as the Silver Line from South Station to Silver Line Way. Although exclusive transit ways significantly improve bus operations, they require extra/reallocation of right or way space that may not be available in an urban environment like Boston.

On-street exclusive facilities can be further classified by travel direction: concurrent-flow, contra-flow, and bi-directional. Concurrent-flow is an exclusive bus lane operating in the same direction as general traffic, such as the bus lane on Essex Street. Contra-flow lane is an exclusive bus lane operating in the opposite direction as general traffic, such as Washington Street over the Massachusetts Turnpike. Bi-directional lane is an exclusive lane that operates in both directions. Even though buses may travel in both directions during the day, this type of lane is restrictive, as buses can only operate in one flow direction at a time.

Exhibit 6 Lane Placement



Restrictive bus lanes are very similar to exclusive bus lanes, but are shared with another vehicle mode, be it carpools, right-turners, taxis, cyclists, etc. The majority of the Silver Line's running way along Washington Street is this type of classification, sharing the lane with right-tuners and cyclists.

Lastly, mixed-use lanes are just general traffic lanes, shared by all users. They offer the least priority to buses, yet are the most common type of facility.

Exhibit 7 Exclusive Bus Use Lane Comparison

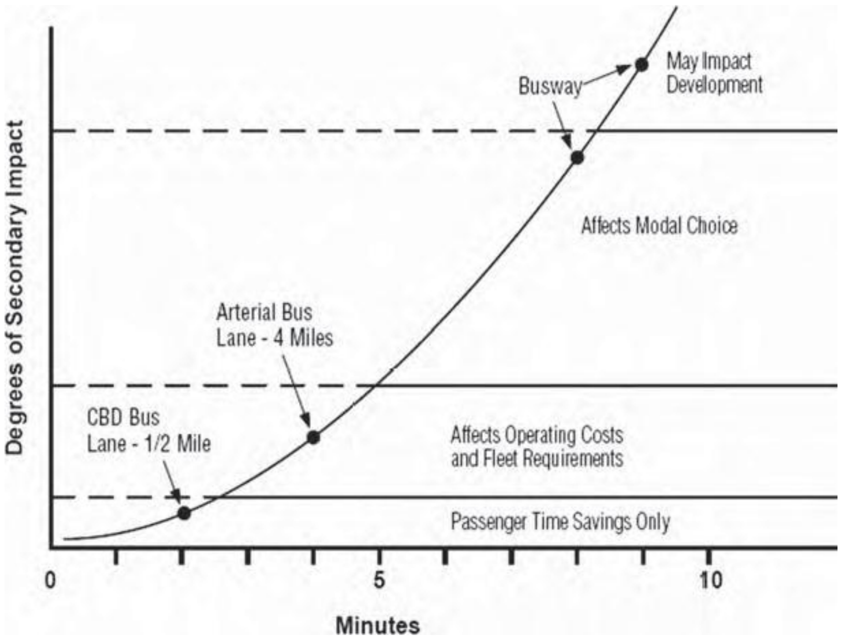
Lane Used	Pros	Cons	Application
Outside	• Lowest cost of installation • Typically occupies less street space • Lower capital costs associated with bus stops • Easier/Safer Pedestrian Access	• Conflicts with on-street deliveries and other curb access needs • Conflicts with right turns • Conflicts with bicycle travel • Lower transit travel times savings • Requires removal of on-street parking • Does not provide strong image to priority service • Can be difficult to enforce	• Restricted lane use; may permit • HOVs, must accommodate turning • vehicles, often restricted to peak • periods only
Middle	• Allows for on-street parking • Removes conflicts with illegally parked vehicles • Allow bus to avoid delays from turning vehicles	• Conflicts with cars parking • May require bus to pull out of traffic or construction of a bus bulb in order to access passengers • Strict enforcement needed	• Restricted lane use with HOV, • turning vehicles, and peak-period only while allowing on-street parking
Center	• Moves bus operations away from the curb and sidewalk	• Conflicts with left turns • May require medians or islands with ample space to accommodate passengers waiting • May require buses with driver-side doors for p passenger boarding	• Restricted lane use; may permit HOVs, must accommodate turning vehicles, often restricted to peak periods only
Median	• Clearly separates the bus stop from sidewalk activity • Provides a strong sense of identity to the priority bus • Enables contra-flow bus operation • Best option for future conversion to streetcars / LRT	• Pedestrian access more challenging • Requires the most space and greatest street width • Safety considerations involving wayward vehicles • Conflicts with left turns • Restricts flexibility of bus operation in using general traffic lanes or entering and exiting bus lane	• 24/7 dedicated bus-only with physical separation

Source: (Vanasse Hangen Brustlin, 2011)

Treatment Impact on Operations

Running way impacts on transit operations can improve travel time and service reliability. These impacts vary based on a number of different factors including the length of the treatment along a corridor (e.g., the length of an exclusive bus lane) and the type of treatment (if any) was in place prior to the treatment implementation. Implementation of running way improvements can have an impact on adjacent lanes as well as adjacent roadways. For example, the installation of a bus lane on a roadway may decrease capacity enough to shift traffic volume to an adjacent parallel roadway.

EXHIBIT 8 DEGREE OF BUS LANE IMPACTS



Source: (St. Jacques & Levinson, 1997)

The likely benefits of implementing bus running way treatments are demonstrated in **Error! Reference ource not found.**. As shown, smaller degrees of travel time improvements will have small benefits for the passengers in the form of time saved. As the impacts (travel time savings) increase, the benefits to operating costs, mode choice and ridership are realized.

Exhibit 9 presents the estimated savings in travel time for several implemented arterial bus lanes. As shown in Exhibit 9, time savings ranges from 0.1 to 1.5 minutes per mile when applied in Los Angeles and Dallas. Travel time savings were expressed in percent reduction in travel time for New York City and San Francisco applications and ranged from 34% to 43% reduction in travel time.

