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MEMORANDUM

DATE **September 29, 2011**

TO **Transportation Planning and Programming Committee of the Boston Region Metropolitan Planning Organization**

FROM **Mark S. Abbott, P.E.**
Steven Andrews

RE **Strategic Visioning for MBTA Bus Service: Bus Route 111**

The purpose of this MassDOT-funded study is to evaluate potential transit signal priority (TSP) strategies, including queue jumps, along three MBTA bus routes that are designated Key Routes: Routes 15, 66, and 111. This memorandum provides detailed intersection analysis and evaluation of TSP strategies for bus Route 111. Separate memoranda for Routes 15 and 66 were also completed.

The analysis in this memorandum demonstrates which intersections along the bus route could feasibly support TSP strategies, including green extension, early green, and queue jump lanes, without significant impacts on general traffic, bicyclists and pedestrians, parking, and side streets.

The primary tasks documented in this memorandum are:

- Evaluate existing conditions at signalized intersections along MBTA bus Route 111.
- Evaluate the potential for TSP and queue jump lanes under bus stop consolidation assumptions that resulted from the 2009 MBTA Key Routes Initiative.
- Project the intersection conditions and bus operations after implementation of TSP strategies. Delays, travel time for general traffic, queues, bus stop locations, pedestrian movement, parking, and bus travel time are assessed.

BACKGROUND

The MBTA has identified 15 Key Routes, which carry approximately 40% of all bus passengers. In the fall of 2009 and in early 2010, the MBTA collaborated with MassDOT and MPO staff on a Key Routes Initiative study to develop conceptual improvement strategies for six of the 15 Key Routes: Routes 1, 15, 23, 28, 66, and 111.

Typical conceptual strategies developed in that study included dedicated bus lanes; prepaid fares; TSP for buses; changing bus headways; and consolidating, eliminating, and relocating bus stops to improve the quality of bus service for existing and potential new riders. Six memoranda, including one about Route 111,[1] completed by MPO staff included recommendations for bus stop consolidation, elimination, and relocation; analysis of bus travel time performance; and recommendations for conceptual plans for TSP strategies (green extension and early green) and possible queue jump lanes.

Transit Signal Priority

Transit signal priority (TSP) is an intelligent transportation systems (ITS) technology applied to traffic signals to improve traffic- and person-carrying capacity along a corridor. TSP allows buses equipped with communication devices to request priority as they approach a traffic signal. Priority strategies include extension of a green interval for the approach where the bus is traveling or return to a green interval to serve the bus. The bus may communicate with the signal in this manner every time it is approaching a traffic signal or only when the bus is late. A TSP system can improve bus travel time and schedule reliability. Such systems have been widely installed around the country, with documented benefits. Like signal coordination, TSP systems require careful examination of impacts on side street traffic delays and queues.

TSP can benefit buses by increasing speeds, reducing intersection delay, and reducing running time. According to “Implementing Transit Signal Priority (TSP)” (in the Research and Innovative Technology Administration (RITA) — Intelligent Transportation Systems website), speeds can increase by 25% to 40%, intersection delays can be reduced by 13%, and running time savings can range from 2% to 18%. Table A-1 in Appendix A provides an overview of these TSP benefits. In Transit Cooperative Research Program (TCRP) Report 118: *Bus Rapid Transit Practitioner’s Guide* (2007) is a survey of selected transit agencies that have implemented TSP. This survey ascertained the location, type of transit service, TSP type, and benefit/impact for each TSP strategy. Table A-2 in Appendix A provides a summary of this survey’s findings.

The MBTA and the City of Boston currently employ a TSP system on the Silver Line along the Washington Street corridor. The Silver Line TSP currently uses a system in which the bus communicates with the MBTA’s transportation center as it approaches a signalized intersection. The MBTA’s transportation center then determines if the bus is behind schedule or not. If it is behind schedule, the transportation center puts in a TSP request to the Boston Transportation Department’s (BTD’s) transportation center. BTD then determines if a signal priority request will be granted or not. If granted, BTD then sends the TSP request to the signal. This TSP approach is one of several which can be applied and is currently the preferred method within the City of Boston.

Another TSP approach is for the buses to communicate directly with the traffic signal to request a priority movement. This system is frequently used by emergency vehicles and is commonly known as an Opticon system. Using an Opticon system allows for different levels of signal priority to be implemented at each traffic signal and also does not require communication between a communication center and the traffic signal.

[1] MBTA Key Routes Initiative (completed 2009).

Queue Jump Lanes

A queue jump lane is a short stretch of bus-only lane combined with TSP. The idea is to enable buses to bypass waiting queues of traffic and to cut out in front by getting an early green signal. A special bus-only signal, with associated signing and pavement markings, may be required. A queue jump lane can be installed between right-turn and through lanes. A similar arrangement can be used to permit a bus to cross traffic lanes to make a left turn, immediately after serving a curbside stop, prior to the general traffic's receiving a green signal.

Another queue jump application utilizes a dedicated right-turn lane, either an existing one or one created by converting on-street parking. The right-turn lane is used by buses as a through movement across the intersection; general traffic must only turn right in the lane. This lane gets an advance signal indication to allow the buses and the right-turn-only traffic to precede the rest of the traffic at the intersection.

Bus Stop Location

One of the key components of TSP and queue jump lanes is bus stop location in relation to the signalized intersection. At an intersection without a queue jump lane, TSP works best when the bus stop is located on the far side of the intersection. This allows for buses to utilize a green extension/early green to pass through the intersection and stop on the far side to board/discharge passengers. When the bus stop is located on the near side of the intersection and buses stop before crossing the intersection, the priority call can be long in duration, thus impacting side street traffic significantly. Also, even if a priority call is underway when a bus is pulling away from the curb, it could encounter difficulty in entering the general traffic lane.

With standard queue jump lanes, however, where the bus has a dedicated bus-only through lane along the curb, it is preferable for the bus stop to be on the near side of the intersection. This allows for buses to serve the stop, pull forward in the queue jump lane, and activate the advance signal for the bus. With alternative queue jump lanes, where a right-turn-only lane is being used by buses as a queue jump lane, the bus stop should be located on the far side of the intersection so that buses do not block the right-turning traffic.

EXISTING BUS OPERATIONS

Route Description

The MBTA's bus Route 111 travels between Haymarket Square in Boston and Woodlawn Station in Everett via the Tobin Bridge. The following is a brief description of Route 111's inbound and outbound routes.

The route has 25 stops in the inbound direction (from Elm Street to Haymarket Station) and 26 stops in the outbound direction (from Haymarket to Elm Street). Figures 1 and 2 show the inbound and outbound routes, along with existing bus stop locations. Most of these stops maintain a bus pull-out area on the outside travel or parking lane next to the sidewalk. The route travels through 11signalized intersections in the inbound direction and 13 signalized intersections in the outbound direction. The intersections the route passes through, the bus movements at the intersections, and the bus stop locations (near side or far side of the intersection) indicated in Appendix B in Tables B-1 and B-2 for the inbound and outbound directions, respectively. There are a few intersections where no bus stops are present nearby.

Existing Bus Performance

The 2009 memorandum on Route 111 included average bus speeds over the inbound and outbound routes during the AM and PM peak periods, average traffic signal delays, and daily boarding and alighting totals by stop. These data from that memo are provided below. For a detailed description of the methodologies used to obtain these data, please see the 2009 memorandum.

Average Speeds

Automatic vehicle location (AVL) data provided by the MBTA for the entire month of May 2009 were used to obtain the average bus speeds along the entire route by direction during the AM (6:00 AM -10:00 AM) and PM (3:00 PM - 7:00 PM) peak periods. Peak periods were used to gather enough data points along the route to calculate average speeds.The average speed includes both the travel time and the dwell time (when buses are stationary and serving a bus stop). The average speeds by route segment are presented for the AM peak period in Figures 3 and 4 for the inbound and outbound trips, respectively, and are presented for the PM peak period in Figures 5 and 6 for the inbound and outbound trips, respectively. Red indicates average speeds between 0 and 10 miles per hour (mph), yellow average speeds between 10 mph and 20 mph, and green average speeds greater than 20 mph.

In the AM peak period in the inbound direction, the slowest speeds occurred from Sagamore Avenue at Washington Avenue to Bellingham Square. The average inbound speed for the entire route in the AM peak period was 15.52 mph.

In the AM peak period in the outbound direction, the slowest speeds occurred from Haymarket Station to the intersection of Causeway Street and Commercial Street. The average outbound speed for the entire route in the AM peak period was 15.26 mph.

In the PM peak period in the inbound direction, the slowest speeds occurred in the approach to Haymarket Station after the intersection of Causeway Street and Commercial Street. The average inbound speed for the entire route in the PM peak period was 14.94 mph.

In the PM peak period in the outbound direction, the average speed for the route was below 10 mph from Haymarket Station to Sagamore Avenue at Washington Avenue. The average outbound speed for the entire route in the PM peak period was 9.60 mph. Note that the sample size for AVL data for the timepoint at Bellingham Square was only 27; therefore, this timepoint was eliminated for this direction and time period.

