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MEMORANDUM

DATE **January 5, 2012**

TO **Boston Region Metropolitan Planning Organization**

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

RE **MBTA Bus Route 1 Transit Signal Priority Study: Task 1 – Existing Conditions Evaluation**

The purpose of this MPO-funded study is to evaluate potential transit signal priority (TSP) strategies, including queue jumps, along MBTA bus Route 1, a Key Route. The present memorandum provides detailed analysis of the existing conditions at intersections on the route. Analysis of what TSP strategies or other improvements are called for is presented in the Task 2 memorandum.

This study will demonstrate which intersections along the bus route could benefit from TSP strategies, including green extension, early green, and queue jump lanes, without any significant negative impacts resulting for general traffic, bicyclists and pedestrians, parking, and side streets. It will develop final recommendations for improvement strategies for the MBTA to design and implement.

The primary objectives of this study are:

- Evaluate existing conditions at signalized intersections along MBTA bus Route 1 *(this memorandum).*
- Evaluate the potential for TSP and queue jump lanes under bus stop consolidation assumptions that resulted from the 2009 MBTA Key Routes Initiative[1] *(this memorandum and the Task 2 memorandum).*
- 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 *(this memorandum and the Task 2 memorandum).*

BACKGROUND

The MPO had identified bus Route 1 as a prime candidate to study for its potential to benefit from transit signal priority (TSP) strategies prior to the MBTA's Key Routes Initiative. This potential was clear, based on information from the MPO's Congestion Management Process (CMP). A work program was

[1] "Key Bus Routes Study: Route 1," memorandum, Central Transportation Planning Staff, January 15, 2010.

included in the 2010 Unified Planning Work Program (UPWP). Since then, the MBTA's Key Routes Initiative has conducted analysis of Route 1 along with five other Key Routes. (The MBTA's 15 Key Routes carry approximately 40% of all MBTA bus passengers.) In the fall of 2009 and in early 2010, the MBTA collaborated with MassDOT and MPO staff on this study, which developed conceptual improvement strategies for six of the Key Routes: 1, 15, 23, 28, 66, and 111. The results of that study are drawn upon by the present study.

The conceptual strategies examined in the Key Routes study included dedicated bus lanes; pre-paid 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 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.

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

MBTA bus Route 1 is the primary transit service in its corridor; the preponderance of the route is on Massachusetts Avenue between Harvard/Holyoke Gate in Cambridge and Dudley Station in Boston. Figures 1 and 2 show the inbound and outbound routes and bus stops. The following is a brief description of the route by community.

Cambridge

In Cambridge, the route has 15 stops in the inbound direction (from Harvard/Holyoke Gate to Memorial Drive) and 13 stops in the outbound direction (from Memorial Drive to Harvard/Holyoke Gate). A majority of the stops are located near the intersections of major roadways and have pull-out areas on the outside travel lane or parking lane next to the sidewalk curb. The route travels through 20 signalized intersections in the inbound direction and 13 signalized intersections in the outbound direction. Information related to the intersections the route passes through, the bus movement at the intersection, and whether the bus stop is located on the near side or far side of the intersection is provided 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.

Boston

The Boston section of the route has 20 stops in the inbound direction (from Beacon Street to Dudley Station) and 20 stops in the outbound direction (from Dudley Station to Beacon Street). As in Cambridge, most of the stops are located near the intersections of major roadways and have pull-out areas on the outside travel or parking lane next to the sidewalk curbs. The route travels through 22 signalized intersections in the inbound direction and 21 signalized intersections in the outbound direction. Information related to intersections and bus stop locations is also shown in Appendix B in Tables B-3 and B-4 for the inbound and outbound directions, respectively. There are a few intersections where no bus stops are present nearby.

Existing Bus Performance

The 2010 memorandum on Route 1 included average bus speeds over the inbound and outbound routes during the AM and PM peak hours, average traffic signal delays, and daily boarding and alighting totals by stop. These sets of data from that memorandum are provided below. For a detailed description of the methodologies used to obtain these data, please see the 2010 memorandum.