EXHIBIT 9 ARTERIAL BUS LANE SAVINGS

City	Street	Savings Minutes/mile
Los Angeles	Wilshire Boulevard	0.1 to 0.2 (a.m.) 0.5 to 0.8 (p.m.)
Dallas	Harry Hines Blvd	1
Dallas	Ft. Worth Blvd.	1.5
New York City	Madison Ave. (dual bus lanes)	43%* express bus 34%* local bus
San Francisco	1st Street	39%* local bus

*Percent reduction in travel time.
Source: TCRP Reports 26, 90, and 118 (16,4,5).

Exhibit 10 presents the observed improvements in reliability for arterial bus lane treatments in Los Angeles and New York City. The measure of reliability is represented by the coefficient of variation in bus travel times.

EXHIBIT 10 OBSERVED RELIABILITY IMPROVEMENTS DUE TO APPLICATION OF ARTERIAL BUS LANES

City	Street	Percent Improvement*
Los Angeles	**Wilshire Boulevard**	**12 to 27**
New York City	**Madison Avenue**	**57**

*Coefficient of variation multiplied by 100.
Source: (St. Jacques & Levinson, 1997), (Levinson, Zimmerman, Clinger, Gast, Rutherford, & Bruhn, 2003)

Treatment Costs

Several roadway characteristics affect the costs related to implementing bus lanes and transitway treatments including the design details of the existing road (e.g., location of utility poles), available right-of-way, and the type and design of the actual treatment. Exhibit 11 presents the estimated cost of running way treatments. It is important to note that the costs below does not include the purchase of property to expand the existing right-of-way.

Exhibit 11 Estimated Cost for Running Way Treatments

Treatment	Capital Cost	Operation and Maintenance
Existing lane converted to bus lane	\$50K to \$100K per mile	Minimal
Curb or off-set lanes	\$2 to 3 million/lane-mile	Under \$10K/lane-mile/year
Median transitway	\$5 to \$10 million/lane-mile	Under \$10K/lane-mile/ year

Source: (Levinson, Zimmerman, Clinger, Gast, Rutherford, & Bruhn, 2003)

Bus Stops

Bus stop location as well as the design of the bus stop are important components of any bus system and directly impact the customer's access to buses in addition to having an impact on bus operations. Several strategies and elements can be applied to bus stops to decrease dwell time while maintaining sufficient customer access, such as:

- The location of on-street stops
- Stop consolidation
- Bus bulbs
- Bus bays

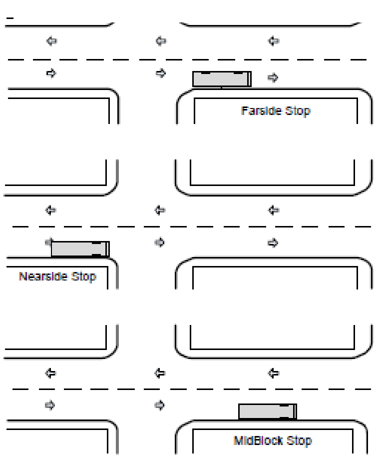
The MBTA currently does not employ the use of bus bulbs or bus bays. Exhibit 12 provides a summary of considerations when implementing bus stop treatments.

Exhibit 12 Bus Stop Treatment Considerations

Type	Applicability	Potential Benefits	Potential Impacts	Consideration
Curbside	Moderate or high volume stops where 110’ to 150’ of curb lane space (5 to 8 parking spaces) is acceptable and a 10’ width curb lane exists	Low cost, location flexibility	Loss of curb lane parking, delays in buses merging into traffic	Cost, lane space for buses to stop and traffic impacts
Bus Bulbs	Moderate or high volume stops where 80’ of curb lane space (4 spaces) is acceptable and a curb lane width of at least 6’ is available	Space for shelter and riders, no delay in buses reentering traffic lane	Traffic delays behind stopped buses, cost, loss of some curb lane parking	Traffic, curb space availability, cost, adjacent land use compatibility
Bus Bays	High volume stops where substantial lineal curb space (over 700’) is acceptable and a curb lane width of 12’ is available	Full speed reentry to traffic lane, reduced curb length is needed	Substantial cost, substantial loss of curb lane parking	Space availability, cost, adjacent land use compatibility

Source: (Vanasse Hangen Brustlin, 2011)

Exhibit 13 Bus Stop Locations



Source: (Texas Transportation Institute, 1996)

On-street bus stops can be located at three general locations along a running way: near-side, far-side, and mid-block. Near-side stops are located just prior to entry into the intersection. This location is best suited for streets with on-street parking, as stops can be shorter in length and allow the operator to utilize the entire intersection for re-entry into the travel lane. Far-side stops are located on the side of the street just after clearing the intersection. Far-side locations are best for operations, as they allow buses to get through the intersection before stopping. Both near-side and far-side stops can be integrated into transit signal priority and queue jump treatments. Mid-block stops are located between intersections. Although this location is not desirable as it requires riders approaching from both side streets to walk extra distance, they can be useful if there is an attraction directly mid-block or if blocks are abnormally long. Mid-block stops are prime candidates to be paired with bus bulbs to help reduce stop curb length. The MBTA uses all of these types of stop locations throughout their bus network.