In summary, Route 111 experienced slower travel speeds in the PM peak period compared to the AM peak period and in the outbound direction compared to the inbound direction. The segment

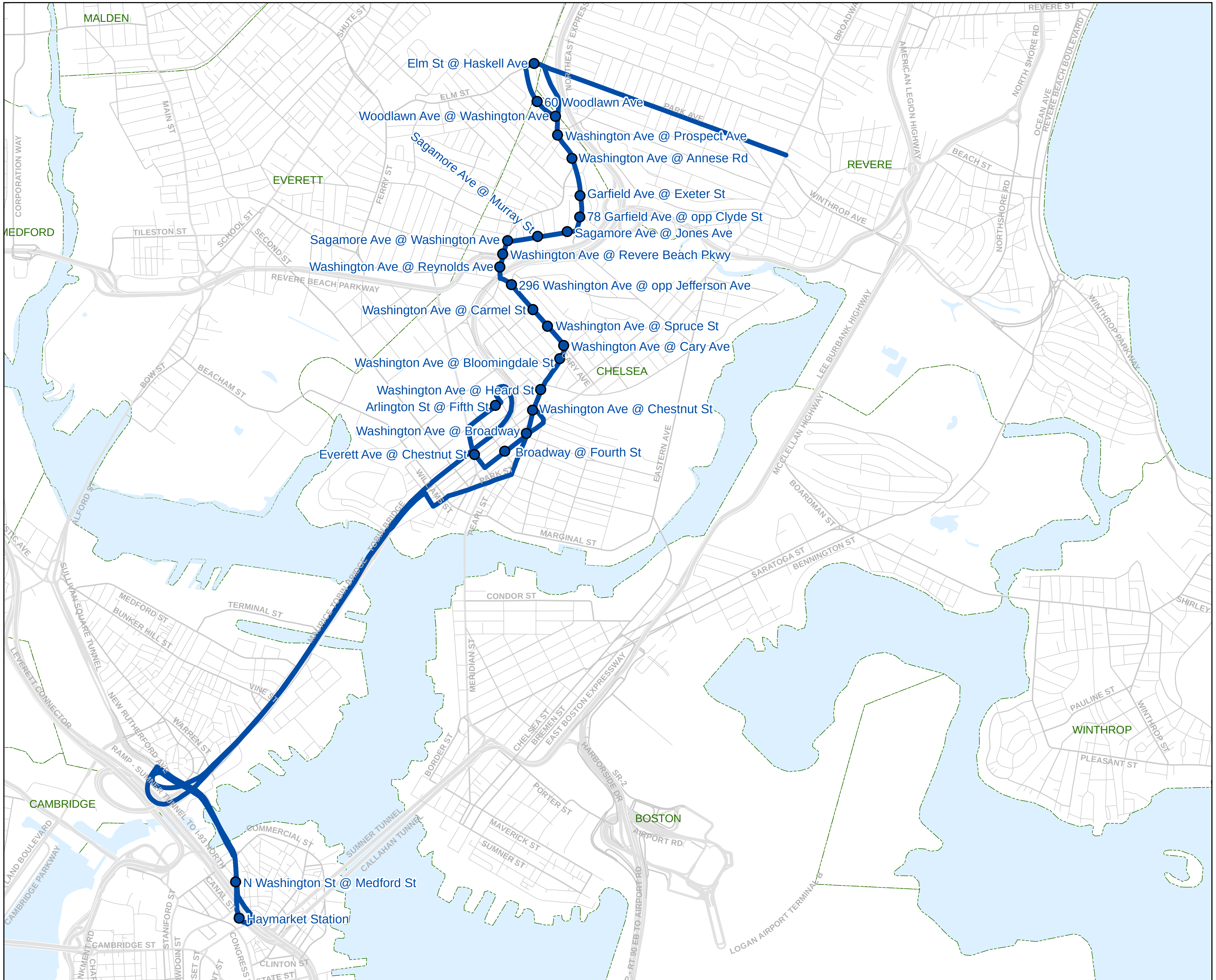

FIGURE 1
MBTA Bus Route 111
Route and Stop Locations:
Inbound

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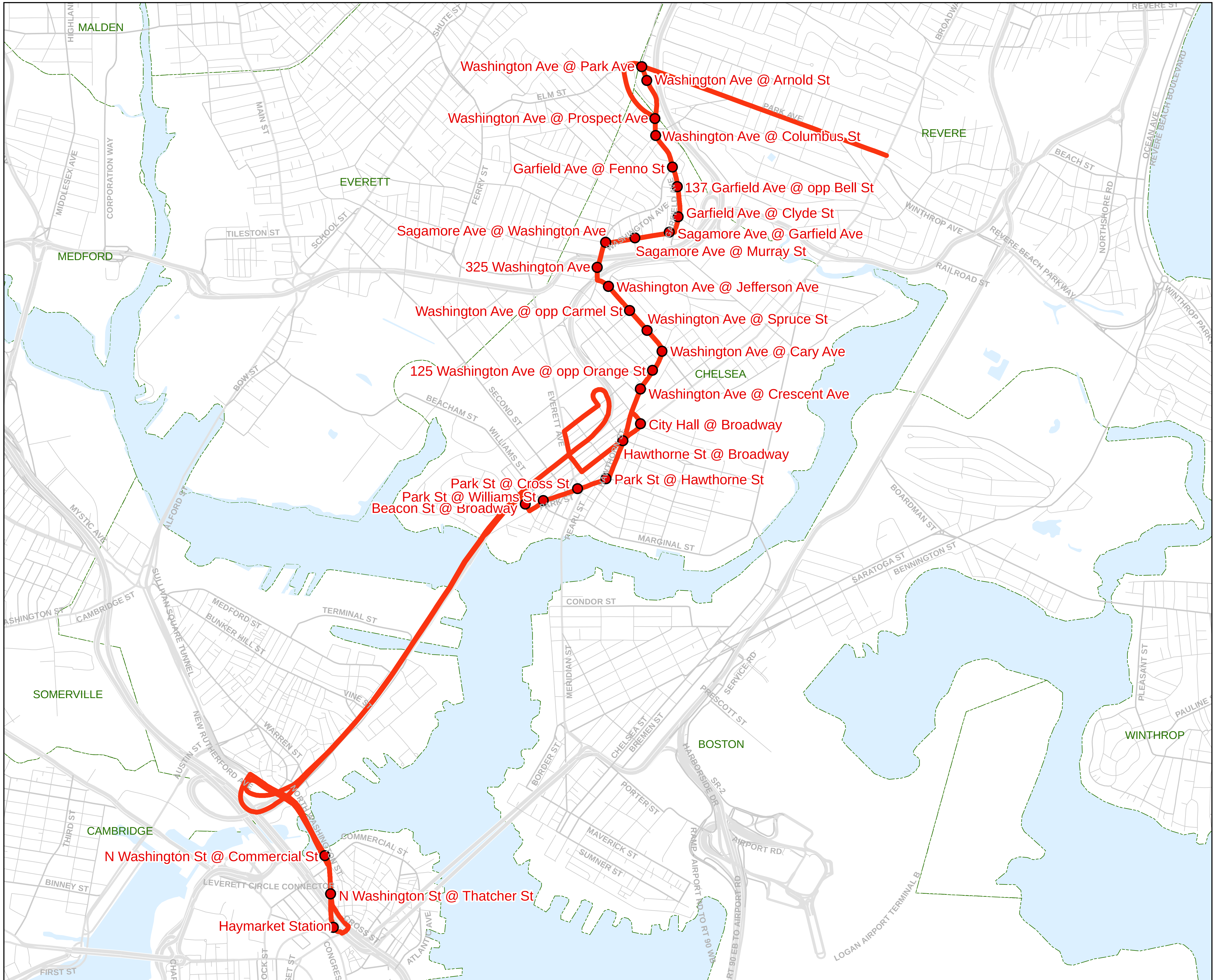
FIGURE 2
MBTA Bus Route 111
Route and Stop Locations: Outbound



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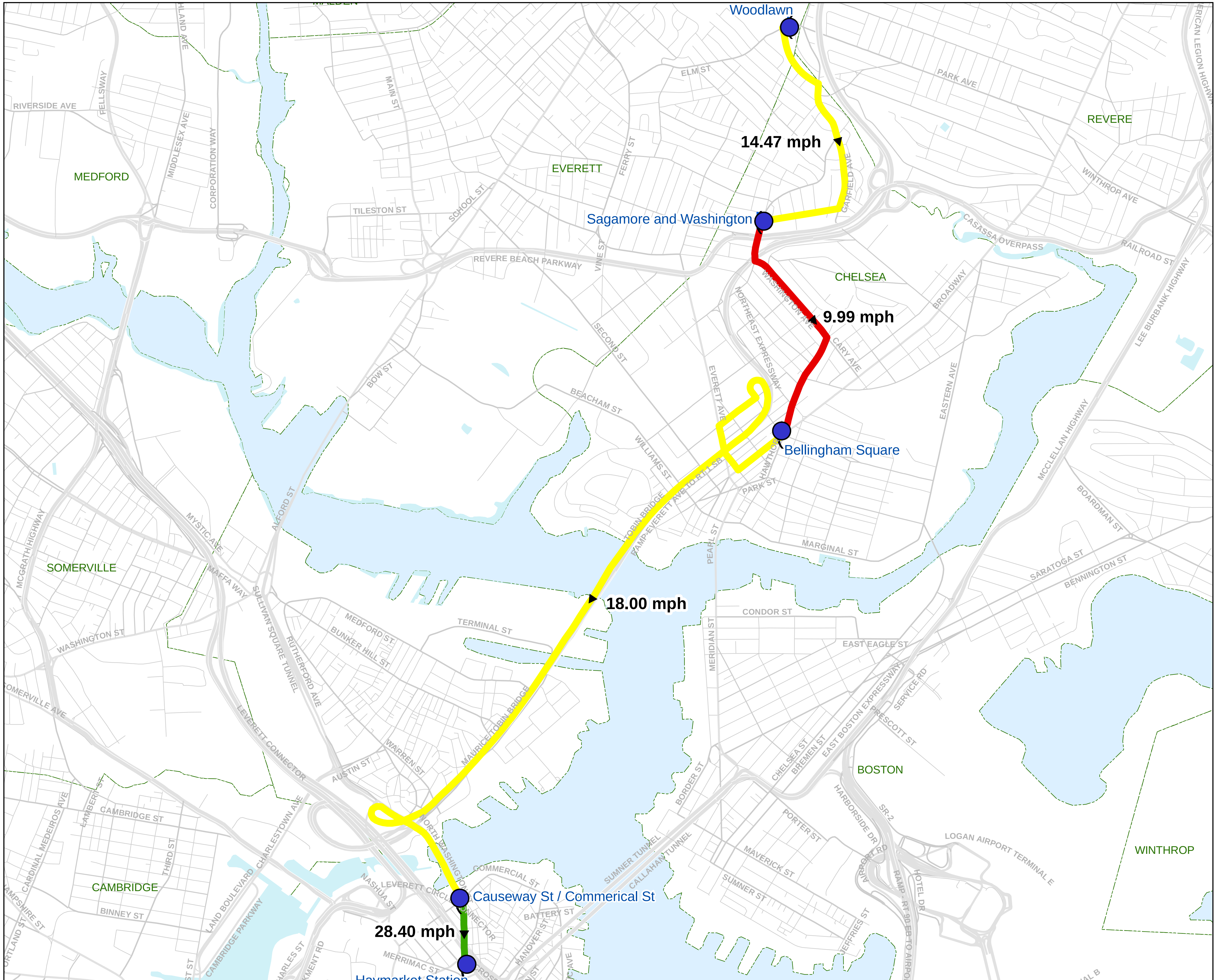

FIGURE 3
MBTA Bus Route 111
Average Travel Speeds:
AM Peak Period (6:00 - 10:00 AM)
Inbound

LEGEND

- Timepoint
- 0 – 10 mph
- 11 – 20 mph
- > 20 mph

Travel speed data estimated from the delay data provided by the MBTA AVL System for May 2009.

