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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 15**

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 15. Separate memoranda for Routes 66 and 111 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 15.
- 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 15,[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 15 operates between Ruggles Station, near Northeastern University, and Kane Square in Dorchester. It has differing inbound and outbound routes. It has 27 stops in the inbound direction (from Kane Square to Ruggles Station) and 23 stops in the outbound direction (from Ruggles Station to Kane Square). Figures 1 and 2 show the inbound and outbound routes, respectively, along with existing bus stop locations. Most of these stops are located near roadway intersections and maintain a pull-out area for the buses on the outside travel or parking lane next to a sidewalk curb. The route travels through 16 signalized intersections in both the inbound and outbound directions. 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) are 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 15 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 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 PM) 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 speeds include 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.

In the AM peak period in the inbound direction, the slowest speeds occurred between the Uphams Corner and Dudley Square commercial districts, and the average speed for the entire route was 12.52 mph. In the AM peak period in the outbound direction, the slowest speeds occurred on Tremont Street between Ruggles and Roxbury Crossing Stations and between the Dudley Square and Uphams Corner commercial districts; the average outbound speed for the entire route was 13.19 mph.

In the PM peak period in the inbound direction, as in the AM peak period, some of the slowest speeds occurred between the Uphams Corner and Dudley Square commercial districts. However, the average speed between Roxbury Crossing and Ruggles Station was even slower. The average inbound speed for the entire route in the PM peak period was 5.46 mph. In the PM peak period in the outbound direction, all route segments from Ruggles Station to Uphams Corner had average speeds below 10 mph. The average outbound speed for the entire route in the PM peak period was 8.96 mph.

In summary, Route 15 experienced significantly slower travel speeds in the PM peak period compared to the AM peak period and slightly slower travel speeds in the inbound direction compared to the outbound direction. The route segments between Dudley Station and Uphams