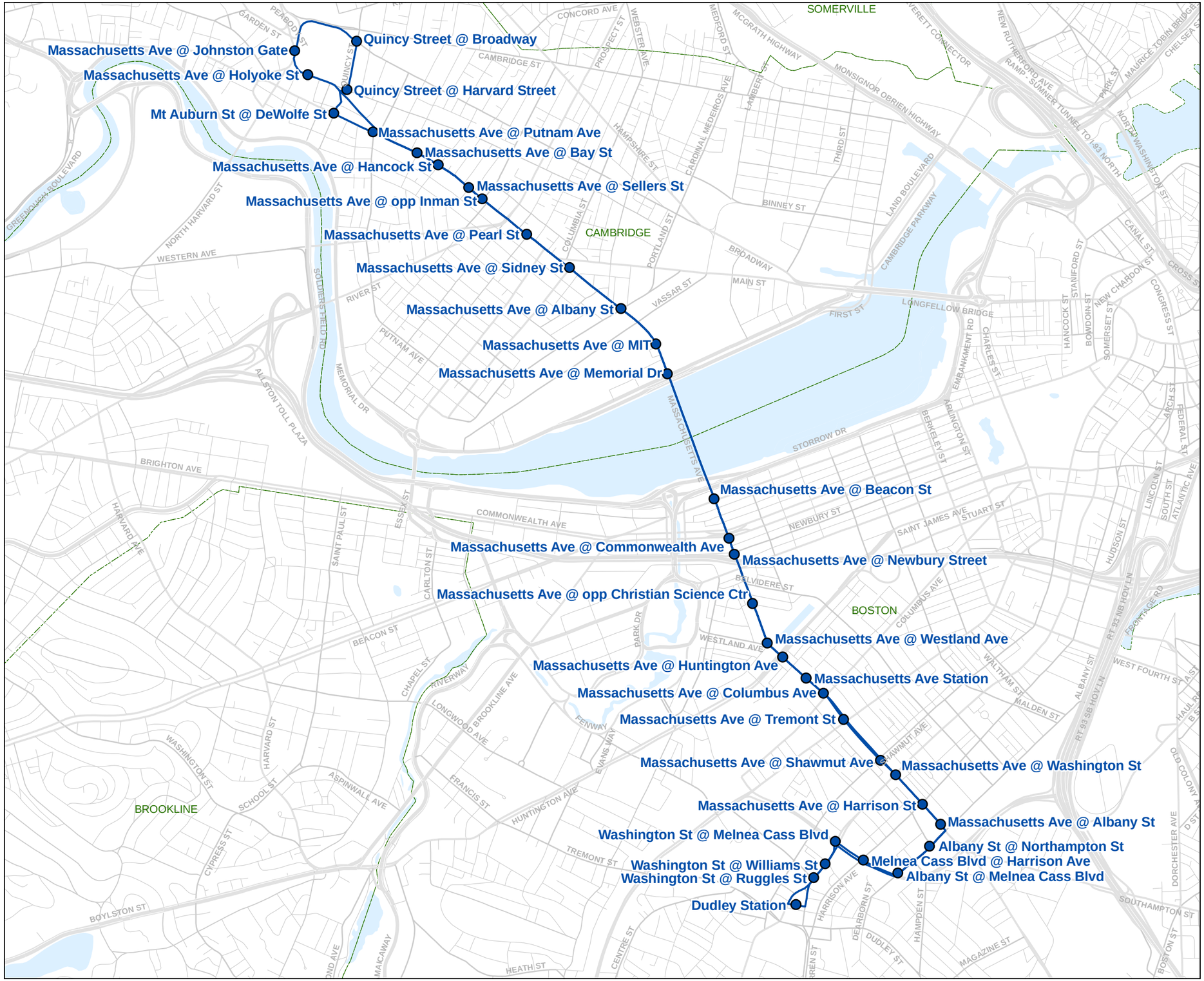

FIGURE 1
MBTA Bus Route 1
Route and Stop Locations: Inbound

MBTA Bus Route 1 Transit Signal Priority Study

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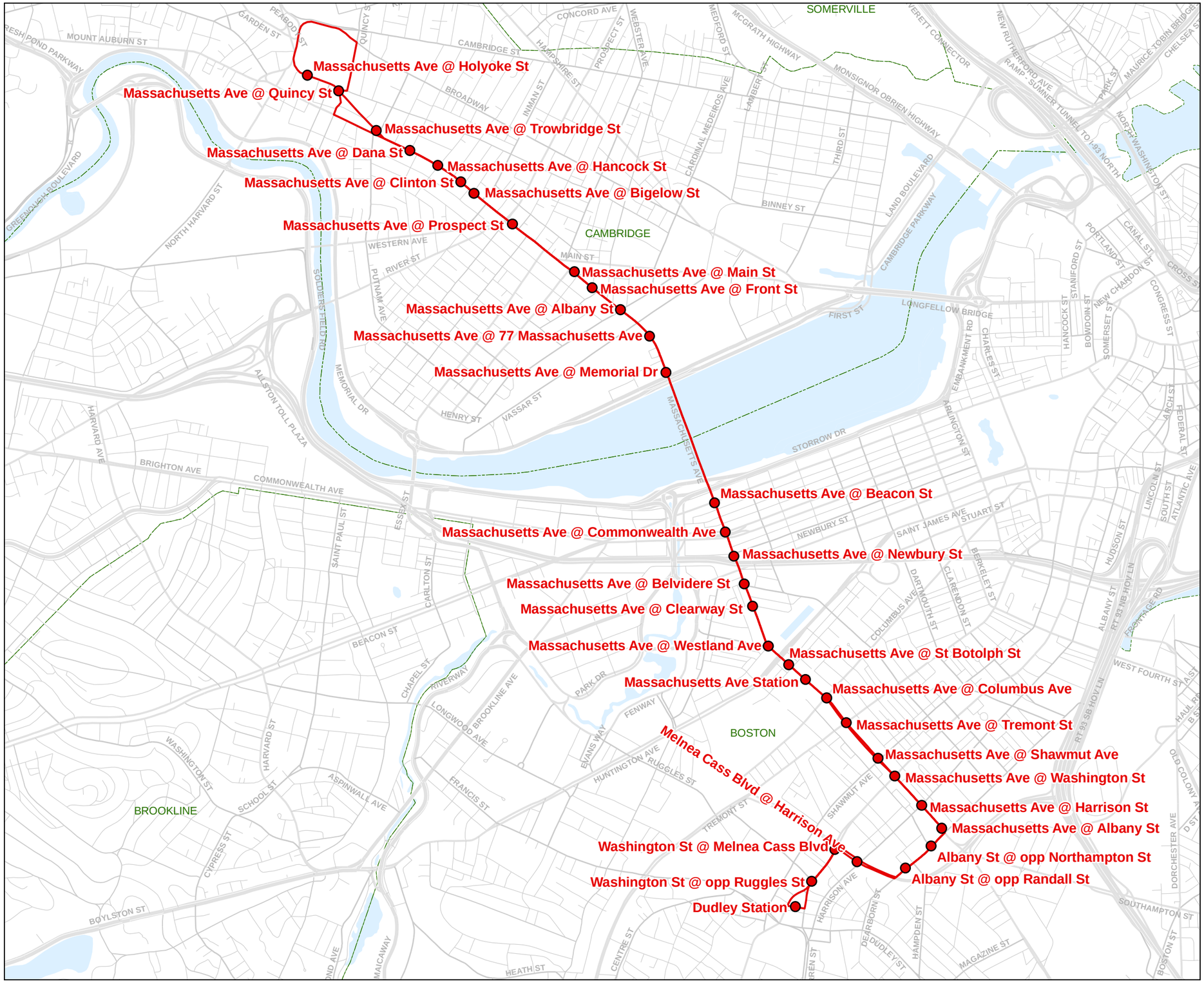

FIGURE 2
MBTA Bus Route 1
Route and Stop Locations: Inbound

MBTA Bus Route 1 Transit Signal Priority Study

BOSTON REGION MPO

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Average Speeds

Massachusetts Avenue is a congested roadway; speeds are generally below posted speed limits in both Cambridge and Boston. Information gathered by the MPO's Congestion Management Program (CMP) indicates a 30 mph speed limit in Cambridge and Boston. Also based on CMP information, the average running speeds of all traffic along the inbound bus route is 19 mph. The outbound average speed of all traffic is 17 mph.

Automatic vehicle location (AVL) data provided by the MBTA for the entire month of May 2009 was used to obtain the average bus speeds along the entire route by direction during the AM (6:00–10:00) and PM (3:00–7:00) peak periods. Peak periods were used instead of peak hours in order 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 mph, yellow average speeds between 11 mph and 20 mph, and green average speeds greater than 20 mph.

Figure 3 shows that in the AM peak period in the inbound direction, the slowest speeds in Cambridge occurred on Massachusetts Avenue between Putnam Street and Central Square. The slowest speeds in Boston occurred between Massachusetts Avenue at Washington Street and Dudley Station. The average inbound speed for the entire route was 6.28 mph.

Figure 4 shows that in the AM peak period in the outbound direction, compared to the Boston service, the Cambridge service ran at higher average speeds for most of the Cambridge segments. The slowest average speeds in Cambridge occurred between MIT and Central Square, while the slowest average speeds in Boston occurred between Melnea Cass Boulevard and Hynes Station. The average outbound speed for the entire route was 10.99 mph.

Figure 5 shows that in the PM peak period in the inbound direction, a majority of the segments had average speeds at or below 10 mph. The slowest average speeds in Cambridge occurred between Putnam Street and Central Square along Massachusetts Avenue. In Boston, the slowest average speeds occurred, as during the AM peak period, between Massachusetts Avenue at Washington Street and Dudley Station. The average inbound speed for the entire route was 6.26 mph.

Figure 6 shows that in the PM peak period in the outbound direction, as in the AM peak period, the slowest speeds in Cambridge occurred between MIT and Central Square. In Boston, half of the route segments had average speeds below 10 mph, with the slowest speeds occurring between Melnea Cass Boulevard and Hynes Station. The average outbound speed for the entire route was 8.29 mph.