Exhibit 14 Comparison of Bus Stop Locations

Lane Used	Pros	Cons
Far-side	• Minimizes conflicts between right turning vehicles and buses • Provides additional right turn capacity by making curb (outside) lane available for traffic • Minimizes sight distance problems on approaches to intersection • Encourages pedestrians to cross behind the bus • Curb-side creates shorter deceleration distances for buses since the bus can use the intersection to decelerate • Results in bus drivers being able to take advantage of the gaps in traffic flow that are created at signalized intersections	• May result in the intersections being blocked during peak periods by stopping buses • May obscure sight distance for crossing vehicles • May increase sight distance problems for crossing pedestrians • Can cause double-stopping, with a bus stopping far side after stopping for a red light, which interferes with both bus operations and all other traffic • May increase number of rear-end collisions since drivers do not expect buses to stop again after stopping at a red light • May increase number of side-swipe collisions • Could result in traffic queued into intersection when a bus is stopped in travel lane
Near-side	• Minimizes interferences when traffic is heavy on the far side of the intersection • Allows passengers to access buses closest to crosswalk • Results in the width of the intersection being available for the driver to pull away from curb • Eliminates the potential of double stopping • Allows passengers to board and alight while the bus is stopped at a red light • Provides driver with the opportunity to look for oncoming traffic, including other buses with potential passengers	• Increases conflicts with right-turning vehicles • May result in stopped buses obscuring curb-side traffic control devices and crossing pedestrians • May cause sight distance to be obscured for cross vehicles stopped to the right of the bus • May block the through lane during peak period with queuing buses • Increases sight distance problems for crossing pedestrians • Triple Stop
Mid-block	• Minimizes sight distance problems for vehicles and pedestrians • May result in passenger waiting areas experiencing less pedestrian congestion	• Requires additional distance for no-parking restrictions • Encourages patrons to cross street at midblock (jaywalking) • Increases walking distances for patrons crossing at intersections

Source: (Texas Transportation Institute, 1996)(Adapted)

Bus stop consolidation is the act of combining bus stops along a route in order to minimize the number of times a bus stops along a route. Bus stop consolidation can lead to the creation of new stops, located between the two combined stops, or the elimination of a stop that can be served by other, nearby stops. Public involvement is an important component of this process, as stop users must understand and accept the need for the consolidation and the benefits to the route.

Bus bulbs are extensions of the sidewalk at the location of the bus stop to the travel lane. This treatment eliminates the need for buses to leave the travel lane to pick passengers up at the edge of sidewalk. While it improves bus operations by eliminating re-entry and increases pedestrian comfort by removing waiting riders from the walkway, it requires two travel lanes in the direction of the route and may degrade general traffic operations.

Bus bays are an exclusive bus stop sidewalk cut-out. This treatment enables buses to be fully removed from the travel lane while passengers board and alight. It is best utilized with a far side stop location but is not ideal in urban environments due to limited right of way and space limitations. Exhibit 13 presents a comparison of bus stop treatments.

EXHIBIT 15 BUS STOP TYPE COMPARISON

Lane Used	Pros	Cons
Curb-side	Provides easy access for bus driver and results in minimal delay to bus Is simple in design and easy and inexpensive for a transit agency to install Is easy to relocate	Can cause traffic to queue behind stopped bus, thus causing traffic congestion May cause drivers to make unsafe maneuvers when changing lanes in order to avoid stopped traffic
Bus Bay	Allows patrons to board and alight out of travel lane Provides a protected area away from moving vehicles for both the stopped bus and bus patrons Minimizes delay to through traffic	May present problems to bus drivers when attempting to reenter traffic, especially during periods of high roadway volumes Is expensive to install compared with curb-side stops Is difficult and expensive to relocate May disrupt the urban fabric in central city areas
Open Bus Bay	Allows the bus to decelerate as it moves through the intersection See Bus Bay advantages	May cause delays to right-turning vehicles when a bus is at the start of the right turn lane See Bus Bay disadvantages
Queue Jumper Bus Bay	Allows buses to bypass queues at a signal See Open Bus Bay advantages	May cause delays to right-turning vehicles when a bus is at the start of the right turn lane See Bus Bay disadvantages
Bus Bulb	Removes fewer parking spaces for the bus stop Decreases the walking distance (and time) for pedestrians crossing the street Provides additional sidewalk area for bus patrons to wait Results in minimal delay for bus Accentuates the streetscape, providing space for shelters, plantings, and street furniture	Costs more to install compared with curb-side stops See Curb-side disadvantages Depending on site conditions, may result in permanent loss of parking

Source: (Texas Transportation Institute, 1996)(Adapted)

Treatment Impacts on Operations

Bus Bulbs and curbside stops

Exhibit 16 Bus Bulb (London)

Photo Credit: Transport for London

Bus bulbs can help reduce travel time delays by allowing buses to pick up passengers and without having to leave the stream of traffic to pull over into a bay. By allowing the bus to remain in the stream of traffic, these treatments eliminate “clearance time”, time it takes a bus to reenter flow of traffic in the adjacent mixed use lane. The travel time savings for this type of treatment varies since bus operators have differing levels of experience and skill, operate in varying conditions, and reenter adjacent lanes with varying traffic flow. TCRP Report 100 presents a table using Highway Capacity Manual unsignalized intersection methodology to estimate clearance time based on adjacent lane traffic flow. Exhibit 17 presents the estimated clearance time based on this methodology.

Exhibit 17 Average Bus Clearance Time

Adjacent-Lane Mixed-Traffic Volume (vehicles/hour)	Average Re-Entry Delay (seconds)
100	1
200	2
300	3
400	4
500	5
600	6
700	8
800	10
900	12
1,000	15

Source: (Kittelson & Associates, Inc, 2003)

Exhibit 18 Bus Bulb with Bicycle Lane Accommodations

Photo Credit: SFMTA

As shown in Exhibit 17, clearance time can vary from approximately 1 second to 15 seconds depending on the adjacent lane traffic volume. Along a corridor with a significant number of stops, the sum of clearance times can contribute significantly to the buses overall cycle time. Decreases in delays can also help with route schedule reliability and if implemented in a systematic manner can help reduce operating costs through reduced fleet needs.