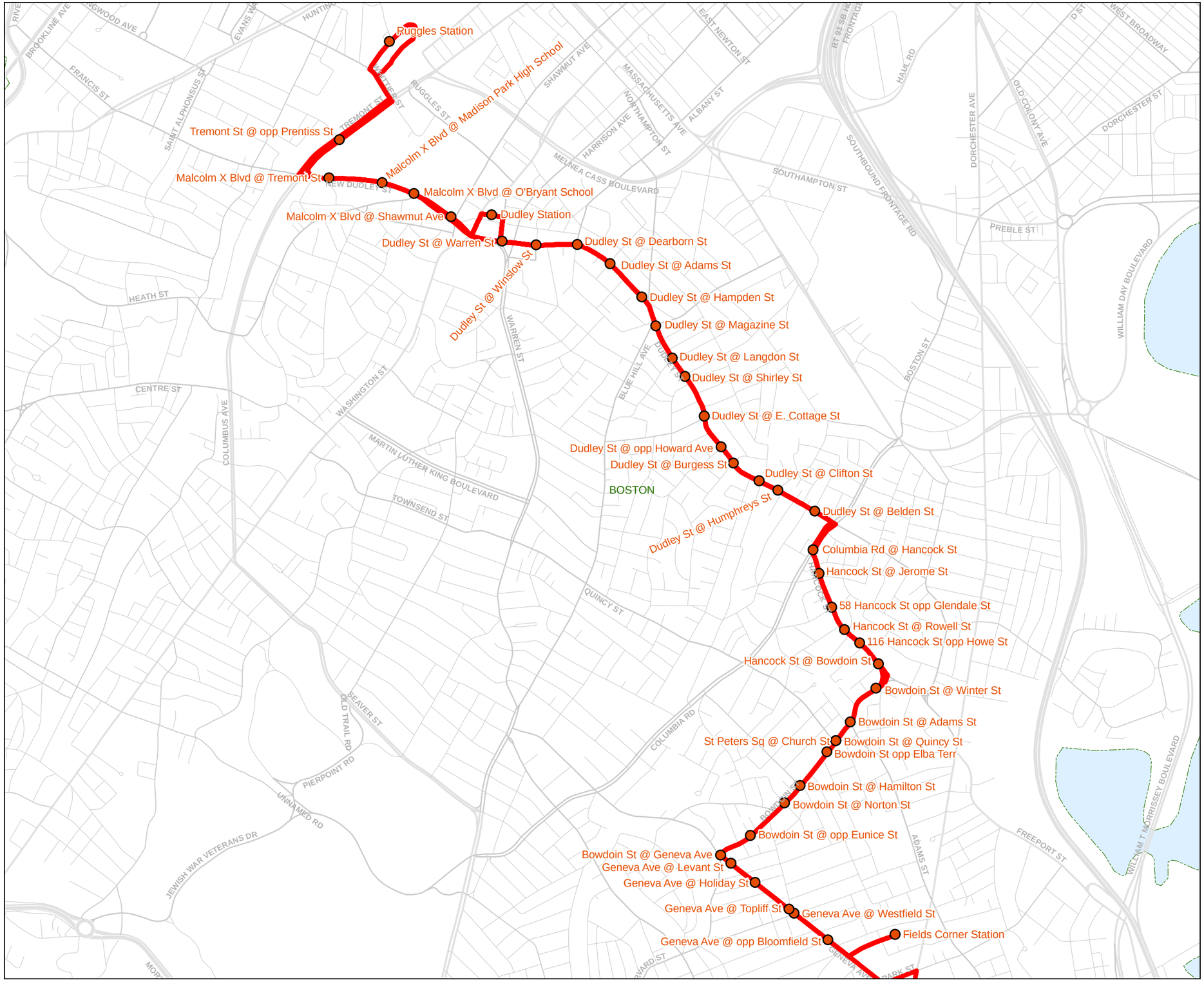

FIGURE 1
MBTA Bus Route 15
Route and Stop Locations: Inbound

Strategic Visioning for MBTA Bus Service: Route 15

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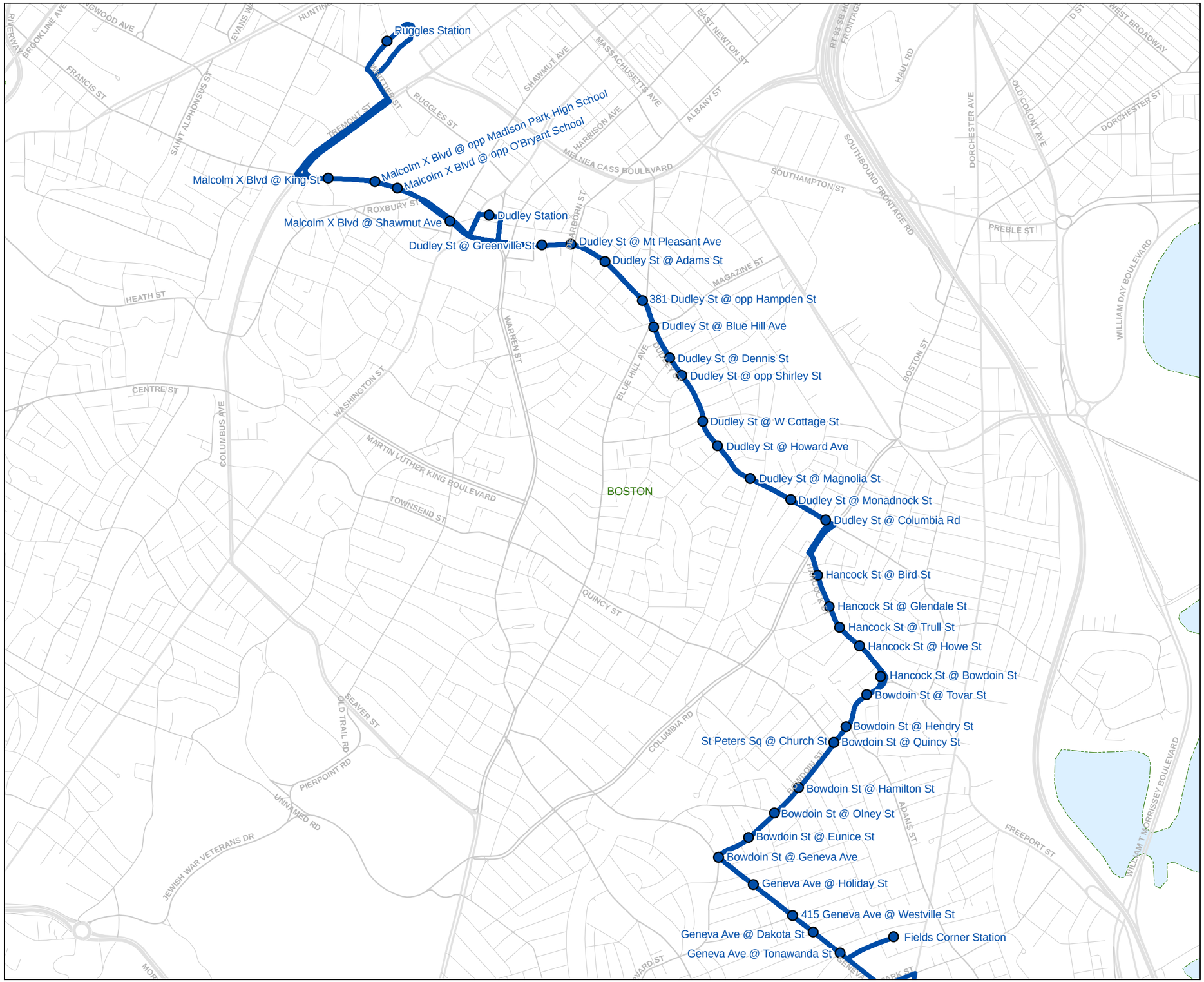

FIGURE 2
MBTA Bus Route 15
Route and Stop Locations: Outbound

Strategic Visioning for MBTA Bus Service: Route 15

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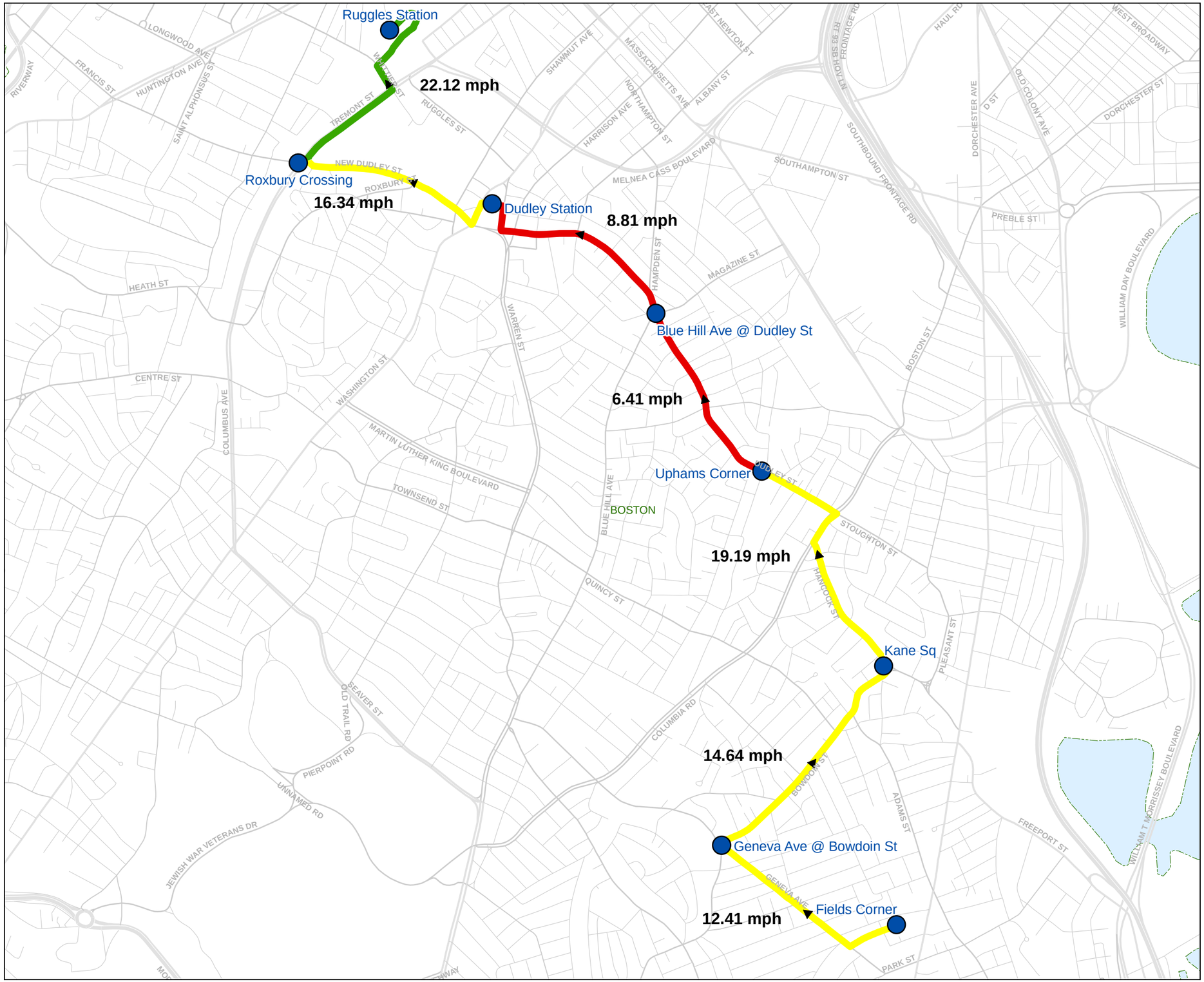

FIGURE 3
MBTA Bus Route 15
Average Travel Speeds:
AM Peak Period (6:00 - 10:00 AM)
Inbound

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.