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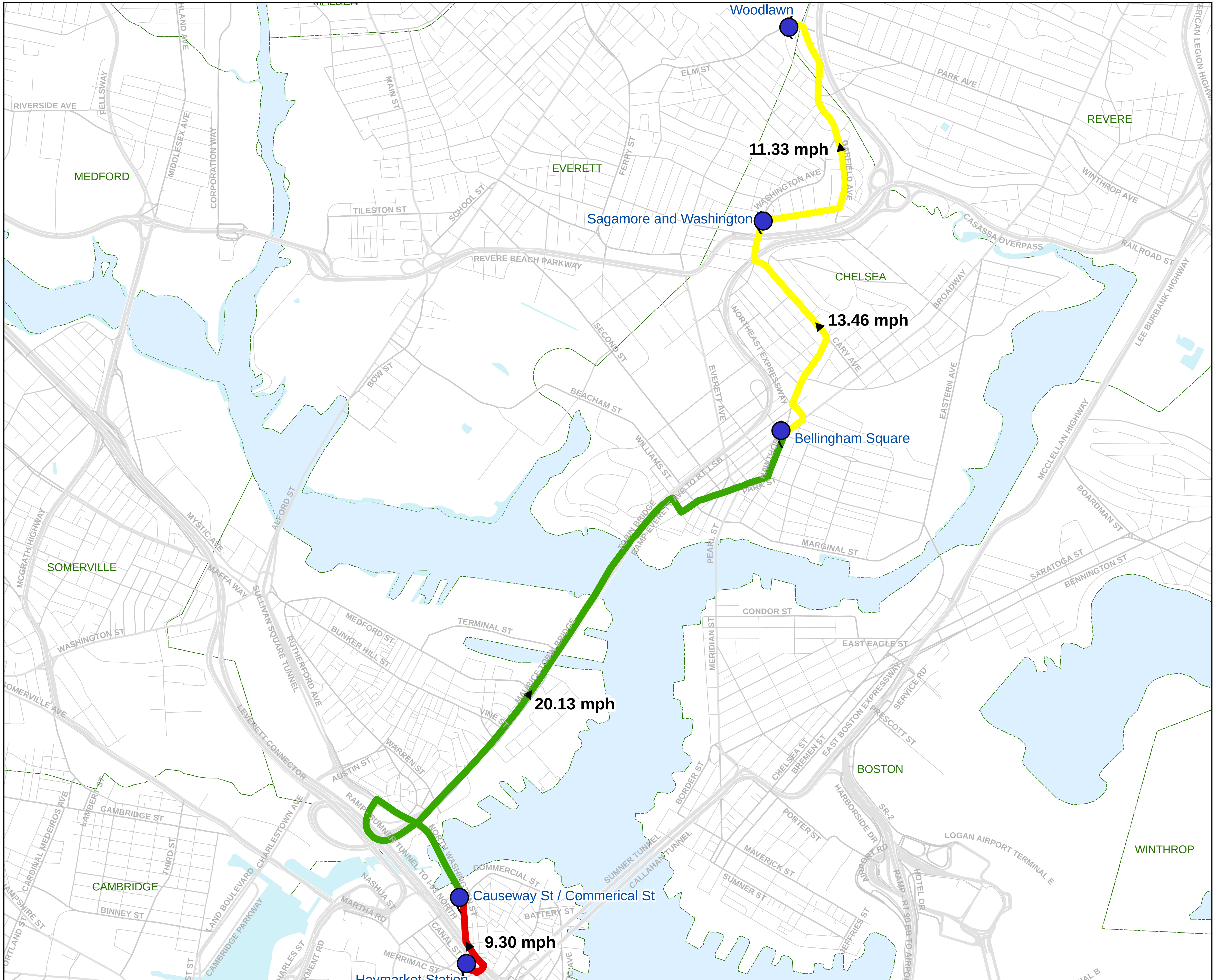

FIGURE 4
MBTA Bus Route 111
Average Travel Speeds:
AM Peak Period (6:00 - 10:00 AM)
Outbound

LEGEND

- Timepoint
- 0 – 10 mph
- 11 – 20 mph
- > 20 mph

Travel speed data estimated from the delay data provided by the MBTA AVL System for May 2009.

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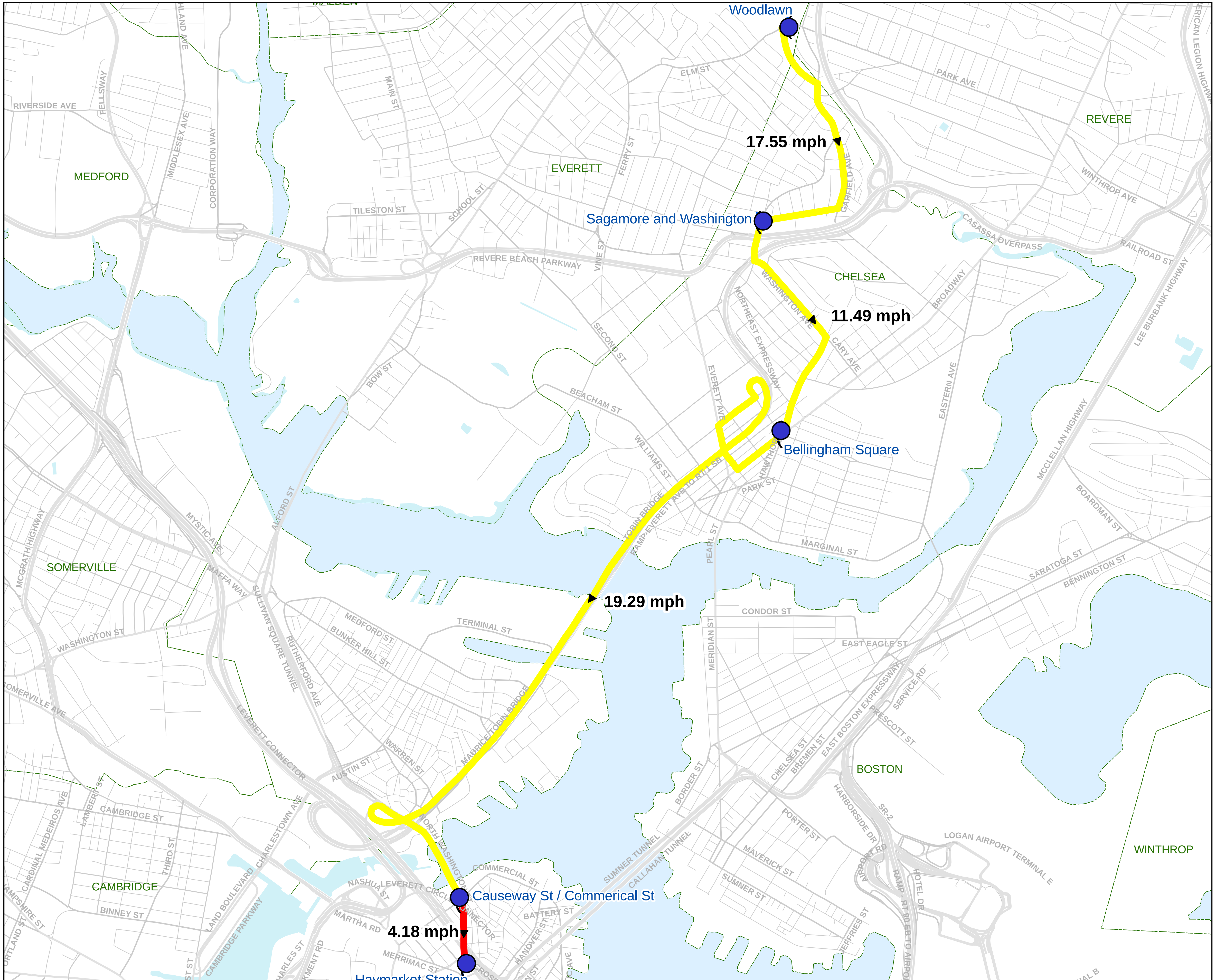

FIGURE 5
MBTA Bus Route 111
Average Travel Speeds:
PM Peak Period (3:00 - 6:00 PM)
Inbound

LEGEND

- Timepoint
- 0 – 10 mph
- 11 – 20 mph
- > 20 mph

Travel speed data estimated from the delay data provided by the MBTA AVL System for May 2009.