The city of San Francisco changed its bus bays to bus bulbs along Mission Street. It undertook a before and after study to determine the impact on this change as it relates to bus operations. As a result of the bus bulb installations, the buses operating in the corridor experienced an increase of 7 percent in bus operating speeds. In addition, pedestrian flow rates improved 11 percent due to the added pedestrian area introduced as part of the bus bulb treatment.

Bus Stop Consolidation

The number of bus stops along a route can have a significant impact on bus operations. Every stop along a route contributes to dwell time to the buses overall travel time. As such, San Francisco's MUNI bus system made an effort to significantly reduce the number of bus stops along several corridors. Exhibit 19 presents the result of this effort.

Exhibit 19 MUNI bus stop consolidation before and after results

	Before		After		Change	
Street	Stops/Mile	Avg Bus Speed	Stops/Mile	Avg Bus Speed	Stops/Mile	Avg Bus Speed
Haight	10.7	8.2 mph	7.1	9.4 mph	−3.6	14.6%
Union	11	9.1 mph	7.1	10.0 mph	−3.9	9.9%
Van Ness	10.6	6.2 mph	8.2	6.5 mph	−2.4	4.8%
Polk (NB)	12	9.1 mph	7.8	9.5 mph	−4.2	4.4%
Mission (NB)	10.4	6.1 mph	5.2	6.8 mph	−5.2	11.5%
Sacramento/Columbus (NB)	13.2	5.4 mph	7.3	5.8 mph	−5.9	7.4%

Source: (San Francisco Municipal Transportation Agency, 1998). NB = Northbound.

As shown in Exhibit 19, bus stop reductions of 2.4 to 5.2 stops per mile resulted in bus speed improvements of 4.4% to 14.6% along these corridors.

Treatment Costs

Bus bulbs require extending the curb from the sidewalk to the travel way. The cost will vary based on the length and width of the curb extension and the site constraints (i.e., utility poles, trees, etc.) and the design of the bus bulb (i.e., whether the design includes a shelter). Another important factor is integrating the drainage into the design which may include regrading the roadway, moving utilities, and altering sidewalk features. The cost to implement bus bulbs can range from $40,000 - $80,000 per treatment.

Stop consolidation costs can be limited if stops are eliminated. If two adjacent stops are moved from their existing locations to a location between both existing stops, the cost can vary based on the amenities and design of the new stop.

Intersections

Intersections can have a significant impact on bus route operations, particularly in an urban environment. This delay can be reduced through various technological and physical treatments. Some of these measures include:

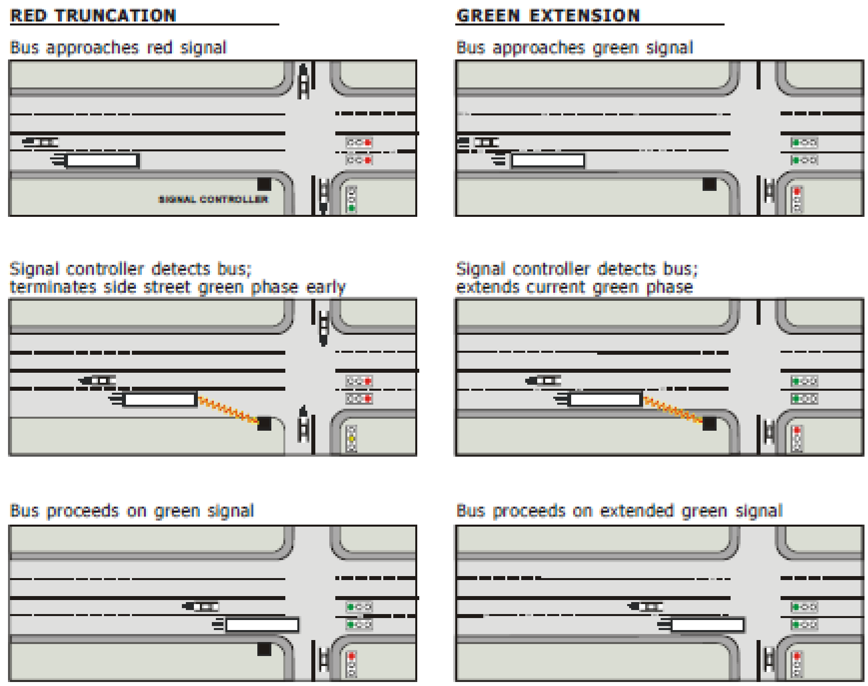
- Transit Signal Priority (TSP)
- Queue Jumps

Transit Signal Priority

The MBTA currently has four intersections with bus TSP. All of these intersections are on Washington Street and serve the Silver Line.

TSP is the practice of providing transit vehicles a green time advantage for getting through a signalized intersection. This can be accomplished by extending the green time or reducing the red time.

Exhibit 21 TSP Examples



Source: (Kittelson & Associates, Inc, 2003)

Exhibit 20MBTA Silver Line Kiosk and Station

Photo Credit: MBTA

There are generally three TSP strategies: active, passive, and real-time. Active (conditional) TSP is linked to buses CAD/AVL units and only sends a TSP request if the bus is behind schedule. This type improves reliability by helping buses get back on-schedule. The MBTA currently uses active TSP on its Silver Line Route. Passive (unconditional) TSP gives priority to the buses every time it approaches the intersection. It allows routes to have shorter running times by reducing the delay buses experience at traffic signals. Real-time (adaptive) TSP gives priority based on the need of the intersection. Priority may be given to general vehicles or transit vehicles based on the current traffic condition. This strategy can be based off of the normal vehicle throughput, or can be based off of person throughput of the intersection. The later favors transit vehicles which carry high volumes of people. Exhibit 22 provides a summary of application and implementation considerations.