Strategic Visioning for MBTA Bus Service: Route 15

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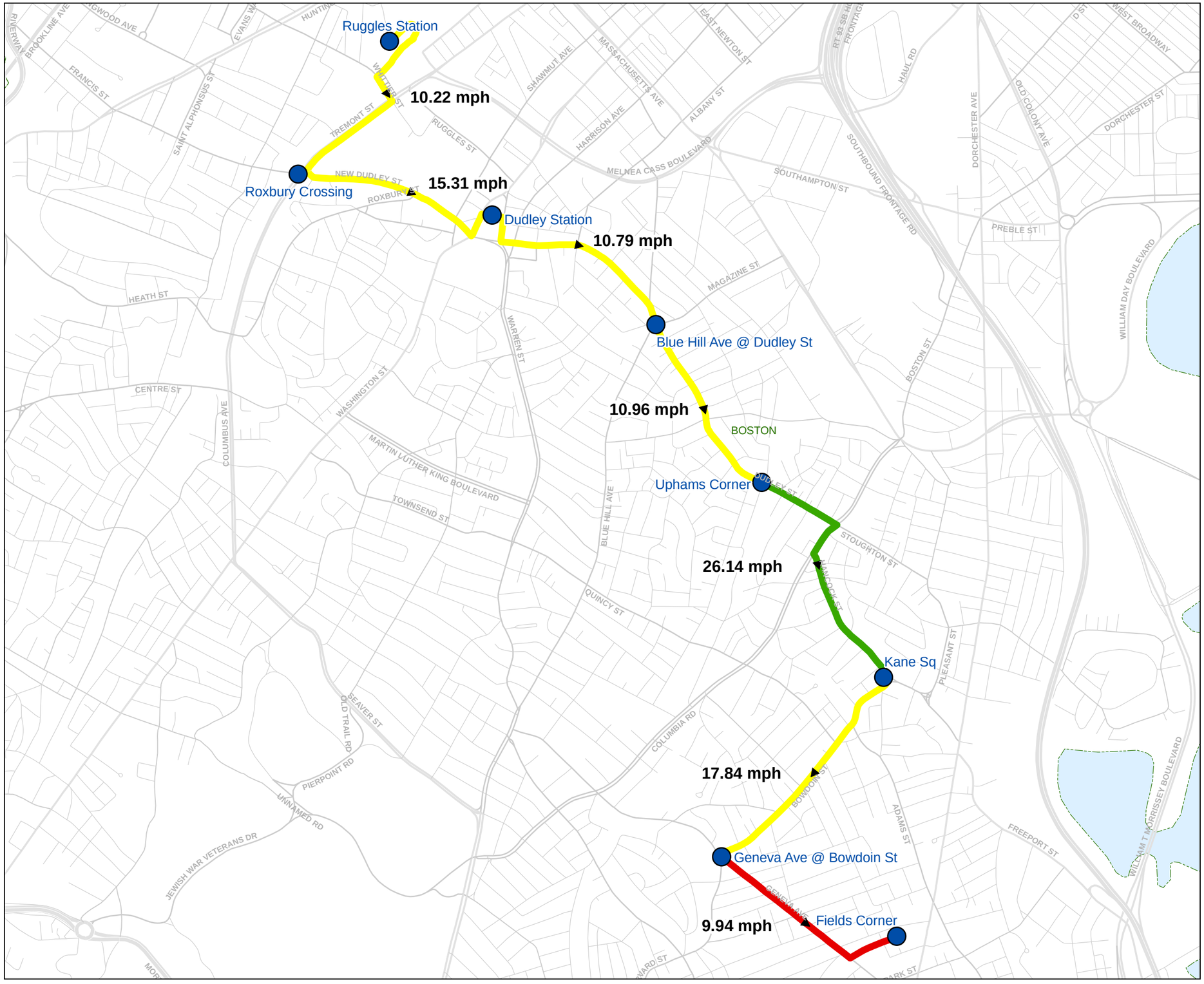

FIGURE 4
MBTA Bus Route 15
Average Travel Speeds:
AM Peak Period (6:00 - 10:00 AM)
Outbound

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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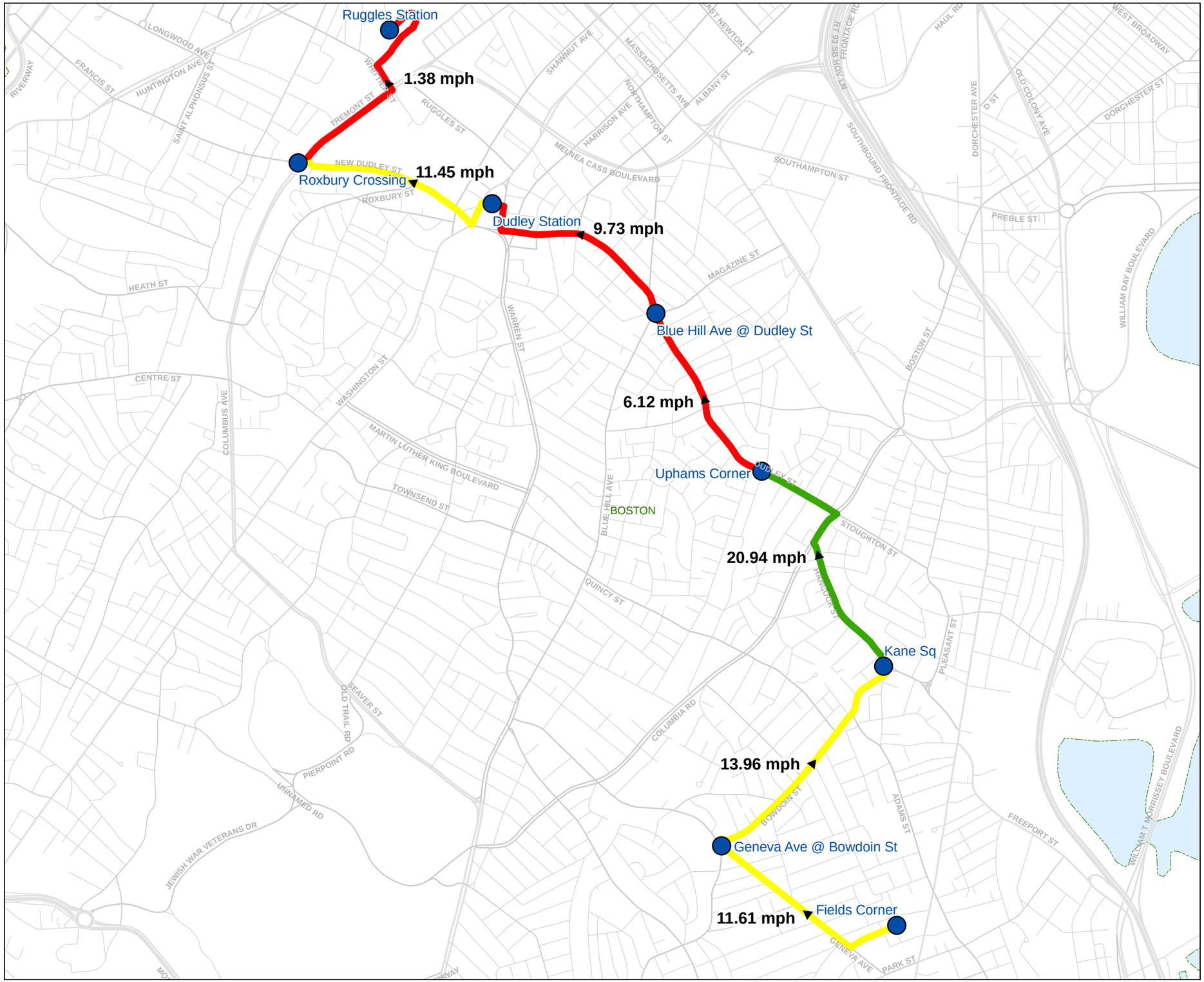