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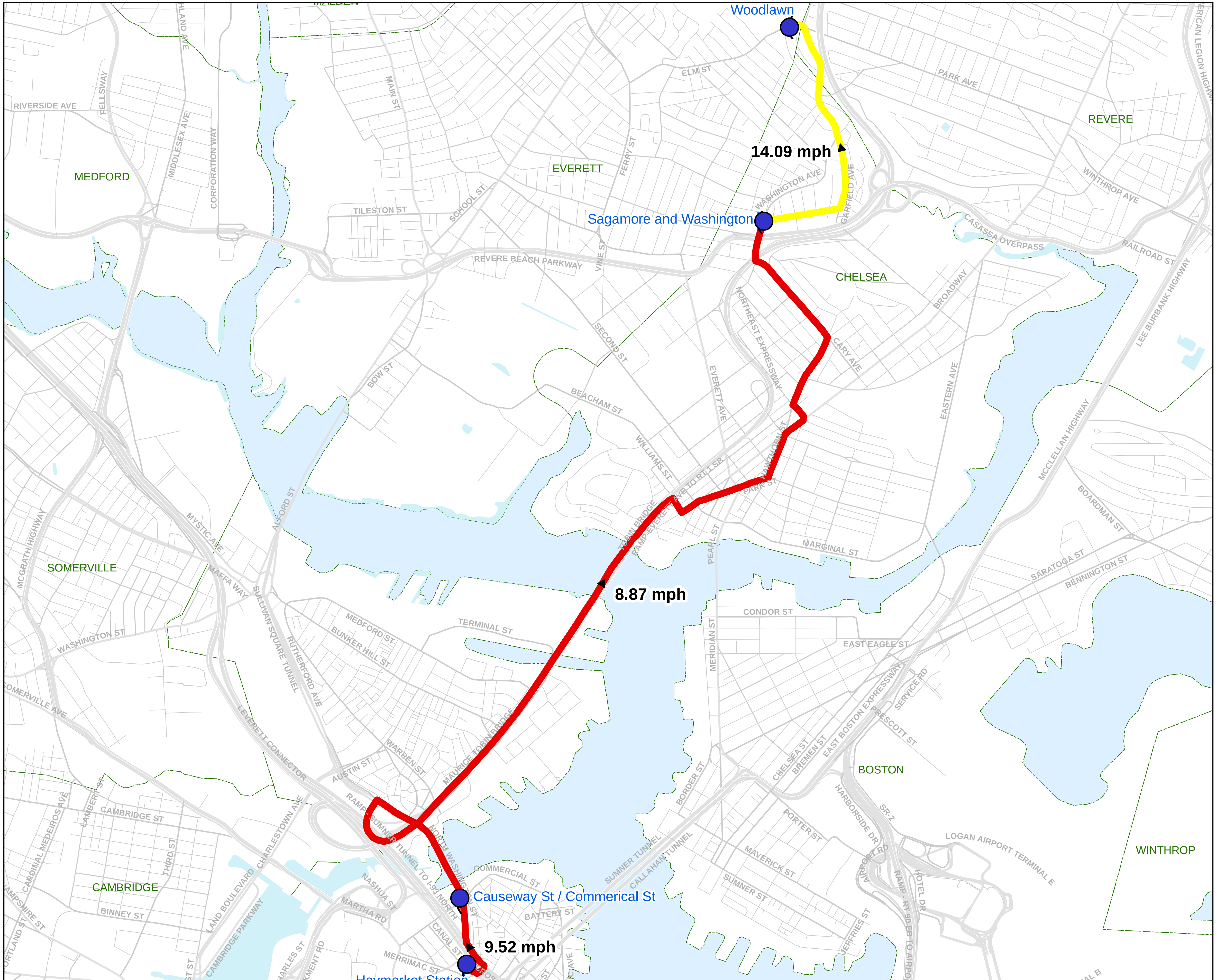

FIGURE 6
MBTA Bus Route 111
Average Travel Speeds:
PM Peak Period (3:00 - 6:00 PM)
Outbound

LEGEND

- ● Timepoint
- Red line: 0 – 10 mph
- Yellow line: 11 – 20 mph
- Green line: > 20 mph

Travel speed data estimated from the delay data provided by the MBTA AVL System for May 2009.

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between Haymarket Station and Causeway Street at Commercial Street consistently had some of the slowest travel speeds. The route segment passing through and north of Bellingham Square also had relatively slow speeds.

Bus Boardings and Alightings

Daily boardings of and alightings from the bus by stop and direction can be found in Appendix C in Tables C-1, Inbound Stops and Load Profiles, and C-2, Outbound Stops and Load Profiles. It should be noted the information is provided by bus stop and not by signalized intersection as in the tables found in Appendix B.

INTERSECTION SCREENING

Bus Route 111 has 11 signalized intersections along its inbound route and 13 along its outbound route. In the work completed in the 2009 Key Bus Routes Initiative, all of these intersections were preliminarily evaluated to see if TSP or other strategies could possibly improve bus service. All of the intersections are listed in Appendix D, with the preliminary recommendations that were made at that time. Recommendations were made for five signalized intersections with bus stops:

Inbound

- Sagamore Avenue at Washington Street (Chelsea) – Green extension/early green
- Third Street/Everett Avenue at Chestnut Street (Chelsea) – Queue jump

Outbound

- Haymarket Square at New Sudbury Street (Boston) – Green extension/early green
- North Washington Street at Thacher Street (Boston) – Queue jump
- Garfield Avenue/Washington Avenue at Fenno Street (Chelsea) - Green extension/early green

In addition to examining the findings of the 2009 Key Routes Initiative, the present study conducted a further qualitative-analysis screening of the intersections. The MBTA, the MBTA's consultants, the Boston Transportation Department, and MPO staff reviewed the following items to identify the intersection locations that should be analyzed:

- Overall intersection congestion
- Type of signal system available
- Side street volume and congestion
- Location of intersection along bus route
- Locations of bus stops
- Adjacent parking and land use
- Roadway speeds

The following intersections were chosen to be analyzed in the present study for TSP or other improvements in both the inbound and outbound route directions:

- New Sudbury Street at southbound Surface Artery
- New Sudbury Street at Cross Street
- North Washington Street at Thacher Street
- North Washington Street at Causeway Street
- Washington Street at Revere Beach Parkway
- Garfield Avenue/Washington Avenue at Fenno Street

EXISTING CONDITIONS AND THREE ALTERNATIVES: ANALYSIS OF TRAFFIC OPERATIONS AND OTHER TRAVEL CHARACTERISTICS

Traffic operations at the six intersections selected through the screening process were analyzed using Synchro 7,[2] data provided by the Boston Transportation Department, and data collected by MPO staff in the field. Analysis was conducted for the existing intersection conditions and for three alternatives, as described below. Tabulations of the analysis results can be found in Appendix E in Tables E-1 and E-2 for the AM (7:00 AM to 9:00 AM) and PM (4:00 PM to 6:00 PM) peak hours, respectively.

The following scenarios were examined:

- **Existing Conditions –** Existing signal timings and phasing were used to evaluate the operations of the intersection and provide a basis for comparing the alternatives.
- **Alternative 1 (Optimized Intersection Timings) –** Signal timings and phasings were optimized and checked to evaluate whether new signal timings would improve bus service by decreasing intersection delays. Some intersection timings are already optimal or are very close to optimal. In these cases no recommendations are made.
- **Alternative 2 (Added Green Time on Bus Approaches) –** Signal timings were adjusted to favor the Route 111 bus approaches and decrease bus delays. This alternative usually has various levels of impact on the operations of the non-bus approaches, depending on the amount of additional green time allocated to the bus approach signal phases. Typically, several seconds were added to the bus approach phases. This additional time was taken away from the side street phases and other underutilized phases.
- **Alternative 3 (Transit Signal Priority and Queue Jumps) –** Early green and green extensions were simulated to evaluate the benefits of TSP for the Route 111 bus. Queue jumps were also analyzed as part of this alternative. Where applicable, signal timings were optimized as a part of the queue jump or TSP evaluation.

The Synchro analysis and observations of the intersections were used to assess these scenarios in terms of intersection level of service, bus service, and other characteristics. The results in those three respects are presented in the following three sections.

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[2] Synchro 7 – Trafficware traffic analysis software, version 7.

INTERSECTION LEVEL OF SERVICE

Existing Conditions

The results of the existing conditions analysis indicate that all intersections are operating at level of service (LOS) D or better except for one. The North Washington Street at Causeway Street intersection is operating at LOS E during the PM peak hour.

Alternative 1: Optimized Intersection Timings

In the analysis of Alternative 1 it was found that, at the majority of the intersections, the LOS did not change significantly for individual approaches or the overall intersection, indicating that the existing timings and phasings are optimal or very nearly optimal at those intersections. The exceptions are as follows. During the PM peak hour the signal at North Washington at Causeway Street could be retimed to reduce total intersection delay. In the AM and PM peak hours, optimizing intersection timings at Garfield Avenue at Fenno Street decreases delay for Route 111 approaches. In the AM peak hour at the intersection of North Washington Street at Causeway Street, optimizing intersection timings benefits both the Route 111 approaches and the side street approaches. This comes at some cost to the vehicles turning left onto Causeway Street.

Alternative 2: Added Green Time on Bus Approaches

This alternative, adding green time to bus approaches at intersections, is beneficial at the intersections of New Sudbury Street with the Surface Artery and Cross Street, and at the North Washington Street at Causeway Street intersection. However, in the PM peak hour, the LOS of the North Washington Street at Causeway Street intersection decreases from E to F. Adding green time to the bus approach at Washington Avenue at Revere Beach Parkway does not significantly affect Revere Beach Parkway. Overall delay at Garfield Avenue at Fenno Street decreases when the bus approaches receive more time. This alternative frequently impacted side street traffic.