Bus detection is done by various means and TSP requests can be accomplished using several technological approaches. **Error! Reference source not found.** provides a epresentation of how TSP works as a transit vehicle approaches an intersection. The most commonly implemented TSP approach is the use of transponders. Transponders which send the TSP requests are installed on each transit vehicle and requires that equipment to receive these signals are installed at each TSP intersection.

In 2006, The MBTA activated TSP at four intersections on the Silver Line corridor on Washington Street. The installed technology used the Kiosk approach to implement TSP at these intersections. For this approach, bus information such as its location is continuously sent to the MBTA Operations Control Center (OCC). If the control center determines that a bus is running behind schedule and is approaching an intersection where TSP is available, it generates a request that is sent to an MBTA kiosk located adjacent to the approaching TSP enabled intersection. A signal is then passed along to the traffic signal controller which processes data from the Boston Transportation Department's Traffic Management Center (TMC) and determines whether or not to grant the TSP request.

The MBTA is embarking on a "center-to-center" (C2C) TSP approach which will connect its OCC directly to the Boston Transportation Department TMC. The OCC continuously receives data from each of its buses on all of its routes. The OCC compares the bus location and time stamp information it receives to a schedule and determines if the bus is running behind schedule. If the bus is running behind schedule within a predetermined threshold (currently set at greater than 1 minute) the OCC issues a TSP request to the BTD TMC. The BTD grants the request for TSP if the volume of the cross street traffic at the intersection for which the request is made does not exceed a certain threshold.

The C2C approach enables the MBTA and BTD to expand the use of TSP to all BTD intersections managed by the TMC without having to add hardware at the intersections or on the buses. As with any TSP application, traffic engineering and analysis would need to be performed at every intersection at which the MBTA is looking to introduce TSP in order to understand existing traffic volume and activity and to determine the thresholds at which to accept TSP requests. To ease the proof of concept, the MBTA and BTD upgraded the same four intersections on Washington Street that used the kiosk approach of TSP on August 20, 2012.

Exhibit 22 Overview of Signal Coordination, Signal Preemption and Signal Priority

	Passive		Active		
	Signal Coordination set for Bus Transit Travel Speeds	Bus Transit Passive Signal Priority	Bus Transit Active Signal Priority	Transit Signal Preemption	Conventional Traffic Signal Preemption (Not used in bus operations
Typical Target Vehicle	Buses	Buses who are behind schedule	Buses who are behind schedule	Light Rail Vehicles	Police vehicles, emergency vehicles, fire trucks, ambulances
Typical Application Location	Specific bus corridor(s)	On conventional intersection approaches	On intersection approaches with bus only lanes or queue jumpers	On routes with railways in or adjacent to the street	Near fire stations and routes leading from fire stations
Description of System Operation	Network / corridor approach	Buses with strobe on vehicle approach	Buses with GPS on vehicle approach if behind schedule	LRT with GPS on vehicle approach	Emergency Vehicles with infrared and white light strobe An Emergency Vehicle is detected on the approach, the signal pre-empts the existing phase in service and "times out" the minimum pedestrian walk, clearance and yellow and all-red intervals of the signal phase in service and then calls into service the programmed pre-empt phase. The pre-empt signal phase is held in service for a minimum time and then is released to the next programmed signal phase.
Pedestrian Crossing Provision	Minimum clearance time provided	Minimum clearance time provided	Minimum clearance time provided	None?	None
Relative Implementation Cost		Low	High	Low	Moderate
Adaptability	Moderate	Moderate	High	Moderate	Moderate
Potential Obstacles to Implementation	Coordination for bus travel speeds may negatively impact other vehicles, particularly those travelling faster than the bus			Same as conventional preemption	Pre-emption kicks signal out of coordination and it takes 3 – 5 cycles, which can be as much as 15 minutes, to get back into coordination. It can take even more time after that for the traffic queued to be "cleared" and the operation to return to a steady state of platoons progressing through coordinated signals. However, preemption is required for emergency response.

Source: (Vanasse Hangen Brustlin, 2011)

It should be noted that the C2C approach is a cost effective way to implement TSP at BTD controlled intersection; however, many MBTA bus routes depart BTD jurisdiction and thus would not be eligible for TSP under this scheme. Cities and towns such as Cambridge, whose intersections are not controlled by a central system, would need to implement another TSP approach if TSP is desired along MBTA routes running through them.

Treatment Impacts on Operations

TSP can have a significant effect on running time and speeds. TSP has reduced running times by between 2% to 18% percent as shown in Exhibit 23.

Exhibit 23 Reported Initial Estimates of Benefits to Buses From Traffic Signal Priority

	% Running Time Saved	% Increase in Speeds	% Reduced Intersection Delay
Anne Arundel County, MD	13–18		
Bremerton, WA	10		
Chicago, IL—Cermak Road	15-18		
Hamburg, Germany		25-40	
Los Angeles—Wilshire/Whittier Metro Rapid	8-10		
Pierce County, WA	6		
Portland, OR	5-12		
Seattle, WA—Rainier Avenue	8		13
Toronto, ON	2-4		

Source: (Danaher A. , 2010)

Additionally, TSP has an effect on reliability, typically measured in variability in travel time. Seattle's Rainier Avenue corridor experienced a reduction in variability of 35 percent in its travel time while Portland's TriMet service was able to eliminate one bus from a corridor when its TSP treatment experienced a 19% reduction in travel time variability. Vancouver's TSP treatment resulted in a variability decrease of 40%.