FIGURE 5
MBTA Bus Route 15
Average Travel Speeds:
PM Peak Period (3:00 - 6:00 PM)
Inbound

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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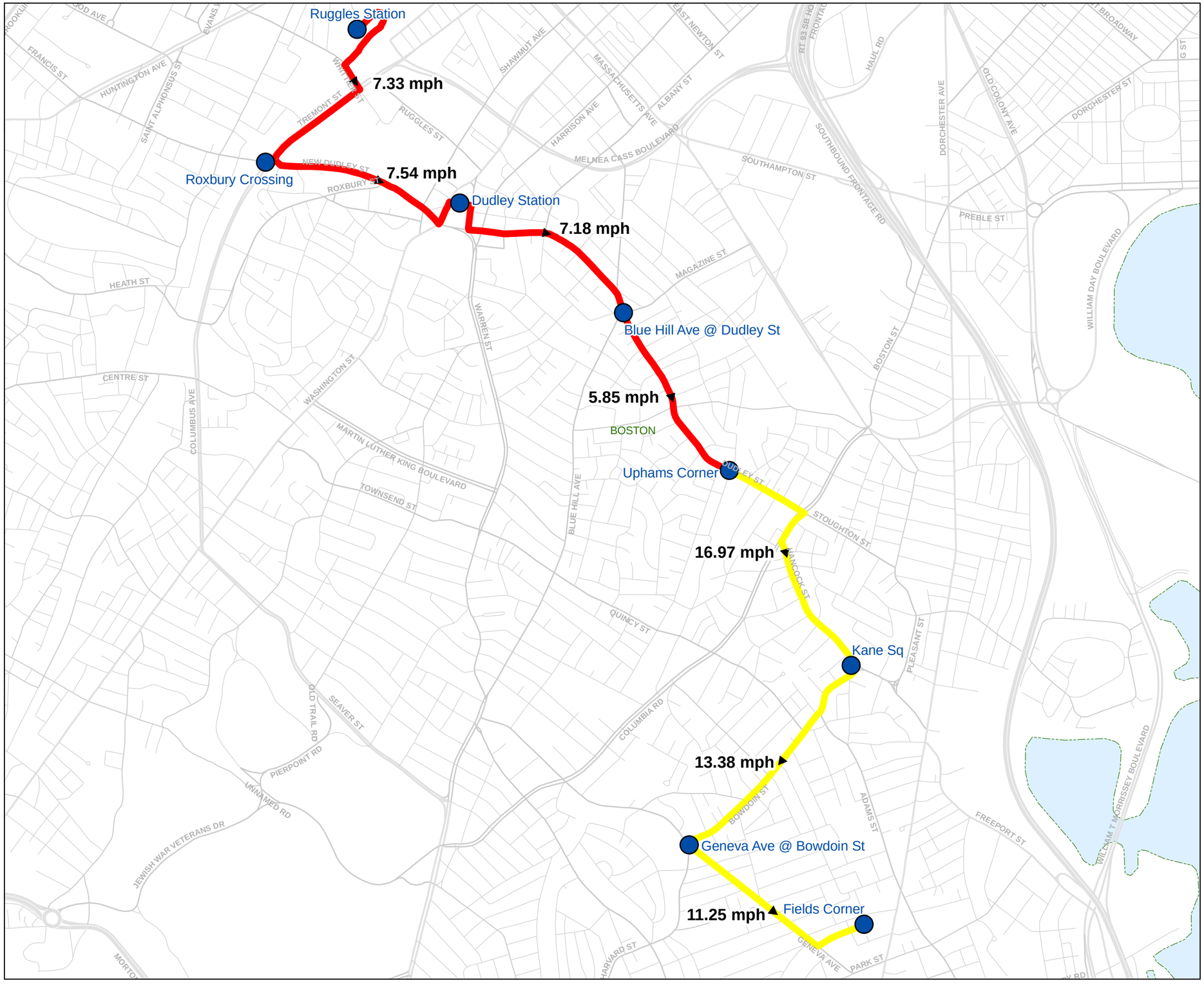

FIGURE 6
MBTA Bus Route 15
Average Travel Speeds:
PM Peak Period (3:00 - 6:00 PM)
Outbound

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.

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Corner consistently had some of the slowest travel speeds of all the route segment speeds, in both directions and peak periods. The route segment between Ruggles Station and Roxbury Crossing also had relatively slow speeds.

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 that the information is provided by bus stop and not signalized intersection as in the tables found in Appendix B. An important finding is that approximately 50% of the daily boardings and 48% of the daily alightings occur between Uphams Corner and Dudley Station, where the average bus speed is below 10 mph during the AM peak period (inbound route) and PM peak period (inbound and outbound routes).

INTERSECTION SCREENING

Bus Route 15 has 16 signalized intersections along its inbound and 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. The resulting preliminary recommendations for the signalized intersections with bus stops were as follows:

Inbound

- Hancock Street at Columbia Road – Queue jump
- Dudley Street at E. Cottage/W. Cottage Streets – Queue jump
- Dudley Street at Blue Hill Avenue – Queue jumpDudley Street at Hampden Street – Green extension/early green
- Dudley Street at Dearborn Street/Mt. Pleasant Street – Green extension/early green
- New Dudley Street at Harrison Avenue – Green extension/early green
- Tremont Street at Prentiss Street – Green extension/early green

Outbound

- Tremont Street at Prentiss Street – Green extension/early green
- Malcolm X Boulevard at Shawmut Avenue – Queue jump
- New Dudley Street at Harrison Avenue – Green extension/early green
- Dudley Street at Dearborn Street/Mt. Pleasant Street – Green extension/early green
- Dudley Street at Hampden Street – Green extension/early green
- Dudley Street at Blue Hill Avenue/Mt. Pleasant Street – Green extension/early green
- Dudley Street at E. Cottage/W. Cottage Streets – Green extension/early green
- Dudley Street/Stoughton Street at Columbia Road – Queue jump

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:

- Tremont Street at Prentiss Street
- Malcolm X Boulevard at Shawmut Avenue
- Dudley Street at Harrison Avenue
- Dudley Street at Dearborn Street/Mount Pleasant Street
- Dudley Street at Hampden Street
- Dudley Street at Blue Hill Avenue/Mount Pleasant Street
- Dudley Street at E. Cottage/W. Cottage Streets
- Dudley Street/Stoughton Street at Columbia Road
- Hancock Street at Columbia Road

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

Traffic operations at the selected intersections were analyzed using Synchro 7[2] and data provided by the Boston Transportation Department and 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 D in Tables D-1 and D-2 for the AM (7:00 to 9:00) and PM (4:00 to 6:00) peak hours, respectively.