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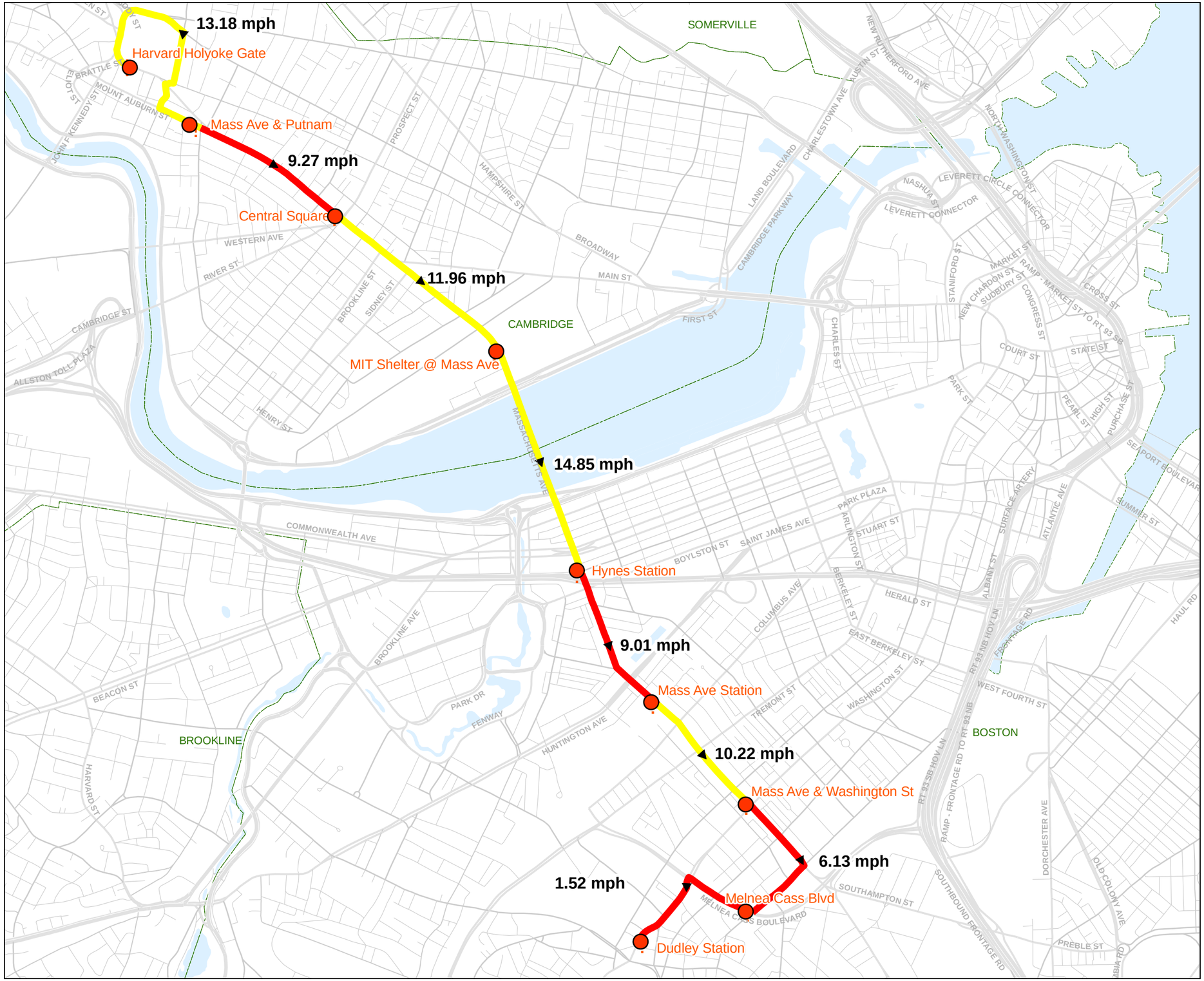

FIGURE 3
MBTA Bus Route 1
Average Travel Speeds:
AM Peak Period (6:00 - 10:00 AM)
Inbound

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.

MBTA Bus Route 1 Transit Signal Priority: Task 1 Memorandum

BOSTON REGION MPO

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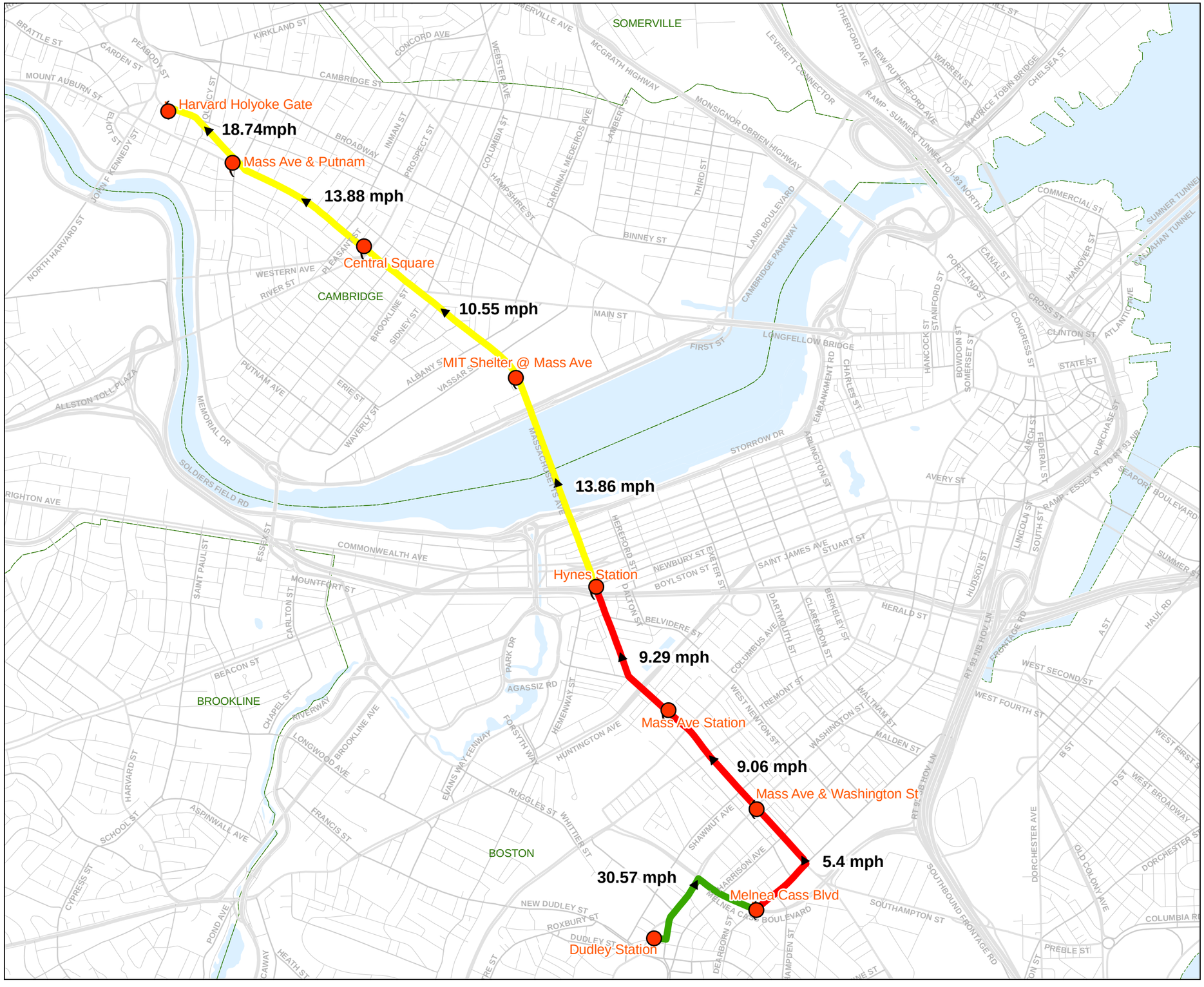

FIGURE 4
MBTA Bus Route 1
Average Travel Speeds:
AM Peak Period (6:00 - 10:00 AM)
Outbound

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.