Treatment Costs

Treatment costs for implementing transit signal priority treatments can vary significantly based on several factors. The state and configuration of the existing signal control system will influence the cost based on whether system upgrades are required. In addition, upgrades for signal equipment, intersection technology, and existing transit fleet vehicles may be necessary. Additionally, the overarching design and architecture of the system regarding whether TSP will be treated locally at intersections or through the centralized signal/transit management system. Exhibit 24 presents the estimates for the cost to implement TSP. It should be noted that TSP application costs vary significantly based on whether significant upgrades are required at intersections and/or on buses. For example, the MBTA currently is exploring a GPS-based center-to-center system. Its buses are currently outfitted with a CAD/AVL system which do not require upgrades to implement TSP and BTD centrally controlled intersections would not require upgrades. Thus, there will be no additional equipment cost per bus and no additional equipment cost per intersection for this system. However, if the MBTA wants to implement TSP along its routes through the city of Cambridge, it may need to upgrade equipment at intersections or install transponders or other communication devices on its buses, given that the city of Cambridge does not operate a centralized signal control center.

Exhibit 24 Transit Signal Priority Cost Estimates

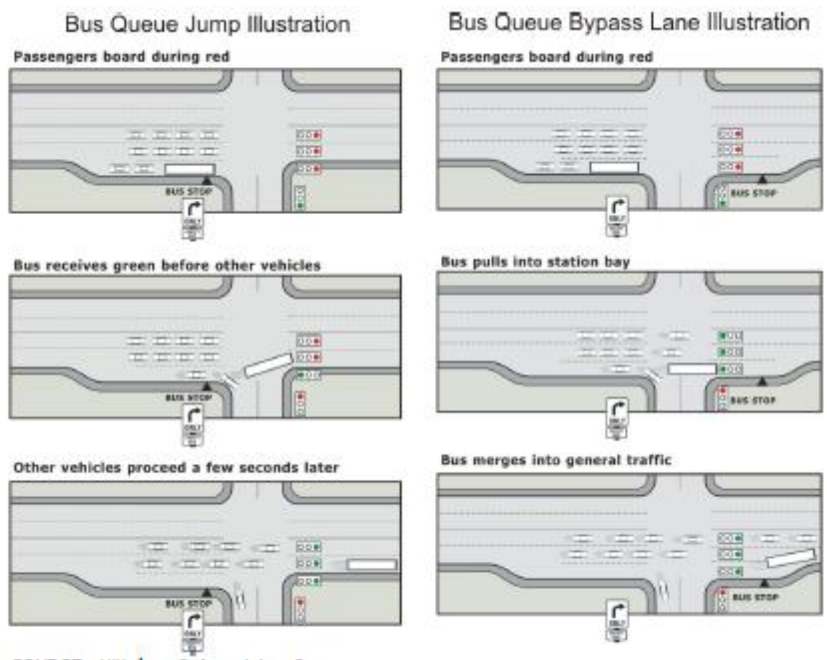
System	Technology	Equipment Cost/Intersection	Equipment Cost/Bus	Operating and Maintenance Cost	Jurisdictions Using This Detection
Optical	Optical emitters	Moderate ($8,000–$10,000)	Moderate ($1,000)	Emitter replacement ($1,000)	Portland; San Francisco; Tacoma; Kennewick, WA; Houston; Sacramento; and others
Wayside Reader	Radio frequency technology. Uses vehicle-mounted tags and wayside antenna, which must be located within 35 ft of transit vehicle. Radio transmits and decoder reads rebound message	High ($20,000–$40,000)	Low ($50)	Tag replacement ($50)	King County, WA
Smart Loops	Loop amplifier detects transmitter powered by vehicle's electrical system.	Low ($2,500 per amplifier; use existing loop detector)	Low ($200)	Same as loop detector	Los Angeles; Chicago; Pittsburgh; San Mateo County, CA
GPS	GPS receivers mounted on transit vehicle. Line of sight not required for detection.	Moderate ($6,000–$10,000)	High ($2,500)	N/A	Broward County, FL; San Jose
Wireless	Applies unused bandwidth. Use of mesh networking.	Moderate (Under $10,000)—Dependent on number of access points	Moderate (under $1,000)	High if Cellular Digital Packet Data system, low if LAN	Los Angeles County

N/A = not available; LAN = local area network.
Source: (Kittelson and Associates, Inc., 2007) and (Danaher & Braud, 2007)

Queue Jump Lanes

Queue jumps are typically a short lane that is available for transit vehicles to bypass general queued traffic at an intersection. They can be integrated with a bus stop design as near-side and/or far-side stops. Queue jump lanes can also be integrated with and without signal priority. Typically, a bus will pull into a short lane at an approach to an intersection. This lane can be exclusive or used by general traffic making a right turn, for example. If signal priority is included in the design, the bus will receive an early green signal of typically 3-4 seconds, allowing it to get in front of stopped general traffic. A queue bypass lane is similar but integrates a far side bus stop as part of the design. Exhibit 25 provides an illustration of how Bus Queue Jump/Bypass Lanes function.

EXHIBIT 25 BUS QUEUE/BYPASS LANE ILLUSTRATION



SOURCE: Kittelson & Associates, Inc.

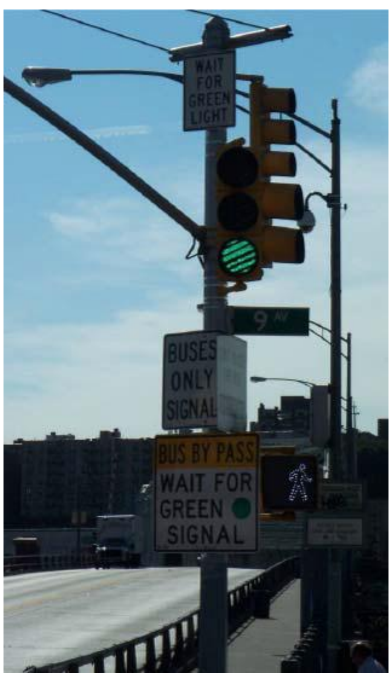


EXHIBIT 26 QUEUE JUMP SIGNAL AND SIGNAGE

Photo Credit: NYC MTA

TREATMENT IMPACTS ON OPERATIONS

Queue jump lanes can have an impact in reducing travel time through intersections. These impacts vary based on the length of bypass treatment, the number of right turning vehicles (if this treatment is incorporated into the design), the length of queue to bypass, and whether TSP is incorporated into the design. Application of queue jump treatments has been shown to reduce travel time for buses through intersections by 5% to 15%.