The following scenarios were examined:

- **Existing Conditions** – Existing signal timings and phasings were used to evaluate the current 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 this would improve bus service by decreasing intersection delays. Some intersections timings are already optimal or 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 15 bus approaches to decrease bus delays. This alternative had various levels of impact on the operations of the non-bus approaches, depending on the amount of additional green time allocated to the bus approaches' signal phases. Typically, several seconds were added to the bus approach phases. This 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 for the Route 15 bus. Queue jumps were also analyzed as part of this alternative.

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.

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

INTERSECTION LEVEL OF SERVICE

Existing Conditions

The results of the existing conditions analysis indicate that there are three intersections that are operating at level of service (LOS) E or worse. The Tremont Street at Prentiss Street and Hancock Street at Columbia Road intersections operate at LOS E during the AM peak hour. In the PM peak hour, both the Hancock Street at Columbia Road intersection and the Dudley Street at Blue Hill Avenue/Mount Pleasant Street intersection operate at LOS F.

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. However, in both the AM and PM peak hours, total intersection delays and bus approach delays were reduced by improving the intersection timings at the Dudley Street/Stoughton Street at Columbia Road and Hancock Street at Columbia Road intersections.

Alternative 2: Added Green Time on Bus Approaches

This alternative, lengthening the green time for the bus approaches to the intersection, reduced intersection delay for the buses significantly. However, this alternative frequently added delays to the side street (non-bus) approach lanes, because the added green time for the bus approaches was taken from these phases.

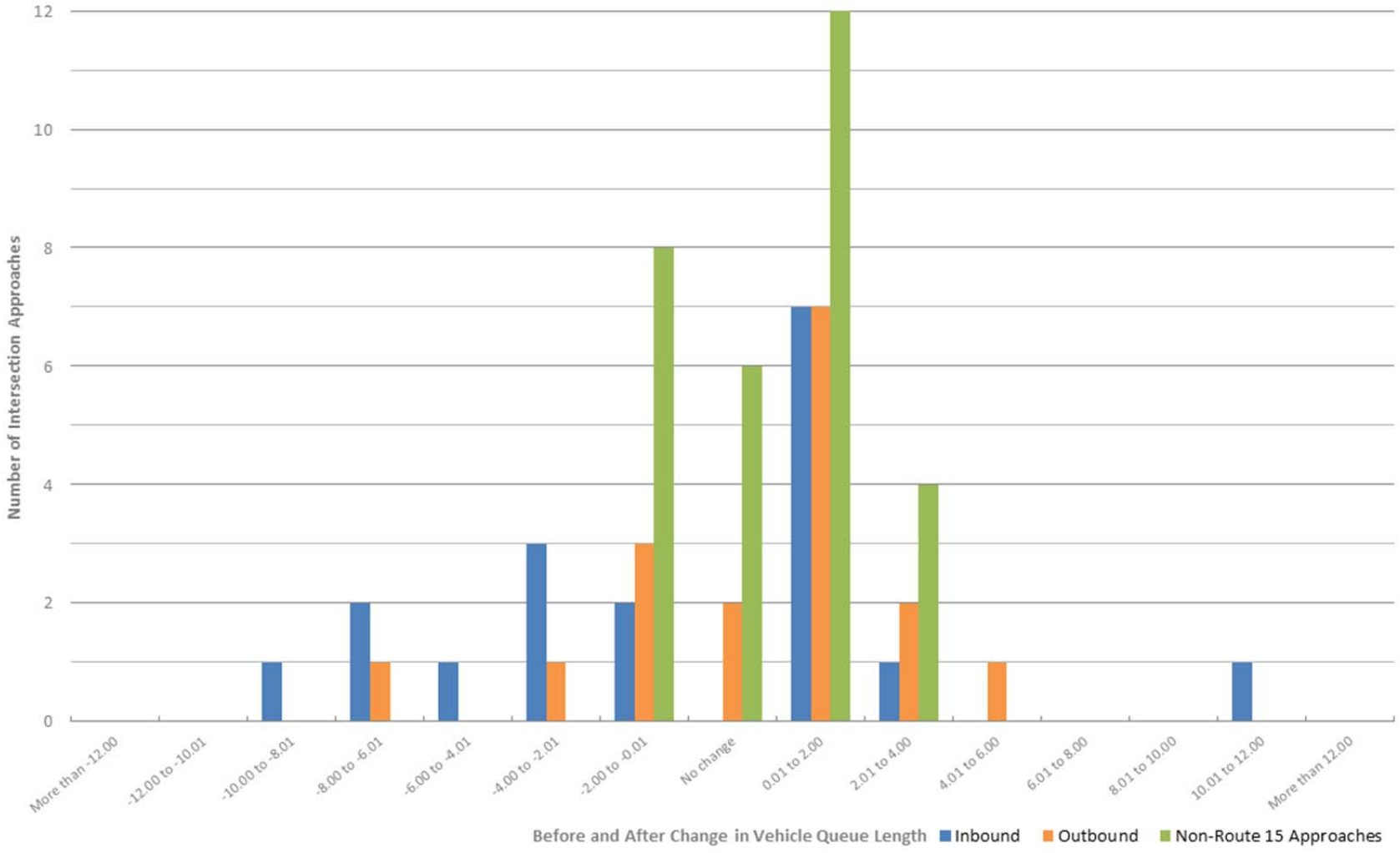
Alternative 3: Transit Signal Priority and Queue Jumps

TSP improvements also decreased delay for the buses. However, as in Alternative 2, there were frequently negative impacts on the side street traffic. On many of the approaches used by buses, however, the impacts on queue length were trivial, less than a few feet. Figure 7 presents the various amounts of change in vehicle queue length that occurred and the number of approaches that experienced each amount.

For 6% of the bus approaches, queue length remained unchanged with TSP; for 14% it decreased by two or fewer vehicles; and for 40% it increased by two or fewer vehicles. In most of the cases where the queue length change was greater than two vehicles, the change was only a few feet longer. Of the non-bus approaches, 44% had no queue length change due to TSP, 17% had a two-vehicle-or-less queue reduction due to TSP, and 36% had a two-vehicle-or-less queue increase due to TSP.