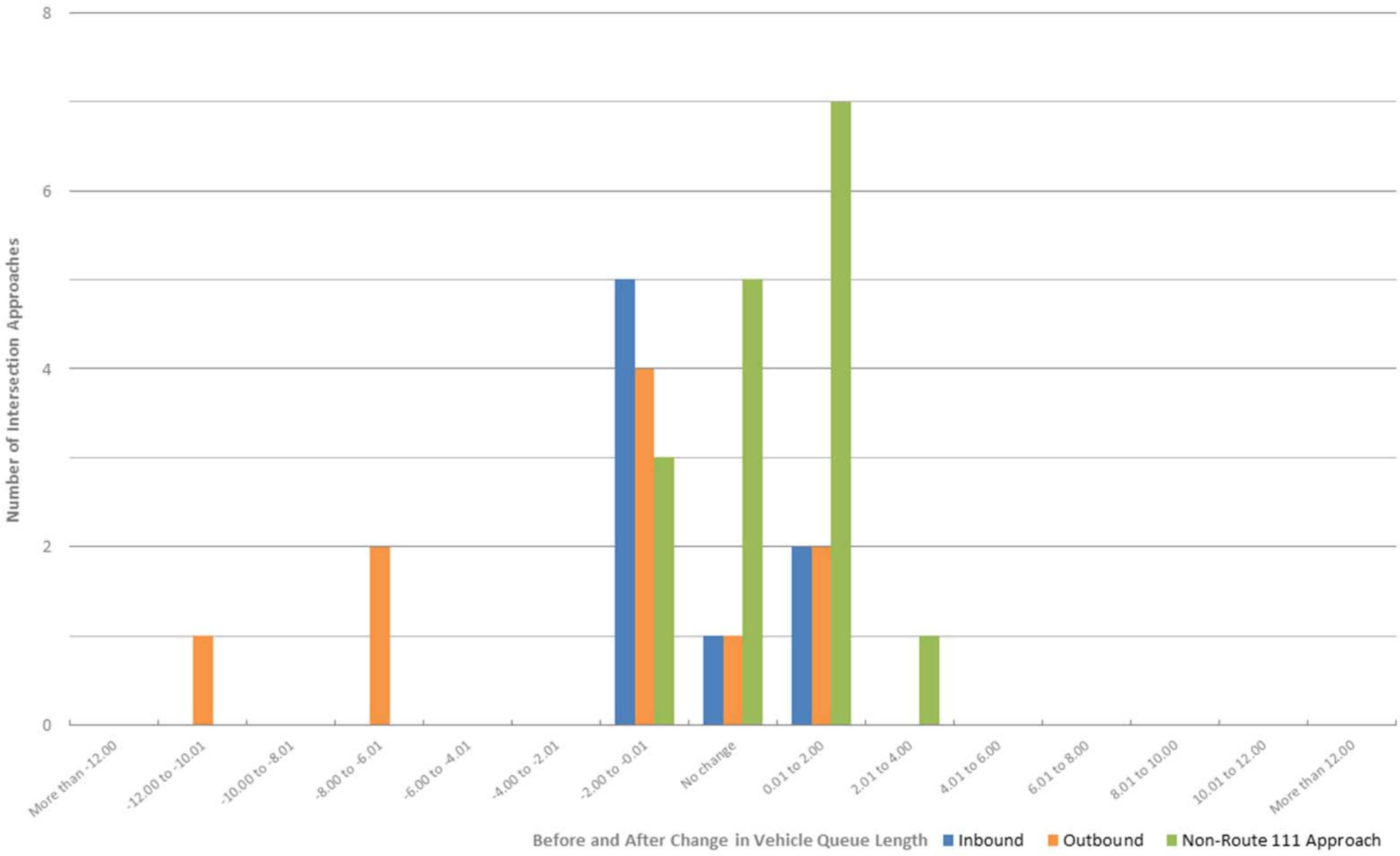
Alternative 3: Transit Signal Priority and Queue Jumps

The intersections that were analyzed simulating TSP improvements also had decreased delay for the buses. However, as in Alternative 2, there were frequently impacts to the side street traffic. There were also minor improvements to bus approach queue lengths. Figure 7 presents the various amounts of change in vehicle queue length that occurred and the number of approaches that experienced each amount.

For 11% of the bus approaches, queue length remained unchanged with all of the recommended TSP treatments; for 50% of the bus approaches, it decreased by two or fewer vehicles; and for 22% of the bus approaches it increased by two or fewer vehicles. Of the non-bus approaches, 31% had no queue changes due to the treatments, 19% had a two-vehicle or less decrease, and 44% had a two-vehicle or less increase.

FIGURE 7 Route 111 RecommendedTreatments AM and PM Peak Hour

Change in Vehicle Queue Length by Number of Intersection Approaches due to Recommended Treatments



BUS SERVICE: IMPACTS OF THE POTENTIAL IMPROVEMENTS

The impacts on bus service that would result from implementation of all of the potential improvements in the three alternatives combined were estimated.

Bus Delays

Under existing conditions, in the outbound direction, the bus delay was 27% higher in the afternoon compared to the morning. In the inbound direction, buses experienced 33% less delay in the afternoon compared to the morning.

Implementing transit signal priority or modifying signal timings for intersections along Route 111 can decrease bus delay. Information about the number of peak-hour Route 111 buses can be found in Table 1; Table 2 gives the passenger delays and bus delays under existing conditions and with implementation of all of the possible improvements from the three alternatives.

TABLE 1
Number of Peak Hour Buses and Passengers

Period/Direction	Buses	Passengers
AM Inbound	11	193
AM Outbound	12	703
PM Inbound	12	694
PM Outbound	10	487

TABLE 2
Peak Hour Bus and Passenger Delays (in Minutes)

Period and Direction	Existing	Recommended Improvements[1]	Existing Delays per Bus[2]	Delays with Improvements per Bus[3]	Absolute Change	Relative Change
AM Inbound						
Total Passenger-Minutes of Peak Hour Delay	629.3	548.4	52.4	45.7	-6.7	-12.9%
Total Bus-Minutes of Peak Hour Delay	22.3	18.1	1.9	1.5	-0.3	-18.7%
AM Outbound						
Total Passenger-Minutes of Peak Hour Delay	306.9	250.7	27.9	22.8	-5.1	-18.3%
Total Bus-Minutes of Peak Hour Delay	32.0	26.5	2.9	2.4	-0.5	-17.0%
PM Inbound						
Total Passenger-Minutes of Peak Hour Delay	244.2	218.4	24.4	21.8	-2.6	-10.6%
Total Bus-Minutes of Peak Hour Delay	15.0	13.2	1.5	1.3	-0.2	-11.7%
PM Outbound						
Total Passenger-Minutes of Peak Hour Delay	1,439.1	1,074.7	119.9	89.6	-30.4	-25.3%
Total Bus-Minutes of Peak Hour Delay	40.4	31.4	3.4	2.6	-0.8	-22.3%

1. Recommended improvements include intersection signal timing modifications, new lane configurations, TSP, and queue-jumps.
2. Existing delays divided by the number of buses per hour
3. Delays with the recommended improvements divided by the number of buses per hour.

With the improvements, in the outbound direction, total bus delay decreases by approximately 17% in the morning and 22% in the afternoon; in the inbound direction, total bus delay decreases by 18% in the morning and 12% in the afternoon.

Bus Travel Times

Directional, peak-hour travel times for Route 111 vary from 20 to 43 minutes. Given that buses were only delayed by a few minutes due to the traffic signals included in this analysis, travel time savings from the potential improvements are relatively small in magnitude. It is likely that only 10 to 50 seconds of travel time per peak-hour directional trip would be saved through decreased delay at traffic signals.

Eliminating the inbound stop at Washington Avenue at Revere Beach Parkway would help reduce travel time. Currently this intersection has a 140-second cycle length with 30 seconds of green time for the Route 111 approaches. If the bus arrives when the light is green, stopping to drop off or pick up passengers will probably cause the bus to miss its chance to go through the intersection. If the bus arrives at a red, regardless of whether it stops to pick up and drop off passengers, it will still have to wait a fairly long time for a green. If there is a queue built up from the red light, the bus may have to wait through two cycles before passing through the intersection. Eliminating the stop would help keep buses moving through this intersection.

Passenger Delay

Passenger-minutes of delay for a single intersection were calculated by multiplying the number of passengers on a bus as it passed through an intersection by the amount of delay the bus incurred at the intersection. To find the total passenger delay in a given direction during a given time period, the passenger delays at all of the intersections were summed.

Applying signal priority, modified signal timings, and modified signal phasings decreases outbound passenger delay by 18% in the AM peak hour and by 25% in the PM peak hour. These treatments decrease inbound passenger delay by 13% in the AM peak hour and by 11% in the PM peak hour.

Bus Stops

Elimination of two of the stops on Route 111 should be considered. One is the inbound bus stop at the intersection of Washington Avenue at Revere Beach Parkway. Moving the stop to the far side of the intersection would put it far too close to the subsequent bus stop, so it would be preferable to simply eliminate it. Moving the outbound bus stop to the far side of the intersection would be worthwhile, except that the resulting distance between bus stops would be far too small. The outbound stop should remain at or near its current location.

The other stop for which elimination should be considered is North Washington at Thacher Street. In order to add an extra through lane at the intersection, the bus stop must be removed. The number of passengers who board or alight at this intersection is small, and this bus stop is frequently blocked by illegally parked vehicles.

OTHER IMPACTS OF THE POTENTIAL IMPROVEMENTS

Other impacts that would result from implementation of all of the potential improvements in the three alternatives combined were estimated.

General-Traffic Travel Times

On average, with implementation of the improvements, general traffic traveling along Route 111's route (in other words, using the same approach as the bus at each intersection) is delayed less at intersections. When a bus receives traffic signal priority, other vehicles traveling along that road also receive extra green time. Other modifications consistently provide more green time to the bus approach regardless of whether a bus is present. The delays for vehicles traveling on the same approach as Route 111 buses are shown in Table 3 for existing conditions and with the recommended improvements. Total vehicle delay for general traffic traveling along the route is expected to decrease by about 25% in the outbound direction and 12% in the inbound direction.

Actuating the intersection of Garfield Avenue and Fenno Street decreases the delay for all of the approaches in the afternoon without significantly increasing delay for the side street. This intersection tends to provide green time to approaches where there are no vehicles present. Letting this intersection stay on green on the main approach except during actuation would help keep traffic moving smoothly through the intersection.

A potential action to consider that would assist general traffic is fully actuating the intersection of North Washington Street at Commercial Street. Because this would increase delay for inbound buses in the afternoon, it is not included in the present study's recommendations. This modification would help improve operations at the intersection, which has a long cycle length (150 seconds). The southbound direction receives a longer green time than it needs for many of its cycles. By letting this approach gap out earlier, the other directions could be served earlier.

Another option deserving consideration though not recommended here is actuating the dedicated bus signal outside Haymarket Station. Presently, the bus driveway receives a green signal each cycle regardless of whether a bus is there or not. This causes vehicles on the southbound and eastbound approaches to wait for no apparent reason. The signal timings at this intersection could be changed to allow buses to trigger this phase, which would give currently unused green time back to the other two approaches.

TABLE 3
Total Peak-Hour Vehicle Delay for General Traffic on Route 111
(Total Vehicle-Minutes at All Intersection Approaches Used)

Period and Direction	Existing	Recommended Improvements[1]	Absolute Change	Relative Change
AM Inbound				
	1,217	1,055	162.3	-13.3%
AM Outbound				
	863	660	203.4	-23.6%
PM Inbound				
	677	607	70.0	-10.3%
PM Outbound				
	1,299	926	373.4	-28.7%

1. Recommended improvements to intersections include intersection signal timing modifications, new lane configurations, TSP, and queue jumps.