MBTA Bus Route 1 Transit Signal Priority: Task 1 Memorandum

BOSTON REGION MPO

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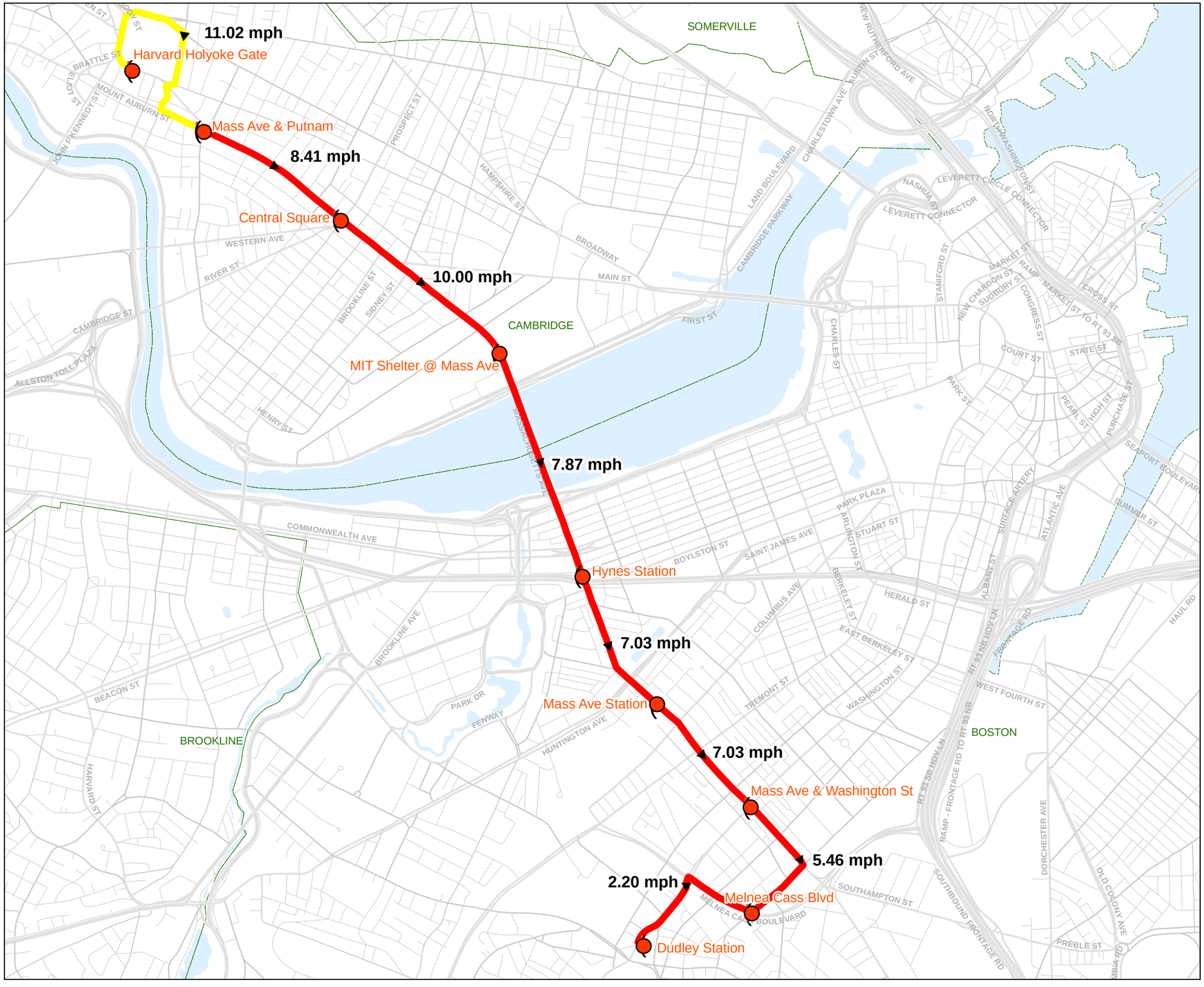

FIGURE 5
MBTA Bus Route 1
Average Travel Speeds:
PM Peak Period (3:00 - 6:00 PM)
Inbound

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.

MBTA Bus Route 1 Transit Signal Priority: Task 1 Memorandum

BOSTON REGION MPO

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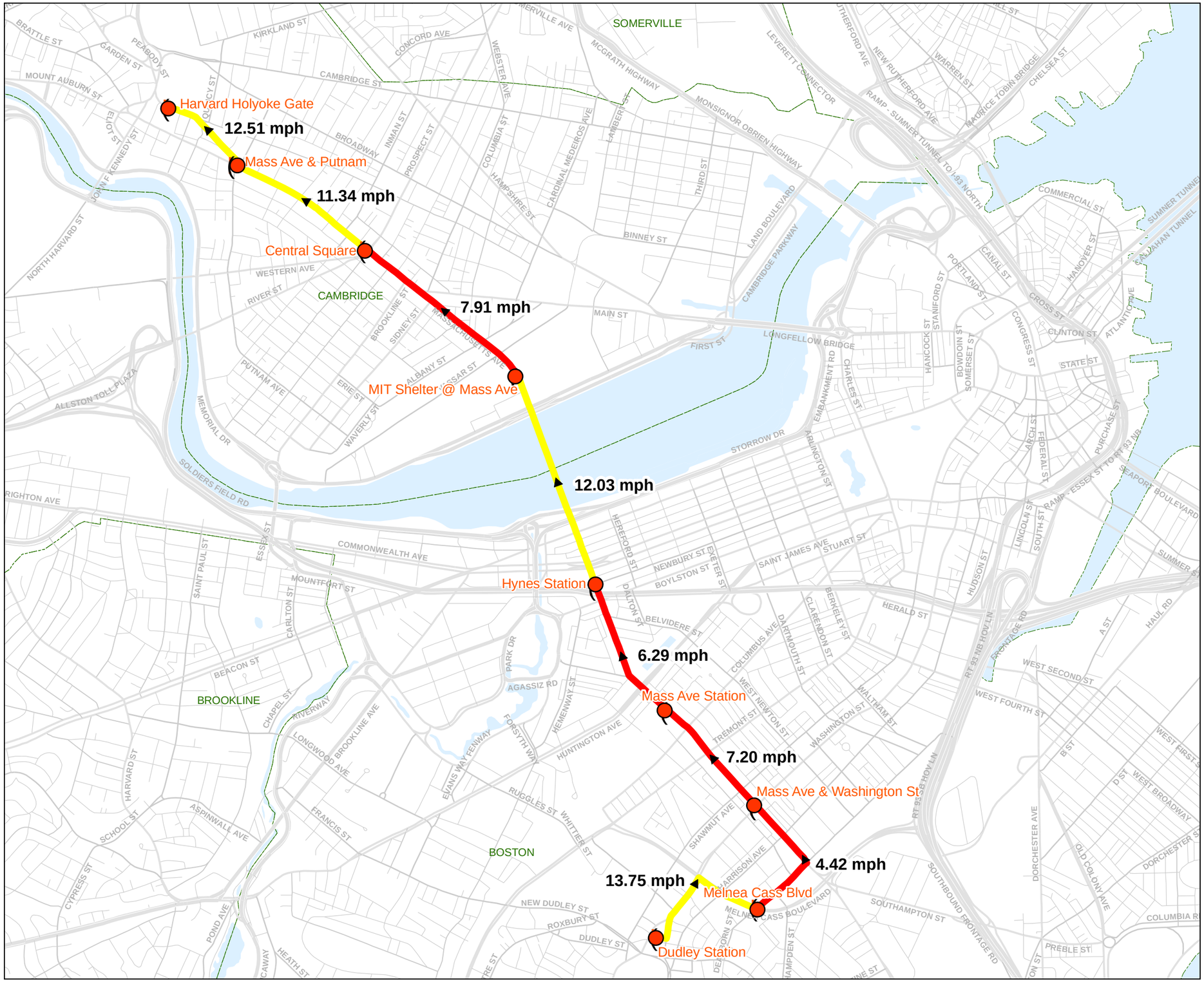

FIGURE 6
MBTA Bus Route 1
Average Travel Speeds:
PM Peak Period (3:00 - 6:00 PM)
Outbound

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.

MBTA Bus Route 1 Transit Signal Priority: Task 1 Memorandum

BOSTON REGION MPO

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In summary, the Boston portion of Route 1 experienced slower outbound travel speeds in the PM peak period than in the AM peak period. Overall, Route 1 experienced significantly slower travel speeds in the inbound direction than in the outbound direction. The portion of Route 1 in Boston south of Hynes Station consistently had the slowest average speeds.

The Cambridge portion Route 1 experienced slower travel speeds in the inbound direction and in the PM peak period. The segment of Route 1 on Massachusetts Avenue between Putnam Street and Central Square consistently had the slowest average speeds in the inbound direction, while the segment on Massachusetts Avenue between MIT and Central Square consistently had the slowest average speeds in the outbound direction.

Bus Boardings and Alightings

Daily bus boardings and alightings 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 name and not signalized intersection as in the tables found in Appendix B.