FIGURE 7 Route 15 Transit Signal Priority AM and PM Peak Hour

Change in Vehicle Queue Length by Number of Intersection Approaches due to 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, both inbound and outbound, bus delays are higher during the PM peak hour than during the AM peak hour. In the outbound direction, the delay per bus was nearly twice as high in the afternoon as in the morning; in the inbound direction, the delay per bus was approximately 56% higher in the afternoon.

Implementing TSP or modifying signal timings for intersections along Route 15 can decrease bus delay. Information about the number of peak-hour Route 15 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.

With the improvements, in the outbound direction, total bus delay decreases by approximately 23% in the morning and 45% in the afternoon; in the inbound direction, total bus delay decreases by 56% in the morning and 63% in the afternoon.

Bus Travel Times

Directional, peak-hour travel times for Route 15 range between 20 and 30 minutes, generally (a few trips take over 50 minutes), depending on the time of day. Giving buses extended green signals and providing buses with signal priority at the seven recommended intersections generally significantly decreases buses' travel times.

Significant travel time savings are gained from providing improved signal timings at the intersections of Dudley Street at Columbia Road and Hancock Street at Columbia Road. For some cycles, Dudley Street at Columbia Road provides too much green time to left-turning vehicles. By changing the exclusive left-turn phase on Columbia Road southbound to a shorter exclusive left-turn phase with a leading green phase, through traffic traveling along Columbia Road is more effectively served. In addition, if the left-turn demand at the time of a given phase is light or metered by an upstream signal, the through and right-turn phase receives extra time. The extra capacity given to through traffic on Columbia Road allows it to serve more vehicles. The extra capacity is important because a recommended overlapped right turn/leading green phase at Hancock Street at Columbia Road will put more vehicles on the northbound approach at the Dudley Street 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.

TABLE 1
Number of Peak-Hour Buses and Passengers

Period/Direction	Buses	Passengers
AM Inbound	10	122
AM Outbound	17	792
PM Inbound	9	387
PM Outbound	7	234

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

Period and Direction	Total: Existing	Total with Recommended Improvements[1]	Per Bus[2]: Existing	Per Bus with Recommended Improvements	Per Bus: Absolute Change with Improvements	Percentage Change with Improvements
AM Inbound						
Passenger-Minutes	2,808.4	1,427.7	165.2	84.0	-81.2	-49%
Bus-Minutes	111.4	49.6	6.6	2.9	-3.6	-56%
AM Outbound						
Passenger-Minutes	168.3	141.2	16.8	14.1	-2.7	-16%
Bus-Minutes	37.0	28.6	3.7	2.9	-0.8	-23%
PM Inbound						
Passenger-Minutes	699.3	369.6	99.9	52.8	-47.1	-47%
Bus-Minutes	71.8	26.7	10.3	3.8	-6.4	-63%
PM Outbound						
Passenger-Minutes	1,362.6	791.4	151.4	87.9	-63.5	-42%
Bus-Minutes	68.2	37.3	7.6	4.1	-3.4	-45%

1. Recommended improvements to intersection are intersection signal timing modifications, TSP, and queue jumps.
2. Per-bus delays are total delays divided by the number of buses in the peak hour.

Applying signal priority, modified signal timings, and modified signal phasings decreases total passenger delay in the morning peak hour by 16% in the inbound direction and 49% in the outbound direction. During the afternoon peak hour, the improvements decrease passenger delay by just over 47% in the inbound direction and 42% in the outbound direction.

Bus Stops

Most of the bus stops are currently in good locations for transit signal priority. Two stops in the inbound direction (Tremont opposite Prentiss and Dudley at Dearborn) should be moved to the far side of the intersection or eliminated. The outbound stop at Dudley opposite Hampden Street is in a less-than-ideal, near-side location; however, this stop provides good connectivity to the area, and moving the stop to the far side of the intersection is not a favorable option. The success of transit signal priority in the outbound direction at this intersection may be limited. The inbound stop is in a good location. At Dudley Street at Columbia Road and Hancock Street at

Columbia Road, to provide for the recommended queue jump lanes, the bus stops would need to be extended or moved.

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

With the recommended improvements, traffic traveling along Route 15's route (in other words, using the same approach as the bus at each intersection) is delayed less at intersections, on average. Modifying the signal sequence and timings at Dudley Street at Columbia Road and Hancock Street at Columbia Road would be expected to result in significant travel time savings for drivers. Currently, the queues for vehicles traveling northbound on Hancock Street can become extremely long. Signal improvements help reduce the queue length and allow more vehicles to travel through the intersection. Reclaiming unused time from the exclusive left-turn phase at Dudley Street and Columbia Road gives Columbia Road a little extra capacity.

A shared right-turn/queue-jump lane at Dudley Street at Cottage Street helps reduce through and left-turn queues, while reducing delay to buses and vehicles making right turns.

The total delays for vehicles traveling on the same approach as Route 15 buses are shown in Table 3 for existing conditions and with the recommended improvements. In the morning, vehicle delay decreases by 26% in the outbound direction and 62% in the inbound direction. In the afternoon, vehicle delay decreases by 48% in the outbound direction and 77% in the inbound direction.

TABLE 3
Total Peak-Hour Vehicle Delay for General Traffic on Route 15
(Total Vehicle-Minutes at All Intersection Approaches Used)

Period and Direction	Existing Conditions	With Recommended Improvements[1]	Absolute Change	Percentage Change
AM Inbound	1,867.3	715.4	-1,151.9	-62%
AM Outbound	1,466.0	1,089.8	-376.2	-26%
PM Inbound	3,333.3	775.0	-2,558.3	-77%
PM Outbound	4,089.3	2,117.2	-1,972.1	-48%

1. Recommended improvements to intersections are intersection signal timing modifications, TSP, and queue jumps.

Parking

Parking is not expected to change significantly. To make room for a shared right-turn/queue-jump lane at the outbound stop at Dudley and Columbia, at least five to six parking spaces would need to be recovered. Five to six parking spaces and a driveway would be enough space to bypass the expected morning and afternoon queues in the improved scenario. To avoid queues caused by heavy congestion, which sometimes occurs due to a traffic incident, nearly double that number of spaces would need to be recovered.

Pedestrian

Pedestrians are mostly unaffected by the changes proposed in this memorandum. Dedicated pedestrian phases are not modified. At Dudley Street at Columbia Road, the only intersection where the pedestrian phase runs concurrently, pedestrian phases are altered, but there is still ample time to cross the street.

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.