Parking

Parking is not expected to change. If the bus stop at North Washington Street at Thacher Street were to be removed, four parking spaces could be added. Because the extra lane helps bus travel times, adding parking is less preferable from a transit standpoint.

Pedestrian

Pedestrians are mostly unaffected by the changes proposed in this memorandum. Dedicated pedestrian phases are not modified. In a few cases, concurrent pedestrian phases are lengthened along the main road and shortened on the side streets. Pedestrians would still have enough time to cross the main road. Pedestrian movements are set to end normally when an extended phase is called for; that is, the pedestrian phase ends when it usually would end, and pedestrians are shown a solid “don’t walk” signal during the extended phase. In these cases, side street pedestrians wishing to cross the main road would have to wait a few seconds longer to receive a walk signal than usual.

RECOMMENDATIONS AND FINDINGS

Table 4 lists the improvements that are recommended. These are the improvements which this study’s analysis showed to provide the greatest benefit for bus route operations. They are drawn from all three of the alternatives.

Several of the intersections are good candidates for immediate improvements. Two of the options are low-cost, and two of the options could be moderately expensive depending on the current signal controller capabilities.

TABLE 4
Recommended Improvements

Intersection	Municipality	Recommended Improvement
New Sudbury Street at Surface Artery	Boston	• Actuate MBTA phase during off-peak • Synchronize with New Sudbury at Cross Street • Retime signal
New Sudbury at Cross Street	Boston	• Synchronize with New Sudbury at Surface Artery • Retime signal
N. Washington Street at Thacher Street	Boston	• If stop at Thacher Street is removed, replace bus stop with an additional through lane
N. Washington Street at Causeway Street	Boston	• Fully actuate signal with new timings during AM peak hours
Washington Avenue at Revere Beach Pkwy	Chelsea	• Remove inbound bus stop at Revere Beach Parkway
Garfield Ave./Wash. Ave. at Fenno Street	Chelsea	• Fully actuate signal during AM/PM peak hours

Synchronizing the intersections of *New Sudbury Street at Surface Artery* (just outside of Haymarket Station) and the following intersection, *New Sudbury Street at Cross Street,* would help smooth out the initial portion of outbound trips. Because so many passengers are riding Route 111 buses through these intersections, changes concentrated at these locations will improve time savings for a large volume of riders. Currently, the *MBTA driveway* receives a dedicated phase during each cycle. As mentioned above, this phase is not used by any buses during many cycles, and other vehicles have to wait for no apparent reason. Setting this phase to an actuated phase with New Sudbury Street receiving any extra time would help to decrease delay for the main movements. However, this decreases the green time available to MBTA buses, which is not favorable. Therefore, it is recommended that the MBTA driveway always receive a green signal as part of the cycle during the morning and afternoon peak hours, but not during the off-peak hours. This solution would be fairer to other approaches, while still providing buses smooth egress from the terminal.

If the bus stop at *North Washington Street and Thacher Street* is removed, it should be converted to another northbound through lane rather than to parking. Adding another lane would help decrease the queues heading northbound on North Washington Street. Buses would pick up passengers only after crossing the intersection at Commercial Street.

In Chelsea, fully actuating the intersection of *Garfield Avenue/Washington Avenue at Fenno Street* would help improve the intersection’s performance for all its users, buses included. Currently, green time is given to Washington Avenue even when no vehicles access the intersection. This improvement is likely the most costly of the recommended improvements, because the intersection would probably need a new controller.

Adding green extensions at *Washington Avenue at Revere Beach Parkway* would also decrease delay for Route 111 buses traveling along Washington. Revere Beach Parkway's delays and queues are not expected to be significantly affected. Eliminating the inbound near-side bus stop at this intersection would go a long way towards reducing delay there. Frequently, the bus must serve this stop during the green signal phase. This causes the bus to have to wait approximately a minute to a minute and a half until the next green light. An intermediate and very cost-effective measure would be to simply remove the bus stop and see if operations at this intersection improve. The next-nearest bus stops are approximately 325 feet away in each direction.

In the morning, fully actuating the signal at *North Washington Street at Causeway Street* would improve the overall level of service at the intersection from D to C. Both bus approaches are also improved. In the afternoon, however, although nearly 20 seconds of total intersection delay is eliminated, some of the benefit comes at a cost to a bus approach. Therefore, actuating the signal in the morning but not in the afternoon is recommended.

MSA/SA/msa/sa

Attachments

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APPENDIX A

Examples of TSP Benefits

TABLE A-1 Reported Initial Estimates of Benefits to Buses from Traffic Signal Priority

Location	% Running Time Saved	% Increase in Speeds	% Reduced Intersection Delay
Anne Arundel County, MD	13–18	-	-
Bremerton, WA	10	-	-
Chicago: 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: Rainier Avenue	8	-	13
Toronto	2–4	-	-

Sources: Research and Innovative Technology Administration (RITA), Intelligent Transportation Systems website, which cites: TCRP Report 100 (2003); TCRP Report 90 (2003); TRR 1841 (2003)[3]

[3] TCRP Report 100, Transit Capacity and Quality of Service Manual 2nd Edition, Washington, DC, 2003. TCRP Report 90, Bus Rapid Transit Volume 1: Case Studies in Bus Rapid Transit, Washington, DC, 2003. Transportion Research Record 1841, "Evaluation of Service Reliability Impacts of Traffic Signal Priority Strategies for Bus Transit," Transportation Research Board of the National Academies, Washington, DC, 2003, pp. 23–31.

TABLE A-2 ITS America's Summary of TSP Benefits and Impacts

Location	Transit	# of Intersections	TSP Type	Strategy Benefit/Impact
Portland, OR: Tualatin Valley Hwy	Bus	10	Early green, green extension	Bus travel time savings = 1.4%–6.4%. Average bus signal delay reduction = 20%.
Portland, OR: Powell Blvd	Bus	4	Early green, green extension, queue jump	5%–8% bus travel time reduction. Bus person delay generally decreased. Inconclusive impacts of TSP on traffic.
Seattle: Rainier Ave at Genesee	Bus	1	Early green, green extension	For prioritized buses: • 50% reduction of signal-related stops. • 57% reduction in average signal delay. 13.5% decrease in intersection average person delay. Average intersection delay did not change for traffic. 35% reduction in bus travel time variability. Side street effects insignificant.
Seattle: Rainier Ave (Midday)	Bus	3	Early green, green extension	For TSP-eligible buses: • 24% average reduction in stops for eligible buses. • 34% reduction in average intersection delay. 8% reduction in travel times. Side street drivers do not miss green signal when TSP is granted to bus.
Europe	Bus	5 study sites		10 seconds/intersection average signal delay reduction. 40%–80% potential reduction in transit signal delay. Transit travel times in England and France reduced 2%–6%.
Sapporo City, Japan: Rt 36	Bus	Unknown		6.1% reduction in bus travel time. 9.9% increase in ridership.
Toronto	Streetcar	36	Early green, green extension	15%–49% reduction in transit signal delay. One streetcar removed from service.
Chicago: Cermak Rd	Bus	15	Early green, green extension	7%–20% reduction in transit travel time. Transit schedule reliability improved. Reduced number of buses needed to operate the service. Passenger satisfaction level increased. 1.5 seconds/vehicle average decrease in vehicle delay. 8.2 seconds/vehicle average increase in cross-street delay.
San Francisco	LRT & Trolley	16	Early green, green extension	6%–25% reduction in transit signal delay.
Minneapolis: Louisiana Ave	Bus	3	Early green, green extension, actuated transit phase	0%–38% reduction in bus travel times depending on TSP strategy. 23% (4.4 seconds/vehicle) increase in traffic delay. Skipping signal phases caused some driver frustration.
Los Angeles: Wilshire and Ventura Blvd	Bus	211	Early green, green extension, actuated transit phase	7.5% reduction in average running time. 35% decrease in bus delay at signalized intersections.

Source: Transit Cooperative Research Program (TCRP) Report 118, *Bus Rapid Transit Practitioner's Guide,* 2007.

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APPENDIX B

Bus Route Intersections, Bus Movement, and Stop Locations

TABLE B-1 Locations of Traffic Signals and Bus Stops: Inbound

Signalized Intersection	Bus Movement	Stop Location
Chelsea		
Washington Street/Garfield Avenue at Fenno Street	Through	
Sagamore Avenue at Washington Avenue	Left	Near-side
Washington Avenue at Revere Beach Parkway	Through	Near-side
Washington Avenue at Cary Avenue/Gardner Street	Right	Mid-block
Washington Avenue at Broadway	Through	Far-side
Third Street/Everett Avenue at Chestnut Street	Through	Far-side
Boston		
Ramp from Route 1 at New Rutherford Avenue	Right	
Rutherford Avenue at Chelsea Street	Through	
North Washington Street at Causeway Street/Commercial Street	Through	
North Washington Street at Thacher Street	Through	Near-side
North Washington Street at Market Street	Through	

TABLE B-2 Locations of Traffic Signals and Bus Stops: Outbound

Signalized Intersection	Bus Movement	Stop Location
Boston		
Haymarket Square at New Sudbury Street	Left	
New Sudbury Street at Cross Street	Left	
Cross Street/North Washington Street at Cooper Street	Through	
North Washington Street at Thacher Street	Through	Mid-block
North Washington Street at Causeway Street/Commercial Street	Through	Far-side
Rutherford Avenue at Chelsea Street	Through	
New Rutherford Avenue at Ramp to Route 1	Left	
Chelsea		
Broadway/Park Street at Williams Street	Through	Far-side
Hawthorne Street/Broadway at Washington Street	Through	Near-side
Washington Avenue at Cary Avenue/Gardner Street	Left	Near-side
Washington Avenue at Revere Beach Parkway	Through	
Washington Avenue at Sagamore Avenue	Right	Far-side
Garfield Avenue/Washington Avenue at Fenno Street	Through	Near-side