INTERSECTION SCREENING

Bus Route 1 has 42 signalized intersections along its inbound route and 34 along its outbound route. In the work completed in the 2009 Key Routes Initiative, all the intersections along the bus route were preliminarily evaluated to see if TSP or other strategies could possibly improve bus service. A list of the signalized intersections evaluated at that time and the preliminary recommendations that were made can be found in Appendix D.

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, Cambridge's Parking and Transportation Department, and MPO staff reviewed the following factors to identify the intersections to study:

- 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

Nineteen intersections were selected for TSP analysis. Many of the intersections selected are located within roadway segments where the average speeds of the buses are below 10 mph (such segments can be identified in Figures 3 through 6).

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:

- Washington Street and Melnea Cass Boulevard (Boston)
- Melnea Cass Boulevard and Harrison Avenue (Boston)
- Melnea Cass Boulevard and Albany Street (Boston)
- Massachusetts Avenue and Harrison Street (Boston)
- Massachusetts Avenue and Shawmut Avenue (Boston)
- Massachusetts Avenue and Tremont Street (Boston)
- Massachusetts Avenue and St. Botolph Street (Boston)
- Massachusetts Avenue and Belvidere Street (Boston)
- Massachusetts Avenue and Marlborough Street (Boston)
- Massachusetts Avenue and Beacon Street (Boston)
- Massachusetts Avenue and Memorial Drive (Boston)
- Massachusetts Avenue and Pedestrian Signal at MIT (Cambridge)
- Massachusetts Avenue and Vassar Street (Cambridge)
- Massachusetts Avenue and Albany Street (Cambridge)
- Massachusetts Avenue and Brookline Street/Douglas Street (Cambridge)
- Massachusetts Avenue and Essex Street (Cambridge)
- Massachusetts Avenue and Prospect Street (Cambridge)
- Massachusetts Avenue and Pleasant Street/Inman Street (Cambridge)
- Massachusetts Avenue and Hancock Street (Cambridge)

TRAFFIC OPERATIONS

Existing Traffic Operations

As stated previously, the purpose of this Task 1 memorandum is to examine the operations under existing conditions at the selected intersections. Traffic operations were analyzed using Synchro 7[1] and data provided by the Boston Transportation Department and Cambridge's Parking and Transportation Department or collected by MPO staff in the field.

Table 1 summarizes the results of the existing conditions signalized intersection analysis for both the AM and PM peak hours. The analysis used existing signal timings and phasing. The results indicate that at many of the intersections, TSP or other improvements could benefit the bus route. Analysis of what improvements are called for at each of these intersections is presented in the Task 2 memorandum.

MSA/SA/msa/sa

Attachments

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

TABLE 1 Peak-Hour Level-of-Service Summary

Intersection/Approach[1]	Movement	AM LOS	AM Delay[2]	AM Q[3]	PM LOS	PM Delay	PM Q
Boston Intersections							
Melnea Cass at Washington							
Melnea Cass Blvd – EB	L	F	204.1	136	D	37.2	71
Melnea Cass Blvd – EB	**TR**	**C**	**29.4**	**295**	**C**	**28.5**	**300**
Melnea Cass Blvd – WB	L	C	29.2	45	D	36.8	46
Melnea Cass Blvd – WB	TR	B	18.5	275	B	14.9	191
Washington Street – NB	L	C	27.5	44	D	42.0	37
Washington Street – NB	T	D	40.2	294	C	31.6	204
Washington Street – NB	**R**	**C**	**20.4**	**12**	**C**	**21.6**	**11**
Washington Street – SB	L	C	23.1	10	C	25.0	27
Washington Street – SB	T	C	26.2	139	C	34.1	248
Washington Street – SB	R	C	20.3	12	C	21.3	3
Overall		**C**	**34.7**	**–**	**C**	**26.2**	**–**
Melnea Cass at Harrison							
Melnea Cass Blvd – EB	L	E	79.0	55	F	400.6	251
Melnea Cass Blvd – EB	**TR**	**C**	**23.6**	**231**	**C**	**29.6**	**356**
Melnea Cass Blvd – WB	L	F	111.0	84	C	30.3	42
Melnea Cass Blvd – WB	**TR**	**D**	**35.7**	**363**	**C**	**25.8**	**317**
Harrison Ave – NB	LT	D	42.7	250	E	75.8	188
Harrison Ave – NB	R	C	22.6	0	C	24.5	3
Harrison Ave – SB	L	C	27.2	38	C	24.3	16
Harrison Ave – SB	TR	C	24.6	102	D	45.6	256
Overall		**D**	**37.6**	**–**	**E**	**63.5**	**–**
Melnea Cass at Albany							
Melnea Cass Blvd – EB	**LTR**	**E**	**63.6**	**246**	**C**	**22.0**	**251**
Melnea Cass Blvd – WB	LTR	E	65.5	514	C	20.4	317
Albany St – NB	LTR	E	71.4	185	D	38.2	70
Albany St – SB	***LTR***	***C***	***33.2***	***85***	***D***	***47.8***	***121***
Overall		**E**	**63.3**	**–**	**C**	**24.8**	**–**
Albany at Northampton							
Northampton St – EB	LT	E	78.7	100	D	41.3	82
Northampton St – EB	R	D	44.5	0	D	36.1	0
Northampton St – WB	LT	D	47.5	66	E	74.7	145
Northampton St – WB	R	D	44.1	1	D	46.9	105
Albany St – NB	**LTR**	**B**	**11.5**	**118**	**B**	**16.1**	**90**
Albany St – SB	**LTR**	**B**	**12.6**	**53**	**C**	**20.6**	**138**
Overall	LT	**C**	**24.5**	**–**	**C**	**32.9**	**–**

[1] Bus Route 1 approaches are bold.
[2] Delay is measured in seconds.
[3] 50th percentile queue, measured in feet.

TABLE 1 (CONT.) Peak-Hour Level-of-Service Summary

Intersection/Approach[1]	Movement	AM LOS	AM Delay[2]	AM Q[3]	PM LOS	PM Delay	PM Q
Massachusetts at Albany							
Massachusetts Ave – SE	L	F	97.1	92	D	54.0	41
Massachusetts Ave – SE	**TR**	**B**	**16.2**	**200**	**C**	**24.3**	**333**
Massachusetts Ave – NW	T	D	38.1	426	F	80.4	604
Massachusetts Ave – NW	R	C	20.7	71	B	16.5	5
Albany St – NE	**L**	**D**	**37.0**	**42**	**D**	**42.5**	**45**
Albany St – NE	TR	E	69.0	276	D	46.5	191
Albany St – SW	L	F	219.5	133	F	131.4	178
Albany St – SW	TR	D	36.0	167	D	53.5	352
Overall		**D**	**45.8**	**–**	E	57.7	**–**
Massachusetts at Harrison							
Massachusetts Ave – SE	L	C	33.2	38	C	26.2	15
Massachusetts Ave – SE	**TR**	**C**	**21.1**	**122**	**C**	**21.7**	**145**
Massachusetts Ave – NW	L	C	20.5	32	C	25.8	32
Massachusetts Ave – NW	**TR**	**D**	**43.7**	**377**	**D**	**47.9**	**410**
Harrison Ave – NE	L	C	27.9	21	D	44.1	29
Harrison Ave – NE	TR	D	40.5	196	D	36.8	179
Harrison Ave – SW	L	D	53.8	55	D	35.2	37
Harrison Ave – SW	TR	C	30.6	98	D	49.1	252
Overall		**D**	**35.0**	**–**	**D**	**37.6**	**–**
Massachusetts at Shawmut							
Massachusetts Ave – SE	**TR**	**B**	**16.2**	**268**	**B**	**10.3**	**247**
Massachusetts Ave – NW	**L**	**A**	**5.0**	**4**	**A**	**4.2**	**3**
Massachusetts Ave –NW	T	A	3.6	54	A	2.8	50
Shawmut Ave – SW	LTR	D	39.7	82	D	39.8	94
Overall		**B**	**13.4**	**–**	**B**	**11.3**	**–**
Massachusetts at Tremont							
Massachusetts Ave – SE	L	C	32.0	52	B	11.6	20
Massachusetts Ave – SE	**TR**	**C**	**22.1**	**148**	**B**	**15.1**	**277**
Massachusetts Ave – NW	L	B	11.7	17	B	18.0	26
Massachusetts Ave – NW	**TR**	**C**	**26.7**	**286**	**C**	**26.0**	**284**
Tremont St – NE	L	C	22.4	33	C	27.9	67
Tremont St – NE	TR	D	44.0	216	D	41.9	190
Tremont St – SW	L	C	34.4	55	C	32.5	64
Tremont St – SW	TR	C	30.6	112	C	34.4	147
Overall		**C**	**29.6**	**–**	**C**	**26.2**	**–**

[1] Bus Route 1 approaches are bold.
[2] Delay is measured in seconds.
[3] 50th percentile queue, measured in feet.