TABLE 4
Recommended Improvements

Intersection	Municipality	Recommended Improvement
Tremont Street at Prentiss Street	Boston	• TSP (IB/OB)
Dudley Street at Blue Hill Avenue/Mount Pleasant Street	Boston	• Retime signals
Dudley Street at E./W. Cottage Streets	Boston	• TSP (IB/OB) • Add a shared right-turn/queue jump lane (IB)
Dudley Street at Columbia Road	Boston	• Add queue-jump along Dudley Street (OB) • Actuate dedicated left-turn phase • Retime signals • Change signal phasing
Hancock Street at Columbia Road	Boston	• Retime signal in conjunction with Dudley Street at Columbia Road

Adding TSP at the intersection of *Tremont Street at Prentiss Street,* adding a shared right-turn/queue-jump lane and TSP at the intersection of *Dudley Street at E./W. Cottage Streets,* and modifying signal timings and adding a queue jump lane with TSP at the intersections of *Dudley Street at Columbia Road* and *Hancock Street at Columbia Road* are four immediately

recommended improvements. Modifying the signal timing at the intersection of *Dudley Street at Blue Hill Avenue and Magazine Street* is a an option that should be given consideration.

Adding TSP at the intersection of *Tremont Street and Prentiss Street* is very beneficial to buses and other vehicles traveling outbound. Side street traffic is fairly light and adverse effects on it are small. This improvement would require moving the inbound bus stop from the near side of the intersection to the far side. Street furniture that is currently at the near side of the intersection would need to be relocated.

Adding TSP and a shared right-turn/queue-jump lane on northbound *Dudley Street at E./W. Cottage* has a positive effect on traffic operations at the intersection. The northbound queue lengths decrease, while vehicles are able to make right turns more easily. TSP decreases delay for Dudley Street at the cost of slightly increased delay on East Cottage/West Cottage Streets, where volumes are small compared to Dudley Street volumes.

The largest performance gains come from modifying the signal timing plan and extending/moving bus stops to make queue jumps at the intersections of *Dudley Street at Columbia Road* and *Hancock Street at Columbia Road*. The dedicated left-turn phase at the intersection of *Dudley Street at Columbia Road* is a few seconds too long for most cycles. Making these phases actuated and giving unused time to Columbia Road helps improve operations. The northbound protected left-turn phase is extended five seconds over existing AM peak-hour conditions. In the afternoon, the southbound protected left-turn phase is extended five seconds. Extending the protected time helps serve the peak direction. An overlapped right-turn phase is added to help move eastbound vehicles during the protected left-turn phase. Moving the bus stop back to the driveway just north of the intersection (and beginning the queue jump lane there) would likely be sufficient to jump most queues. The overlapped right-turn phase would likely keep right-turning vehicles out of the bus stop most of the time. The *Hancock Street at Columbia Road* signal is retimed in conjunction with the Dudley Street intersection to provide for improved overall traffic operations.

Modifying the signal timing at *Dudley Street at Blue Hill Avenue and Magazine Street* would be beneficial not only to the buses but to all vehicles using the Dudley Street approaches. This gain comes at the cost of increased delay for Blue Hill Avenue.

Buses do not suffer significant delay at the other intersections, and therefore those locations would not benefit greatly from the kinds of treatments being considered in this study. While it would be beneficial to eventually add preferential treatments at those intersections, they are not as high a priority as the intersections recommended for improvements in this memorandum.

MSA/SA/msa/sa

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
Bowdoin Street at Hancock Street (Kane Square) – ped. signal	Left	
Hancock Street at Cameron Street – ped. signal	Through	Mid-block
Hancock Street at Columbia Road	Right	Far-side
Columbia Road at Dudley Street/Stoughton Street	Left	
Dudley Street at East Cottage Street/West Cottage Street	Through	Far-side
Dudley Street at Blue Hill Avenue/Mount Pleasant Street	Through	Near-side
Dudley Street at Hampden Street	Through	Far-side
Dudley Street at Dearborn Street/Mount Pleasant Street	Through	Near-side
New Dudley Street at Harrison Avenue	Through	
Dudley Street at Warren Street	Left	Near-side
Washington Street at Dudley Street/Malcolm X Boulevard	Right	
Malcolm X Boulevard at Shawmut Avenue	Through	Near-side
Malcolm X Boulevard at Madison Park High School – ped. sig.	Through	Mid-block
Malcolm X Boulevard at Tremont Street/Columbus Avenue	Right	Near-side
Tremont Street at Prentiss Street	Through	Near-side
Tremont Street Ruggles Street/Whittier Street	Left	

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

Signalized Intersection	Bus Movement	Stop Location
Ruggles Street/Whittier Street at Tremont Street	Right	
Tremont Street at Prentiss Street	Through	Near-side
Tremont Street/Columbus Avenue at Malcolm X Boulevard	Left	
Malcolm X Boulevard at Madison Park High School – ped. sig.	Through	Mid-block
Malcolm X Boulevard at Shawmut Avenue	Through	Far-side
Dudley Street/Malcolm X Boulevard at Washington Street	Through	
Dudley Street at Warren Street	Left	
Washington Street at Dudley Street/Malcolm X Boulevard	Left	
Dudley Street at Warren Street	Through	
New Dudley Street at Harrison Avenue	Through	
Dudley Street at Dearborn Street/Mount Pleasant Street	Through	Far-side
Dudley Street at Hampden Street	Through	Near-side
Dudley Street at Blue Hill Avenue/Mount Pleasant Street	Through	Far-side
Dudley Street at East Cottage Street/West Cottage Street	Through	Far-side
Dudley Street/Stoughton Street at Columbia Road	Right	Near-side
Hancock Street at Columbia Road	Left	
Hancock Street at Cameron Street – ped. signal	Through	
Hancock Street (Kane Square) at Bowdoin Street – ped. signal	Right	Mid-block

APPENDIX C

Bus Boardings and Alightings

TABLE C-1 Inbound Stops and Load Profiles

Stop Name	Ons	Offs
BOL Dummy	10	0
Hancock Street at Bowdoin Street	547	2
116 Hancock Street opposite Howe Street	79	0
Hancock Street at Rowell Street	78	4
58 Hancock Street opposite Glendale Street	54	3
Hancock Street at Jerome Street	95	30
Hancock Street at Columbia Road	302	48
Dudley Street at Belden Street	469	19
Dudley Street at Humphrey Street	236	12
Dudley Street at Clifton Street	159	14
Dudley Street at Burgess Street	76	10
Dudley Street opposite Howard Avenue	116	31
Dudley Street at East Cottage Street	196	81
Dudley Street at Shirley Street	85	32
Dudley Street at Langdon Street	115	30
Dudley Street at Magazine Street	140	70
Dudley Street at Hampden Street	66	17
Dudley Street at Adams Street	36	31
Dudley Street at Dearborn Street	12	41
Dudley Street at Winslow Street	9	75
Dudley Street at Warren Street	9	450
Dudley Station	389	949
Malcolm X Boulevard at Shawmut Street	19	28
Malcolm X Boulevard at O'Bryant High School	30	78
Malcolm X Boulevard at Madison Park High School	14	189
Malcolm X Boulevard at Tremont Street	21	198
Tremont Street opposite Prentiss Street	5	35
Ruggles Station	0	1084
EOL Dummy	0	2