APPENDIX C

Bus Boardings and Alightings

TABLE C-1 Inbound Stops and Load Profiles

Stop Name	Ons	Offs
Everett		
BOL Dummy	0	0
Elm Street at Haskell Avenue	101	4
Chelsea		
60 Woodlawn Avenue	17	0
Woodlawn Avenue at Washington Avenue	23	1
Washington Avenue at Prospect Avenue	55	3
Washington Avenue at Annese Road	77	2
Garfield Avenue at Exeter Street	188	1
78 Garfield Avenue opposite Clyde Street	48	0
Sagamore Avenue at Jones Avenue	143	3
Sagamore Avenue at Murray Street	84	2
Sagamore Avenue at Washington Avenue	274	15
Washington Avenue at Revere Beach Parkway	46	5
Washington Avenue at Reynolds Avenue	83	34
296 Washington Avenue opposite Jefferson Avenue	84	4
Washington Avenue at Carmel Street	178	6
Washington Avenue at Spruce Street	154	11
Washington Avenue at Cary Avenue	266	22
Washington Avenue at Bloomingdale Street	89	9
Washington Avenue at Heard Street	113	68
Washington Avenue at Chestnut Street	136	66
Washington Avenue at Broadway	798	237
Broadway at Fourth Street	346	119
Everett Avenue at Chestnut Street	535	96
Arlington Street at Fifth Street	166	15
Boston		
North Washington Street at Medford Street	49	236
Haymarket Station	0	3230
EOL Dummy	0	0

TABLE C-2 Outbound Stops and Load Profiles

Stop Name	Ons	Offs
Boston		
BOL Dummy	0	0
Haymarket Station	3526	0
North Washington Street at Thacher Street	10	0
North Washington Street at Commercial Street	24	2
Chelsea		
Beacon Street at Broadway	14	222
Park Street at Williams Street	39	166
Park Street at Cross Street	27	327
Park Street at Hawthorne Street	50	381
Hawthorne Street at Broadway	445	971
City Hall at Broadway	33	121
Washington Avenue at Crescent Avenue	55	163
125 Washington Avenue opposite Orange Street	9	98
Washington Avenue at Cary Avenue	51	314
Washington Avenue at Spruce Street	5	137
Washington Avenue opposite Carmel Street	4	162
Washington Avenue at Jefferson Avenue	8	163
325 Washington Avenue	16	66
Sagamore Avenue at Washington Avenue	14	247
Sagamore Avenue at Murray Street	4	109
Sagamore Avenue at Garfield Avenue	8	123
Garfield Avenue at Clyde Street	3	64
137 Garfield Avenue opposite Bell Street	4	165
Garfield Avenue at Fenno Street	2	64
Washington Avenue at Columbus Street	2	51
Washington Avenue at Woodlawn Avenue	0	29
Revere		
Washington Avenue at Arnold Street	0	25
Washington Avenue at Park Avenue	0	93
EOL Dummy	0	3

APPENDIX D

Key Routes Initiative, Phase I:
Preliminary Recommendations for Intersections

Inbound Bus Routes

- Washington Avenue/Garfield at Fenno Street - No recommendation
- Sagamore Avenue at Washington Avenue (Chelsea) - Green extension/early green
- Washington Avenue at Revere Beach Parkway - No recommendation
- Washington Avenue at Cary Avenue/Gardner Street - No recommendation
- Washington Avenue at Broadway - No recommendation
- Third Street/Everett Avenue at Chestnut Street - Queue-jump
- Ramp from Route 1 at New Rutherford Avenue - No recommendation
- Rutherford Avenue at Chelsea Street - No recommendation
- North Washington Street at Causeway Street - No recommendation
- North Washington Street at Thacher Street - No recommendation
- North Washington Street at Market Street - No recommendation

Outbound Bus Routes

- Haymarket Square at New Sudbury Street - Green extension/early green
- New Sudbury Street at Cross Street - No recommendation
- Cross Street/North Washington Street at Cooper Street - No recommendation
- North Washington Street at Thacher Street - Queue-jump
- North Washington Street at Causeway Street - No recommendation
- Rutherford Avenue at Chelsea Street - No recommendation
- New Rutherford Avenue at Ramp to Route 1 - No recommendation
- Broadway/Park Street at Williams Street - No recommendation
- Hawthorne Street/Broadway at Washington Street - No recommendation
- Washington Avenue at Cary Avenue/Gardner Street - No recommendation
- Washington Avenue at Revere Beach Parkway - No recommendation
- Washington Avenue at Sagamore - No recommendations
- Garfield Avenue/Washington Avenue at Fenno Street - Green extension/early green

APPENDIX E

Peak-Hour Traffic Analysis
Using Synchro 7

TABLE E-1 AM-Peak-Hour Level-of-Service Summary

Intersection/Approach[1]	Mvmt	Existing Conditions				Alt. 1 (Intersect. Timings)				Alt. 2 (Bus Timings)				Alt. 3 (TSP)			
		LOS	Delay[2]	V/C	Q[3]	LOS	Delay[2]	V/C	Q[3]	LOS	Delay[2]	V/C	Q[3]	LOS	Delay[2]	V/C	Q[3]
Boston Intersections																	
New Sudbury at SB Surface										Sync. with Cross / **max.** MBTA (30s MBTA)				Sync. with Cross / **act.** MBTA (25s MBTA)			
New Sudbury St – EB	T	D	36.3	0.45	78	C	28.3	0.33	70	C	33.0	0.40	75	C	26.8	0.31	70
New Sudbury St – EB	R	C	31.9	0.10	0	C	25.8	0.10	0	C	29.6	0.10	0	C	24.6	0.10	0
Surface Arterial – SB	LT	C	23.2	0.36	94	C	25.6	0.39	98	C	26.5	0.40	101	B	17.5	0.30	80
MBTA Driveway – SB	**LTR**	**C**	**31.5**	**0.15**	**14**	**D**	**36.6**	**0.18**	**15**	**C**	**30.6**	**0.14**	**14**	**D**	**53.8**	**0.56**	**17**
Overall		**C**	**29.0**	**0.32**	**–**	**C**	**26.9**	**0.32**	**–**	**C**	**29.2**	**0.32**	**–**	**C**	**22.7**	**0.32**	**–**
New Sudbury at Cross																	
New Sudbury St – EB	**L**	**A**	**7.3**	**0.32**	**10**	**A**	**7.0**	**0.32**	**20**	**A**	**2.4**	**0.21**	**11**	**A**	**4.9**	**0.27**	**12**
Cross St – NB	LTR	B	10.6	0.54	175	B	10.6	0.54	175	B	18.5	0.29	257	B	10.3	0.62	205
Overall		**A**	**9.7**	**0.44**	**–**	**A**	**9.6**	**0.44**	**–**	**B**	**14.1**	**0.44**	**–**	**A**	**8.8**	**0.44**	**–**
N. Washington at Thacher														Replace bus stop with NBT			
North Washington St – NB	L	E	73.0	0.93	188	E	64.2	0.88	186	F	98.4	1.02	199	E	73.0	0.93	188
North Washington St – NB	**TR**	**B**	**15.2**	**0.75**	**262**	**B**	**16.3**	**0.76**	**272**	**B**	**13.4**	**0.73**	**241**	**A**	**7.0**	**0.37**	**88**
North Washington St – SB	**LTR**	**B**	**10.8**	**0.68**	**214**	**B**	**11.6**	**0.70**	**224**	**A**	**9.4**	**0.66**	**196**	**B**	**10.7**	**0.68**	**214**
Overall		**B**	**19.2**	**0.79**	**–**	**B**	**19.0**	**0.79**	**–**	**C**	**20.8**	**0.79**	**–**	**B**	**16.9**	**0.74**	**–**
N. Washington at Causeway														Fully actuated & new timings			
Causeway St – EB	L	E	63.4	0.52	138	F	82.8	0.71	147	E	63.4	0.52	138	E	57.7	0.70	116
Causeway St – EB	TR	E	59.2	0.47	106	E	71.8	0.66	114	E	59.2	0.47	106	D	51.6	0.65	90
Commercial St – WB	L	F	132.6	1.03	246	E	74.8	0.76	222	F	132.6	1.03	246	E	55.3	0.76	177
Commercial St – WB	T	E	77.8	0.70	161	E	61.4	0.52	152	E	77.8	0.70	161	D	44.1	0.52	121
Commercial St – WB	R	C	25.9	0.39	180	C	24.6	0.38	174	C	29.5	0.42	192	B	18.2	0.38	137
North Washington St – NB	**TR**	**E**	**63.0**	**0.77**	**182**	**D**	**54.4**	**0.66**	**173**	**D**	**54.4**	**0.66**	**173**	**D**	**47.3**	**0.76**	**146**
North Washington St – SB	L	D	53.1	0.71	338	E	62.5	0.79	355	E	62.5	0.79	355	D	51.7	0.83	288
North Washington St – SB	**T**	**C**	**24.5**	**0.68**	**453**	**C**	**24.5**	**0.68**	**455**	**C**	**24.5**	**0.68**	**455**	**C**	**21.8**	**0.73**	**398**
North Washington St – SB	R	B	26.6	0.67	370	C	26.6	0.67	370	B	26.6	0.67	370	C	22.9	0.71	324
Overall		**D**	**46.3**	**0.75**	**–**	**D**	**43.2**	**0.72**	**–**	**D**	**46.3**	**0.72**	**–**	**C**	**34.9**	**0.74**	**–**