TABLE 1 (CONT.) Peak-Hour Level-of-Service Summary

Intersection/Approach[1]	Movement	AM LOS	AM Delay[2]	AM Q[3]	PM LOS	PM Delay	PM Q
Massachusetts at St. Botolph							
Massachusetts Ave – SE	**LTR**	**A**	**6.7**	**115**	**B**	**13.0**	**195**
Massachusetts Ave – NW	**LTR**	**A**	**6.6**	**86**	**B**	**14.0**	**91**
St. Botolph St – NE	LTR	E	58.2	52	D	46.7	65
St. Botolph St – SW	LTR	D	42.6	26	E	64.4	84
Overall		**A**	**9.5**	**–**	**B**	**17.8**	**–**
Massachusetts at Westland							
Westland Ave – EB	R	C	26.8	189	D	40.4	282
Massachusetts Ave – NB	L	F	133.1	399	F	287.1	551
Massachusetts Ave – NB	**T**	**A**	**4.7**	**71**	**A**	**4.8**	**79**
Massachusetts Ave – SB	**TR**	**D**	**40.3**	**227**	**D**	**49.2**	**250**
Overall		**D**	**41.4**	**–**	**E**	**77.6**	**–**
Massachusetts at Belvidere							
Belvidere St – EB	LTR	D	39.3	95	D	40.8	100
Massachusetts Ave – NB	**LT**	**C**	**24.0**	**213**	**C**	**23.3**	**252**
Massachusetts Ave – SB	**TR**	**C**	**21.5**	**197**	**C**	**20.6**	**215**
Overall		**C**	**24.5**	**–**	**C**	**23.8**	**–**
Massachusetts at Newbury							
Newbury St – WB	LTR	D	43.0	104	D	42.3	36
Massachusetts Ave – NB	L	F	241.1	196	F	1034.4	633
Massachusetts Ave – NB	**T**	**A**	**5.8**	**92**	**A**	**3.6**	**40**
Massachusetts Ave – SB	**TR/T**	**B**	**13.4**	**111**	**B**	**12.5**	**192**
Overall		**D**	**43.9**	**–**	**F**	256.4	**–**
Massachusetts at Marlborough							
Marlborough St – EB	LTR	D	39.5	94	D	42.4	65
Massachusetts Ave – NB	**TR**	**B**	**17.1**	**234**	**B**	**12.3**	**247**
Massachusetts Ave – SB	**LT**	**B**	**13.0**	**145**	**B**	**16.7**	**168**
Overall		**B**	**18.6**	**–**	**B**	**17.0**	**–**
Massachusetts at Beacon							
Beacon St – WB	LT	D	41.1	118	D	42.9	166
Beacon St – WB	R	D	38.7	79	D	52.1	143
Massachusetts Ave – NB	**LT**	**B**	**18.0**	**154**	**C**	**28.1**	**182**
Massachusetts Ave – SB	**TR**	**C**	**26.4**	**31**	**F**	**106.9**	**667**
Overall		**C**	**26.0**	**–**	**E**	**68.2**	**–**

[1] Bus Route 1 approaches are bold.
[2] Delay is measured in seconds.
[3] 50th percentile queue, measured in feet.

TABLE 1 (CONT.) Peak-Hour Level-of-Service Summary

Intersection/Approach[1]	Movement	AM LOS	AM Delay[2]	AM Q[3]	PM LOS	PM Delay	PM Q
Cambridge Intersections							
Massachusetts at Memorial							
N. Intersection Memorial Dr – WB	R	D	54.0	103	D	49.1	81
Massachusetts Ave – NB	L	A	1.3	0	A	1.8	0
Massachusetts Ave – NB	**T**	**A**	**0.7**	**0**	**A**	**0.4**	**0**
Massachusetts Ave – SB	**T**	**B**	**12.9**	**102**	**B**	**15.0**	**170**
S. Intersection Memorial Dr – EB	R	F	268.5	268	F	559.9	370
Massachusetts Ave – NB	**T**	**A**	**8.0**	**149**	**B**	**12.0**	**218**
Massachusetts Ave – SB	**T**	**A**	**4.1**	**17**	**A**	**4.3**	**25**
Overall Not applic. (acts as 2 ints.[4])		–	–	–	–	–	–
Massachusetts at 77 Mass Ave							
Massachusetts Ave – EB	**T**	**B**	**15.6**	**430**	**D**	**41.6**	**613**
Massachusetts Ave – WB	**T**	**A**	**6.4**	**61**	**A**	**7.4**	**78**
Overall		**B**	**10.9**	–	C	24.0	–
Massachusetts at Vassar							
Massachusetts Ave – EB	**LTR**	**A**	**9.2**	**58**	**B**	**13.4**	**119**
Massachusetts Ave – WB	**LTR**	**A**	**10.0**	**64**	**C**	**28.5**	**231**
Vassar St – NB	L	C	22.0	39	C	22.6	35
Vassar St – NB	TR	C	24.4	138	C	23.9	144
Vassar St – SB	L	C	27.8	59	C	31.8	77
Vassar St – SB	TR	C	22.0	88	C	23.9	137
Overall		**B**	**14.0**	–	***C***	***22.1***	–
Massachusetts at Albany							
Massachusetts Ave – EB	**LTR**	**A**	**6.8**	**100**	**A**	**9.6**	**177**
Massachusetts Ave – WB	**LTR**	**D**	**53.1**	**280**	**B**	**15.5**	**251**
Albany St – NB	L	B	17.3	5	B	17.7	10
Albany St – NB	TR	C	22.7	132	C	29.0	225
Albany St – SB	LTR	D	53.2	215	E	70.0	160
Overall		**C**	**33.6**	–	C	22.5	–
Massachusetts at Brookline							
Massachusetts Ave – EB	**LT**	**A**	**3.7**	**0**	**B**	**12.4**	**110**
Massachusetts Ave – WB	**TR**	**C**	**23.1**	**143**	**B**	**18.4**	**426**
Brookline St – NB	L	C	24.6	81	C	27.7	89
Brookline St – NB	TR	C	28.7	130	D	36.4	167
Overall		**B**	**16.7**	–	C	20.9	–
Massachusetts at Essex							
Massachusetts Ave – EB	L	A	6.1	6	A	5.2	1
Massachusetts Ave – EB	**T**	**B**	**10.1**	**145**	**A**	**6.7**	**95**
Massachusetts Ave – WB	**TR**	**B**	**13.3**	**138**	**C**	**21.1**	**386**
Overall		**B**	**11.5**	–	B	15.4	–

[1] Bus Route 1 approaches are bold.
[2] Delay is measured in seconds.
[3] 50th percentile queue, measured in feet.
[4] Massachusetts at Memorial was analyzed as two separate intersections.