TREATMENT COSTS

The costs to implement queue jump and bypass lanes vary based on the existing intersection and roadway configuration. If the existing roadway currently includes right-turn lanes, shoulder, or on-street parking, the queue jump treatment can repurpose this existing piece of roadway width. With available roadway width, capital cost is approximately $500 to $2,000 for signage and striping. An additional $5,000 to $15,000 will be added to the cost for signal detection equipment if TSP is integrated into the treatment. If additional roadway width is required to implement the treatment, costs for roadway reconstruction, utility modifications, and right-of-way adjustments should be included in the capital cost estimates.

Fare Collection

Photo Credit: MBTA

Fare collection can be one of the leading causes of delay to bus operations due to increased dwell time. Fare collection can occur on-board the vehicle or off-board with proof of payment and can be in the form of a variety of fare mediums.

The MBTA employs both on-board and off-board proof of payment types collection policies for its bus service, although off-board fare collection is limited to just the four underground bus stations serving the Silver Line. On other routes, and above ground on the Silver Line, riders pay on-board.

On-board fare collection is fare collection is collected when the passenger boards the bus and pays their fare at fare boxes or at validators located at bus doorways. MBTA buses only collect fares at the front of the bus; no additional validators are located at the other bus doorways. Fare collection at the front of the bus ensures that passengers pay the correct fare and drivers can assist passengers with questions. However, fare collection at a single doorway typically have longer dwell times in that passengers queue up behind other passengers who may not be familiar with the payment system, need to add value to their card/ticket or pay cash fare, or need additional assistance. Off-board fare collection allows riders to pay their fare while waiting for the bus and leads to faster boarding upon bus arrival. This type of fare collection may be either an enclosed station or a proof of purchase system. Either system will require fare boxes to be placed at all bus stops along a route for prepayment by riders.

Another way to decrease fare collection time is to conduct on-board fare collection at multiple doors. This allows riders with cards and monthly passes, which is the majority of riders on most routes, to board quickly while those that need help or need to add money can board at the front of the bus with the driver. Multi-door and off-board fare collection are rarely used in the US, however, due to the fare evasion and enforcement concerns. Currently, passengers are only permitted to board at the front door on MBTA Buses.

TCRP Report 90 provides a discussion regarding the boarding time required by different payment methods and policies.

Exhibit 27 presents estimated boarding time (in seconds) for each passenger paying with different payment methods.

Exhibit 27 Default Boarding times

Type of Collection	Time(seconds)/Passenger
Single-door Channel	
Prepayment	+2.5
Single ticket or token	+3.5
Smart Cards	+3.5
Exact change	+4.0
Swipe or dip card	+4.2
Add to boarding times when standees are present	+0.5
Low floor bus - Subtract from boarding times	-0.5
Low floor bus - Subtract from alighting times	-1.0
Two-door Channel	
Prepayment	+1.8
Smart Cards	+2.4

Source: (Levinson, Zimmerman, Clinger, Gast, Rutherford, & Bruhn, 2003)

As shown in Exhibit 27 prepayment provides the fastest payment method, approximately 1 second faster than any other payment method. When prepayment is coupled with the possibility of entering the bus at two-doors, the boarding time is further reduced. Other factors contributing significantly to boarding times are whether standees are present on the bus and whether the bus is low floor. MBTA buses collect fares using exact change, smart cards (Charlie Card), and dip card (Charlie Ticket).

Prepayment or Proof of Payment (PoP) is gaining traction in terms of the number of transit agencies using it as a form of fare collection. According to TCRP Report 96, most agencies have a positive opinion regarding the cost-effectiveness of PoP. According to a survey of transit agencies, approximately 56.3% of the respondents express themselves as being moderately to very satisfied with the cost effectiveness of PoP, 31.3% were not significantly positive or negative and the remaining operators were moderately to very dissatisfied. The transit operators also proved their opinions regarding the public's overall perception of PoP. Approximately 58.4% of the respondents said the public were moderately to very positive of PoP, while 18.8% said the public had an overall negative feeling about the service.

Treatment Impacts on Operations

New York City Transit's (NYCT) Select Bus Service (SBS) implemented several bus priority elements including PoP. While several factors contribute to improved operations along the corridor, it is clear that several operational measures improved with the help of PoP's contribution to reducing dwell time. Dwell time per trip decreased from 16 minutes to 9.5 minutes while in-motion time increased from 49% to 61%. By some accounts, PoP was responsible for decreasing running times by 10% (total running time improvements were estimated to be 20%).

Treatment Costs

Costs to implement PoP for bus routes include the cost of fare collection machines at each stop and an increase in the number of fare inspectors to counter fare evasion. The NYCT SBS placed 140 MetroCard Fare Collectors for the two SBS bus route, typically two per stop. Each machine cost approximately $27,000. In addition, at least one Coin Fare Collection machines was installed at each stop (at a cost of approximately $7,000 each) to service exact fare payments and patrons who pay discounted fares such as seniors and students.