TABLE E-1 cont. AM-Peak-Hour Level-of-Service Summary

Intersection/Approach[1]	Mvmt	Existing Conditions				Alt. 1 (Intersect. Timings)				Alt. 2 (Bus Timings)				Alt. 3 (TSP)			
		LOS	Delay[2]	V/C	Q[3]	LOS	Delay[2]	V/C	Q[3]	LOS	Delay[2]	V/C	Q[3]	LOS	Delay[2]	V/C	Q[3]
Chelsea Intersections																	
Wash. Ave at Rev. Bch. Pkwy						Existing timing optimal								IB G.Ext. (NB/SB)			
Revere Beach Pkwy – EB	L	F	118.2	1.01	141					F	129.2	1.04	149	F	145.0	1.08	147
Revere Beach Pkwy – EB	TR	C	25.5	0.57	191					C	26.4	0.57	199	C	28.7	0.59	191
Revere Beach Pkwy – WB	L	E	67.5	0.78	93					E	72.3	0.80	98	E	75.1	0.80	97
Revere Beach Pkwy – WB	TR	D	40.2	0.93	412					D	41.7	0.93	428	D	44.8	0.94	412
Washington Ave – NB	L	F	137.1	1.00	66					F	108.8	0.93	68	E	70.6	0.79	68
Washington Ave – NB	**TR**	**D**	**42.0**	**0.51**	**95**					**D**	**41.8**	**0.49**	**99**	**D**	**41.6**	**0.44**	**100**
Washington Ave – SB	**LTR**	**E**	**54.5**	**0.82**	**141**					**D**	**44.7**	**0.78**	**145**	**D**	**47.5**	**0.71**	**147**
Overall		**D**	**45.1**	**0.96**	**–**					**D**	**45.7**	**0.95**	**–**	**D**	**47.3**	**0.92**	**–**
Garfield/Wash. at Fenno														Fully actuate w/ 90sec. max CL			
Washington Ave – EB	LT	B	19.5	0.25	25	C	30.9	0.46	32	E	58.1	0.76	35	C	21.1	0.52	17
Washington Ave – EB	R	B	16.9	0.01	0	C	23.4	0.01	0	C	27.2	0.01	0	B	18.8	0.01	0
Garfield Ave – NB	L	B	13.8	0.08	3	A	8.5	0.05	2	A	6.5	0.04	1	A	8.0	0.05	1
Garfield Ave – NB	**TR**	**B**	**15.3**	**0.28**	**29**	**A**	**9.6**	**0.21**	**18**	**A**	**7.3**	**0.19**	**13**	**A**	**8.7**	**0.24**	**15**
Washington Ave – SB	**LT**	**C**	**21.6**	**0.63**	**77**	**B**	**12.6**	**0.47**	**49**	**A**	**9.5**	**0.42**	**35**	**B**	**10.6**	**0.53**	**39**
Washington Ave – SB	R	B	19.3	0.49	44	B	11.6	0.37	28	A	8.3	0.33	20	A	9.7	0.42	22
Overall		**B**	**19.4**	**0.47**	**–**	**B**	**14.1**	**0.47**	**–**	**B**	**15.2**	**0.47**	**–**	**B**	**11.4**	**0.53**	**–**

1. Route 111 approaches are shown in bold.
2. Delay is measured in seconds.
3. 50th percentile queue, measured in feet.

TABLE E-2 PM-Peak-Hour Level-of-Service Summary

Intersection/Approach[1]	Mvmt	Existing Conditions LOS	Delay[2]	V/C	Q[3]	Alt. 1 (Intersect. Timings) LOS	Delay[2]	V/C	Q[3]	Alt. 2 (Bus Timings) LOS	Delay[2]	V/C	Q[3]	Alt. 3 (TSP) LOS	Delay[2]	V/C	Q[3]
Boston Intersections																	
New Sudbury at SB Surface										Sync. with Cross/ **max.** MBTA (21sec. MBTA)				Sync. with Cross/ **act.** MBTA (21s MBTA)			
New Sudbury St – EB	T	B	19.4	0.53	171	C	22.8	0.57	186	C	27.6	0.65	204	C	22.3	0.56	191
New Sudbury St – EB	R	B	15.8	0.19	0	B	18.1	0.19	0	C	21.3	0.19	0	B	17.8	0.19	0
Surface Arterial – SB	LT	D	38.8	0.50	84	D	40.2	0.53	86	C	29.2	0.35	73	C	29.2	0.35	73
MBTA Driveway – SE	**LTR**	**D**	**51.4**	**0.49**	**37**	**D**	**40.3**	**0.38**	**34**	**D**	**51.4**	**0.49**	**37**	**E**	**70.4**	**0.77**	**38**
Overall		**C**	**25.1**	**0.51**	**–**	**C**	**27.1**	**0.51**	**–**	**C**	**28.3**	**0.51**	**–**	**C**	**25.7**	**0.51**	**–**
New Sudbury at Cross																	
New Sudbury St – EB	**L**	**B**	**11.0**	**0.61**	**47**	**A**	**8.5**	**0.61**	**32**	**A**	**6.3**	**0.61**	**28**	**B**	**19.5**	**0.61**	**62**
Cross St – NB	LTR	B	15.7	0.80	301	B	15.7	0.80	301	B	14.6	0.80	302	B	14.6	0.80	302
Overall		**B**	**14.0**	**0.69**	**–**	**B**	**13.0**	**0.69**	**–**	**B**	**11.5**	**0.69**	**–**	**B**	**16.4**	**0.69**	**–**
N. Washington at Thacher						Existing timings optimal								Replace bus stop with NBT			
North Washington St – NB	L	D	82.7	0.97	200					F	113.4	1.07	224	F	82.7	0.97	200
North Washington St – NB	**TR**	**B**	**25.7**	**0.90**	**393**					**C**	**21.8**	**0.87**	**362**	**A**	**7.7**	**0.45**	**111**
North Washington St – SB	**LTR**	**A**	**10.2**	**0.64**	**160**					**A**	**8.8**	**0.61**	**146**	**A**	**9.6**	**0.61**	**155**
Overall		**C**	**25.0**	**0.92**	**–**					**C**	**27.0**	**0.92**	**–**	**B**	**18.4**	**0.69**	**–**
N. Washington at Causeway														Fully actuated & new timings			
Causeway St – EB	L	E	69.9	0.65	179	F	89.6	0.81	186	E	75.5	0.71	181	D	54.4	0.70	135
Causeway St – EB	TR	E	61.1	0.57	153	E	70.6	0.70	160	E	64.2	0.61	156	D	48.0	0.61	116
Commercial St – WB	L	E	64.7	0.40	84	C	34.4	0.15	62	E	70.3	0.47	86	D	37.7	0.23	54
Commercial St – WB	T	E	70.9	0.58	131	D	35.5	0.22	97	F	80.8	0.68	134	D	38.7	0.34	85
Commercial St – WB	R	F	191.8	1.30	1029	E	68.5	1.01	801	F	223.7	1.37	1060	F	133.9	1.19	713
North Washington St – NB	**TR**	**D**	**47.4**	**0.61**	**226**	**E**	**69.0**	**0.87**	**257**	**D**	**42.5**	**0.55**	**214**	**D**	**45.1**	**0.76**	**185**
North Washington St – SB	L	D	54.6	0.51	180	F	92.5	0.85	203	D	54.6	0.51	180	D	54.6	0.72	146
North Washington St – SB	**T**	**B**	**17.7**	**0.36**	**184**	**D**	**36.3**	**0.52**	**269**	**B**	**15.1**	**0.34**	**168**	**C**	**22.2**	**0.45**	**180**
North Washington St – SB	R	B	16.7	0.25	98	C	34.1	0.56	145	B	14.2	0.23	90	C	20.6	0.31	96
Overall		**E**	**79.6**	**0.94**	**–**	**E**	**60.8**	**0.94**	**–**	**F**	**86.8**	**0.94**	**–**	**E**	**61.9**	**0.97**	**–**

TABLE E-2 cont. PM-Peak-Hour Level-of-Service Summary

Intersection/Approach[1]	Mvmt	Existing Conditions				Alt. 1 (Intersect. Timings)				Alt. 2 (Bus Timings)				Alt. 3 (TSP)			
		LOS	Delay[2]	V/C	Q[3]	LOS	Delay[2]	V/C	Q[3]	LOS	Delay[2]	V/C	Q[3]	LOS	Delay[2]	V/C	Q[3]
Chelsea Intersections																	
Wash. Ave at Rev. Bch. Pkwy														IB G.Ext. (NB/SB)			
Revere Beach Pkwy – EB	L	F	152.8	1.15	156	E	63.0	0.80	187	F	157.4	1.16	188	F	149.1	1.14	156
Revere Beach Pkwy – EB	TR	C	31.4	0.82	283	C	28.9	0.75	324	C	32.8	0.83	318	C	33.5	0.83	286
Revere Beach Pkwy – WB	L	D	52.9	0.63	55	E	64.9	0.71	72	D	53.6	0.63	61	D	54.8	0.64	55
Revere Beach Pkwy – WB	TR	D	35.0	0.83	280	D	45.4	0.90	364	C	36.4	0.84	308	D	38.0	0.85	280
Washington Ave – NB	L	D	50.2	0.70	48	E	63.9	0.76	64	D	45.7	0.66	50	D	42.8	0.63	48
Washington Ave – NB	**TR**	**D**	**40.1**	**0.64**	**118**	**D**	**45.3**	**0.66**	**156**	**D**	**38.9**	**0.61**	**123**	**D**	**38.4**	**0.59**	**118**
Washington Ave – SB	**TR**	**D**	**42.7**	**0.72**	**88**	**D**	**49.1**	**0.76**	**116**	**D**	**40.7**	**0.69**	**90**	**D**	**40.1**	**0.66**	**87**
Overall		**D**	**43.0**	**0.83**	**–**	**D**	**41.6**	**0.85**	**–**	**D**	**43.9**	**0.83**	**–**	**D**	**44.1**	**0.82**	**–**
Garfield/Wash. at Fenno														Fully actuate w/ 90s max CL			
Washington Ave – EB	LT	C	26.8	0.63	69	D	36.1	0.75	77	D	36.1	0.75	77	C	23.6	0.68	57
Washington Ave – EB	R	B	17.2	0.04	2	B	19.6	0.05	3	B	19.6	0.05	3	B	16.9	0.04	2
Garfield Ave – NB	L	B	14.8	0.16	7	B	12.4	0.13	6	B	12.4	0.13	6	B	12.2	0.15	5
Garfield Ave – NB	**TR**	**C**	**26.3**	**0.76**	**101**	**C**	**20.4**	**0.68**	**87**	**C**	**20.4**	**0.68**	**87**	**B**	**19.7**	**0.73**	**83**
Washington Ave – SB	**LT**	**B**	**19.1**	**0.52**	**60**	**B**	**15.8**	**0.47**	**52**	**B**	**15.8**	**0.47**	**52**	**B**	**14.4**	**0.50**	**49**
Washington Ave – SB	R	B	17.5	0.40	34	B	14.6	0.36	29	B	14.6	0.36	29	B	13.6	0.39	28
Overall		**C**	**23.0**	**0.70**	**–**	**C**	**21.7**	**0.70**	**–**	**C**	**21.7**	**0.70**	**–**	**B**	**18.2**	**0.71**	**–**

1. Route 111 approaches are shown in bold.
2. Delay is measured in seconds.
3. 50th percentile queue, measured in feet.