TABLE 1 (CONT.) Peak-Hour Level-of-Service Summary

Intersection/Approach[1]	Movement	AM LOS	AM Delay[2]	AM Q[3]	PM LOS	PM Delay	PM Q
Massachusetts at Prospect							
Massachusetts Ave – EB	**T**	**B**	**17.0**	**248**	**C**	**29.7**	**168**
Massachusetts Ave – EB	R	A	6.3	7	C	23.6	24
Massachusetts Ave – WB	**T**	**C**	**21.6**	**101**	**C**	**23.2**	**168**
Massachusetts Ave – WB	R	B	19.3	38	B	16.1	23
Western Ave – NB	L	C	28.4	320	C	27.2	373
Western Ave – NB	TR	C	27.9	105	F	128.2	129
Prospect St – SB	LTR	C	25.2	284	B	15.4	190
Overall		C	23.6	–	C	31.3	–
Massachusetts at Pleasant/Inman							
Massachusetts Ave – EB	**T**	**C**	**26.4**	**236**	**C**	**33.3**	**296**
Massachusetts Ave – WB	L	C	21.6	23	C	26.4	28
Massachusetts Ave – WB	**T**	**B**	**12.0**	**44**	**A**	**5.1**	**27**
Inman St – NB	T	E	80.0	313	F	86.9	270
Inman St – SB	R	C	28.1	80	D	53.7	169
Overall		**D**	**41.8**	**–**	D	42.5	–
Massachusetts at Hancock							
Massachusetts Ave – EB	**T**	**A**	**5.6**	**121**	**A**	**8.3**	**230**
Massachusetts Ave – WB	**T**	**A**	**4.7**	**80**	**A**	**5.5**	**179**
Overall		**A**	**5.2**	**–**	A	6.9	–

[1] Bus Route 1 approaches are bold.
[2] Delay is measured in seconds.
[3] 50th percentile queue, measured in feet.

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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. Transportation 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 Movements, and Stop Locations

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

Signalized Intersection	Bus Movement	Stop Location
Massachusetts Avenue at Ped Signal Holyoke Street	Through	Near-side
Massachusetts Avenue at Ped Signal Dunster Street	Through	Near-side
Massachusetts Avenue at Ped Signal opposite Brattle Street	Through	
Massachusetts Avenue at Ped Signal opposite Church Street	Through	
Massachusetts Avenue at Garden Street	Through	Far-side
Broadway at Cambridge Street	Right	
Broadway at Quincy Street	Right	Far-side
DeWolfe Street at Mt. Auburn Street	Through	Far-side
Mt. Auburn Street at Putnam Street	Through	Near-side
Massachusetts Avenue at Hancock Street	Through	Near-side
Massachusetts Avenue at Pleasant Street	Through	Near-side
Massachusetts Avenue at Prospect Street	Through	
Massachusetts Avenue at Essex Street	Through	Far-side
Massachusetts Avenue at Brookline Street	Through	
Massachusetts Avenue at Sidney Street	Through	Far-side
Massachusetts Avenue at Landsdowne Street	Through	Far-side
Massachusetts Avenue at Albany Street	Through	Near-side
Massachusetts Avenue at Vassar Street	Through	
Massachusetts Avenue at Ped Signal MIT	Through	Far-side
Massachusetts Avenue at Amherst Street	Through	
Massachusetts Avenue at Memorial Drive	Through	Near-side

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

Signalized Intersection	Bus Movement	Stop Location
Massachusetts Avenue at Memorial Drive	Through	Far-side
Massachusetts Avenue at Amherst Street	Through	
Massachusetts Avenue at Ped Signal MIT	Through	Far-side
Massachusetts Avenue at Vassar Street	Through	Near-side
Massachusetts Avenue at Albany Street	Through	Near-side
Massachusetts Avenue at Landsdowne Street	Through	Far-side
Massachusetts Avenue at Sidney Street	Through	Near-side
Massachusetts Avenue at Douglass Street	Through	
Massachusetts Avenue at Essex Street	Through	Far-side
Massachusetts Avenue at Prospect Street	Through	
Massachusetts Avenue at Pleasant Street	Through	Far-side
Massachusetts Avenue at Hancock Street	Through	Near-side
Massachusetts Avenue at Trowbridge Street	Through	Far-side

TABLE B-3 Locations of Traffic Signals and Bus Stops: Inbound - Boston

Signalized Intersection	Bus Movement	Stop Location
Massachusetts Avenue at Beacon Street	Through	Near-side
Massachusetts Avenue at Marlborough Street	Through	
Massachusetts Avenue at Commonwealth Avenue	Through	Mid-block
Massachusetts Avenue at Newbury Street	Through	Far-side
Massachusetts Avenue at Boylston Street	Through	
Massachusetts Avenue at Belvidere Street	Through	
Massachusetts Avenue at Ped Signal North of Westland Avenue	Through	Near-side
Massachusetts Avenue at Westland Avenue	Through	Near-side
Massachusetts Avenue at Huntington Avenue	Through	Far-side
Massachusetts Avenue at St. Botolph Street	Through	
Massachusetts Avenue at Columbus Avenue	Through	Near-side
Massachusetts Avenue at Tremont Street	Through	Near-side
Massachusetts Avenue at Shawmut Avenue	Through	Far-side
Massachusetts Avenue at Washington Street	Through	Far-side
Massachusetts Avenue at Harrison Avenue	Through	Far-side
Massachusetts Avenue at Albany Street	Right	Near-side
Albany Street at Northampton Street	Through	Far-side
Melnea Cass Boulevard at Albany Street	Right	Near-side
Melnea Cass Boulevard at Harrison Street	Through	Near-side
Melnea Cass Boulevard at Washington Street	Left	Far-side
Washington Street at Williams Street/Eustis Street	Through	
Washington Street at Vernon Street	Through	

TABLE B-4 Locations of Traffic Signals and Bus Stops: Outbound - Boston

Signalized Intersection	Bus Movement	Stop Location
Washington Street at Williams Street/Eustis Street	Through	
Melnea Cass Boulevard at Washington Street	Right	Near-side
Melnea Cass Boulevard at Harrison Avenue	Through	Near-side
Melnea Cass Boulevard at Albany Street	Left	Far-side
Albany Street at Northampton Street	Through	Far-side
Albany Street at Massachusetts Avenue	Left	Far-side
Massachusetts Avenue at Harrison Avenue	Through	Near-side
Massachusetts Avenue at Washington Street	Through	Near-side
Massachusetts Avenue at Shawmut Avenue	Through	Far-side
Massachusetts Avenue at Tremont Street	Through	Near-side
Massachusetts Avenue at Columbus Avenue	Through	Near-side
Massachusetts Avenue at St. Botolph Street	Through	
Massachusetts Avenue at Huntington Avenue	Through	Near-side
Massachusetts Avenue at Westland Avenue	Through	Near-side
Massachusetts Avenue at Ped Signal North of Westland Avenue	Through	Far-side
Massachusetts Avenue at Belvidere Street	Through	Far-side
Massachusetts Avenue at Boylston Street	Through	
Massachusetts Avenue at Newbury Street	Through	Near-side
Massachusetts Avenue at Commonwealth Avenue	Through	Mid-block
Massachusetts Avenue at Marlborough Street	Through	
Massachusetts Avenue at Beacon Street	Through	Near-side