The MBTA's recent ticketless mobile technology initiative to implement PoP on commuter rail service can be expanded to bus and light (Green Line) and heavy rail service (Orange, Blue, and Red Lines). However, there are significant challenges to linking ticketless mobile technology within the existing CharlieCard fare payment paradigm. Existing transit stations with fare payment gates currently accept two forms of fare medium, CharlieTicket (magnetic stripe) and CharlieCard (smart card). Introducing ticketless mobile technology would require the MBTA to retrofit existing station gates with additional media readers such as those that can read bar or quick response (QR) codes. Given proprietary intellectual property of existing gate and fare payment system, integrating additional hardware into the fare payment system may be challenging and costs may be significant. However, further investment in the fare payment system is necessary to improve the customer's experience, improve the level of service, and ensure its relevance in the future.

Summary and Recommendations

Bus priority measures can provide effective means to reduce bus travel time, potentially increase reliability, reduce costs, and improve customer service. Bus priority measures reduce travel time by reducing dwell time through increased loading efficiency at bus stops, reducing delay at intersections, and reducing running time by reducing friction with other roadway vehicles. As a result, reducing dwell time, delay and running time has the potential to reduce cycle time and lead to lower operation cost due to a reduction in the necessary fleet to service routes.

The bus priority measures identified in this paper vary significantly in cost and effort to implement. In several cases, implementing these measures would require increases to the width of the available right-of-way, construction of roadway accommodations or amenities, and integration with systems such as central traffic control centers or local traffic control signals.

Exhibit 28 Measure Cost Effectiveness Matrix presents a qualitative representation of the cost-effectiveness of each measure reviewed in this document. As shown, stop consolidation is the most cost effective measure given the limited cost in pursuing the measure and the return in terms of travel time savings. However, the removal of bus stops can increase walk time for patrons and can be difficult to pursue politically. Therefore, other implications of implementing these measure should be understood and addressed prior to deciding which measure to pursue.

EXHIBIT 28 MEASURE COST EFFECTIVENESS MATRIX

Effectiveness \ Cost	Low	Medium	High
High	Stop Consolidation	Restricted Bus Lane	Exclusive Bus Lane Proof of Payment (PoP)
Medium	C2C TSP Stop Placement	Two-Door Boarding	
Low	Queue Jump	Curb Extension	

The MBTA has done a good job pursuing some bus priority measures given the physical constraints of the roadways on which they operate and the fiscal constraints that they operate under. In fact, the MBTA has explored nearly all of these measures and has implemented some a number of them. Given additional funding, capital or operational, many more bus priority measures could be pursued. The bus priority measures that the MBTA is pursuing and should continue to pursue are:

- Center-to-center transit signal priority coordination between MBTA and BTD
- Key Bus Routes Initiative
  - Bus stop consolidation
  - Elimination of low ridership stops

Given the constraints of limited right-of-way available throughout Boston's roadway network and limited funding available to pursue new initiative there are several bus priority measures which should be pursued. These are:

- Prioritize corridors suitable for bus running way accommodations such as bus priority lanes
- Change boarding policy to allow boarding through rear doors for monthly pass holders on articulated buses
  - Develop a fare enforcement strategy to support rear door boarding
  - Increase enforcement fines to deter fare evasion
  - Modify legislation to enable MBTA inspectors to request proper identification from fare evaders

    - Install rear door validators on articulated buses to enable stored-value riders to validate cards
    - Improve access to CharlieCard vending machines to eliminate need to add value at fare boxes
    - Set minimum amount riders can add at fare-box
- Increase the number of 60-foot articulated buses in fleet
- Install bus bulbs where appropriate
- Leverage ticketless mobile technology deployed on commuter rail as proof of payment on buses
    - Invest in upgrading fare gates at stations to accept other fare medium including ticketless mobile technology

Exhibit 29 presents the recommended bus priority measures, their respective benefits as they relate to improving travel time, and the necessary supporting actions to implement these measures.

Exhibit 29 Recommended Bus Priority Measures and Associated Benefits

Bus Priority Measure	Benefit	Supporting Actions
C2C TSP coordination between MBTA and BTD	Reduce delay through intersections	• Intersection traffic analysis for each affected intersection
Key Bus Routes initiative – Bus stop consolidation and elimination of low ridership stops	Reduce travel time by reducing the number of bus stops and the number of times bus needs to stop	• Work with local towns and cities to implement changes and inform public of actions
Prioritize corridors suitable for bus running way accommodations such as bus priority lanes	Reduce running time by reducing bus-vehicle friction on roadways	• Running way evaluation study
Change rear-door boarding policy	Reduce dwell time at stops	• Develop a fare enforcement strategy to support rear door boarding • Increase enforcement fines to deter fare evasion • Modify legislation to enable MBTA inspectors to request proper identification from fare evaders • Install rear door validators on articulated buses to enable stored-value riders to validate cards • Improve access to CharlieCard vending machines to eliminate need to add value at fare boxes • Set minimum amount riders can add at fare-box
Increase number of 60-foot articulated 3-door buses in fleet	Reduce dwell time at stops by providing additional capacity on buses and reducing crowding on buses Allows for rear door boarding	• Rear-door boarding policy • Proof of payment system

EXHIBIT 29 RECOMMENDED BUS PRIORITY MEASURES AND ASSOCIATED BENEFITS (CONTINUED)

Bus Priority Measure	Benefit	Supporting Actions
Install bus bulbs where appropriate	Reduce dwell time at stops by eliminating time required to re-enter flow of traffic on mixed traffic streets Improves pedestrian safety at bus stops	• Work with BTD to determine appropriateness of bus bulbs and appropriate locations
Proof of payment system	Reduce dwell time at stops by allowing passengers to board at multiple doors (can potentially be applied to Green Line service)	• Investigate and invest in station gate technology and upgrade CharlieCard technology to incorporate ticketless mobile technology PoP

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