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APPENDIX C

Bus Boardings and Alightings

TABLE C-1 Inbound Stops and Load Profiles

Stop Name	Ons	Offs
BOL Dummy	18	0
Massachusetts Avenue at Holyoke Street	679	0
Massachusetts Avenue at Johnston Gate	253	2
Quincy Street at Broadway opposite Fogg Museum	130	9
Quincy Street at Harvard Street	81	0
Mt Auburn Street at DeWolfe Street	87	0
Mt Auburn Street at Putnam Street	203	24
Massachusetts Avenue at Bay Street	195	25
Massachusetts Avenue at Hancock Street	112	23
Massachusetts Avenue at Sellers Street	42	27
Massachusetts Avenue at Pleasant Street	132	69
Massachusetts Avenue at Pearl Street	964	265
Massachusetts Avenue at Sidney Street	290	90
Massachusetts Avenue at Landsdowne Street[4]	--	--
Massachusetts Avenue at Albany Street	138	78
84 Massachusetts Avenue	393	248
Massachusetts Avenue at Memorial Drive	34	3
Massachusetts Avenue at Beacon Street	29	245
Massachusetts Avenue at Commonwealth Avenue	33	158
Massachusetts Avenue at Newbury Street	411	919
Massachusetts Avenue opposite Christian Science Center	103	143
Massachusetts Avenue at Westland Avenue	184	290
Massachusetts Avenue at Huntington Avenue	193	153
Massachusetts Avenue at Massachusetts Avenue Station	527	254
Massachusetts Avenue at Columbus Avenue	51	68
Massachusetts Avenue at Tremont Street	39	142
Massachusetts Avenue at Shawmut Avenue	13	136
Massachusetts Avenue at Washington Street	66	204
Massachusetts Avenue at Harrison Avenue	440	841
Massachusetts Avenue at Albany Street	126	211
Albany Street at Northampton Street	13	33
Albany Street at Melnea Cass Boulevard	5	96
Melnea Cass Boulevard at Harrison Avenue	1	32
Washington Street at Melnea Cass Boulevard	1	33
Washington Street at Williams Street	3	75
Washington Street at Ruggles Street	1	61
Dudley Station	0	1,033
EOL Dummy	0	0

[4]No ridership information was collected for this bus stop.

TABLE C-2 Outbound Stops and Load Profiles

Stop Name	Ons	Offs
BOL Dummy	0	0
Dudley Station	1,191	0
Washington Street opposite Ruggles Street	85	1
Washington Street at Melnea Cass Boulevard	59	15
Melnea Cass Boulevard at Harrison Avenue	28	17
Albany Street opposite Randall Street	17	8
Albany Street opposite Northampton Street	4	19
Massachusetts Avenue at Albany Street	290	250
Massachusetts Avenue at Harrison Avenue	787	286
Massachusetts Avenue at Washington Street	233	44
Massachusetts Avenue at Shawmut Avenue	95	19
Massachusetts Avenue at Tremont Street	127	55
Massachusetts Avenue at Columbus Avenue	102	63
Massachusetts Avenue at Massachusetts Avenue Station	227	480
Massachusetts Avenue at St. Botolph Street	226	143
Massachusetts Avenue at Westland Avenue	357	111
Massachusetts Avenue at Clearway Street	109	77
Massachusetts Avenue at Belvidere Street	118	138
Massachusetts Avenue at Newbury Street	939	381
Massachusetts Avenue at Commonwealth Avenue	152	16
Massachusetts Avenue at Beacon Street	246	38
Massachusetts Avenue at Memorial Drive	1	77
77 Massachusetts Avenue	345	315
Massachusetts Avenue at Albany Street	49	133
Massachusetts Avenue at Front Street	29	133
Massachusetts Avenue at Main Street	63	242
Massachusetts Avenue at Prospect Street	304	944
Massachusetts Avenue at Bigelow Street	81	95
Massachusetts Avenue at Clinton Street	13	75
Massachusetts Avenue at Hancock Street	20	118
Massachusetts Avenue at Dana Street	20	210
Massachusetts Avenue at Trowbridge Street	22	215
Massachusetts Avenue at Quincy Street	1	212
Massachusetts Avenue at Holyoke Street	13	1,405
EOL Dummy	0	18

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APPENDIX D

Key Routes Initiative:
Preliminary Recommendations for Intersections

Inbound Bus Route

- DeWolfe Street at Mt. Auburn Street (Cambridge) – Early green/green extension
- Massachusetts Avenue at Hancock Street (Cambridge) – Early green/green extension
- Massachusetts Avenue at Essex Street (Cambridge) – Early green/green extension
- Massachusetts Avenue at Pedestrian Signal North of Pearl Street (Cambridge) – Early green/green extension
- Massachusetts Avenue at Brookline Street (Cambridge) – Early green/green extension
- Massachusetts Avenue at Sidney Street (Cambridge) – Early green/green extension
- Massachusetts Avenue at Landsdowne Street (Cambridge) – Early green/green extension
- Massachusetts Avenue at Albany Street (Cambridge) – Early green/green extension
- Massachusetts Avenue at Vassar Street (Cambridge) – Early green/green extension
- Massachusetts Avenue at Pedestrian Signal at MIT (Cambridge) – Early green/green extension
- Massachusetts Avenue at Beacon Street (Boston) – Queue jump
- Massachusetts Avenue at Marlborough Street (Boston) – Early green/green extension
- Massachusetts Avenue at Newbury Street (Boston) – Early green/green extension
- Massachusetts Avenue at Belvidere Street (Boston) – Early green/green extension
- Massachusetts Avenue at Pedestrian Signal North of Westland Avenue (Boston) – Early green/green extension
- Massachusetts Avenue at Westland Avenue (Boston) – Queue jump
- Massachusetts Avenue at St. Botolph Street (Boston) – Queue jump
- Massachusetts Avenue at Tremont Street (Boston) – Queue jump
- Massachusetts Avenue at Shawmut Avenue (Boston) – Queue jump
- Massachusetts Avenue at Harrison Avenue (Boston) – Early green/green extension
- Massachusetts Avenue at Albany Street (Boston) – Early green/green extension
- Albany Street at Northampton Street (Boston) – Early green/green extension
- Albany Street at Melnea Cass Boulevard (Boston) – Early green/green extension
- Melnea Cass Boulevard at Harrison Avenue (Boston) – Bus-only signal

Outbound Bus Route

- Melnea Cass Boulevard at Harrison Avenue (Boston) – Early green/green extension
- Melnea Cass Boulevard at Albany Street (Boston) – Early green/green extension
- Albany Street at Northampton Street (Boston) – Early green/green extension
- Albany Street at Massachusetts Avenue (Boston) – Early green/green extension
- Massachusetts Avenue at Harrison Avenue (Boston) – Queue jump
- Massachusetts Avenue at Shawmut Avenue (Boston) – Queue jump
- Massachusetts Avenue at Tremont Street (Boston) – Queue jump
- Massachusetts Avenue at St. Botolph Street (Boston) – Early green/green extension
- Massachusetts Avenue at Westland Avenue (Boston) – Early green/green extension
- Massachusetts Avenue at Pedestrian Signal North of Westland Avenue (Boston) – Early green/green extension
- Massachusetts Avenue at Belvidere Street (Boston) – Early green/green extension
- Massachusetts Avenue at Marlborough Street (Boston) – Early green/green extension
- Massachusetts Avenue at Beacon Street (Boston) – Queue jump
- Massachusetts Avenue at Memorial Drive (Cambridge) – Early green/green extension
- Massachusetts Avenue at Pedestrian Signal at MIT (Cambridge) – Early green/green extension
- Massachusetts Avenue at Vassar Street (Cambridge) – Early green/green extension
- Massachusetts Avenue at Albany Street (Cambridge) – Queue jump
- Massachusetts Avenue at Landsdowne Street (Cambridge) – Early green/green extension
- Massachusetts Avenue at Sidney Street (Cambridge) – Queue bypass
- Massachusetts Avenue at Douglass Street (Cambridge) – Early green/green extension
- Massachusetts Avenue at Essex Street (Cambridge) – Early green/green extension
- Massachusetts Avenue at Prospect Street (Cambridge) – Queue jump
- Massachusetts Avenue at Pleasant Street (Cambridge) – Early green/green extension
- Massachusetts Avenue at Hancock Street (Cambridge) – Queue jump
- Massachusetts Avenue at Trowbridge Street (Cambridge) – Queue bypass