TABLE C-2 Outbound Stops and Load Profiles

Stop Name	Ons	Offs
BOL Dummy	0	0
Ruggles Station	995	0
Malcolm X Boulevard at King Street	253	7
Malcolm X Boulevard opposite Madison Park High School	200	6
Malcolm X Boulevard opposite O'Bryant High School	62	7
Malcolm X Boulevard at Shawmut Avenue	8	24
Dudley Station	1263	112
Dudley Street at Greenville Street	77	48
Dudley Street at Mount Pleasant Street	51	52
Dudley Street at Adams Street	21	70
381 Dudley Street opposite Hampden Street	15	98
Dudley Street at Blue Hill Avenue	92	157
Dudley Street at Dennis Street	33	118
Dudley Street opposite Shirley Street	33	170
Dudley Street at West Cottage Street	73	191
Dudley Street at Howard Avenue	27	159
Dudley Street at Magnolia Street	15	189
Dudley Street at Monadnock Street	4	198
Dudley Street at Columbia Road	85	641
Hancock Street at Bird Street	23	201
Hancock Street at Glendale Street	5	96
Hancock Street at Trull Street	1	94
Hancock Street at Howe Street	0	33
Hancock Street at Bowdoin Street	1	446
EOL Dummy	0	10

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APPENDIX D

Peak-Hour Traffic Analysis
Using Synchro 7

TABLE D-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]
Tremont at Prentiss															Green extension		
Prentiss St – EB	LR	F	101.4	1.00	144	F	202.7	1.27	183	F	256.3	1.40	194	F	114.7	1.03	166
Tremont St – NB	L	F	398.6	1.77	274	F	99.1	1.09	237	F	261.5	1.47	217	F	413.1	1.83	276
Tremont St – NB	**TR**	**F**	**17.1**	**1.80**	**217**	**B**	**19.0**	**0.87**	**306**	**B**	**13.8**	**0.86**	**185**	**C**	**20.2**	**0.88**	**513**
Tremont St – SB	**LTR**	**C**	**34.0**	**0.80**	**409**	**D**	**51.0**	**0.95**	**462**	**C**	**30.3**	**0.78**	**388**	**B**	**18.0**	**0.77**	**340**
Overall		**E**	**70.9**	**1.61**	**–**	**D**	**50.8**	**1.10**	**–**	**E**	**62.9**	**1.45**	**–**	**E**	**69.5**	**1.58**	**–**
Malcolm X at Shawmut															OB queue jump		
Malcolm X Blvd – EB	**QJ**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**B**	**16.3**	**0.03**	**3**
Malcolm X Blvd – EB	**LTR**	**B**	**16.6**	**0.29**	**70**	**B**	**16.8**	**0.29**	**70**	**B**	**16.2**	**0.29**	**71**	**B**	**19.0**	**0.31**	**70**
Dudley St – WB	**LTR**	**A**	**2.6**	**0.38**	**13**	**A**	**3.1**	**0.68**	**12**	**A**	**2.6**	**0.37**	**13**	**A**	**8.1**	**0.39**	**22**
Shawmut St – NB	L	D	47.9	0.91	215	D	47.1	0.90	213	D	52.1	0.92	217	D	48.8	0.91	207
Shawmut St – NB	TR	B	18.8	0.27	45	B	18.7	0.27	46	B	19.2	0.27	46	B	19.1	0.27	46
Shawmut St – SB	L	C	21.4	0.19	40	C	21.3	0.19	40	C	21.9	0.19	39	C	21.4	0.19	40
Shawmut St – SB	T	C	22.2	0.27	68	C	22.0	0.27	69	C	22.6	0.27	68	C	22.2	0.27	68
Shawmut St – SB	R	C	24.6	0.50	117	C	24.5	0.49	118	C	25.1	0.50	117	C	24.6	0.50	117
Overall		**C**	**20.5**	**0.61**	**–**	**C**	**20.4**	**0.61**	**–**	**C**	**21.3**	**0.61**	**–**	**C**	**22.5**	**0.64**	**–**
Dudley at Harrison															Green extension		
Dudley St – EB	L	C	21.4	0.63	26	C	30.7	0.73	34	B	18.2	0.60	28	B	15.8	0.57	70
Dudley St – EB	**TR**	**A**	**6.5**	**0.37**	**32**	**A**	**8.4**	**0.39**	**44**	**A**	**6.3**	**0.36**	**35**	**B**	**14.6**	**0.45**	**121**
Dudley St – WB	L	C	22.1	0.16	22	C	20.7	0.15	21	C	20.7	0.15	21	C	20.1	0.15	22
Dudley St – WB	**TR**	**D**	**36.4**	**0.74**	**215**	**C**	**32.9**	**0.70**	**207**	**C**	**32.9**	**0.70**	**207**	**C**	**28.6**	**0.68**	**215**
Harrison Ave – NB	LT	D	39.6	0.91	315	C	28.9	0.84	280	D	50.9	0.96	322	E	64.3	0.96	297
Harrison Ave – NB	R	A	8.0	0.13	12	A	6.4	0.12	10	A	9.1	0.14	12	C	24.8	0.14	22
Harrison Ave – SB	L	C	26.3	0.25	12	C	22.6	0.20	11	C	30.0	0.30	12	C	32.7	0.30	14
Harrison Ave – SB	TR	C	28.2	0.62	129	**C**	**25.1**	**0.57**	**127**	**C**	**30.7**	**0.66**	**131**	D	35.9	0.66	175
Overall		**C**	**27.7**	**0.79**	**–**	**C**	**24.9**	**0.78**	**–**	**C**	**29.9**	**0.79**	**–**	**C**	**35.0**	**0.77**	**–**

TABLE D-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]
Dudley at Dearbrn/Mt. Plsnt						Existing timings optimal								Green extension			
Dudley St – EB	**LT**	**B**	**16.6**	**0.81**	**86**					**B**	**15.2**	**0.80**	**93**	**B**	**14.5**	**0.79**	**94**
Dudley St – WB	**TR**	**A**	**7.6**	**0.62**	**75**					A	7.3	0.60	80	**A**	**7.2**	**0.60**	**82**
Mt. Pleasant Ave – NB	LTR	D	29.5	0.55	35					C	32.5	0.56	39	C	33.0	0.57	36
Dearborn St – SB	LR	E	34.3	0.64	35					D	39.0	0.66	39	D	40.2	0.67	35
Overall		**C**	**15.3**	**0.78**	**–**					B	15.4	0.77	**–**	**B**	**15.2**	**0.77**	**–**
Dudley at Hampden														Green extension			
Dudley St – NB	**L**	**B**	**14.4**	**0.64**	**79**	B	14.1	0.64	78	**B**	**14.1**	**0.64**	**80**	**B**	**12.5**	**0.56**	**91**
Dudley St – NB	TR	B	14.9	0.67	89	B	14.7	0.67	88	B	14.7	0.67	90	B	16.3	0.72	139
Hampden St – SB	LTR	C	23.2	0.66	52	C	23.6	0.67	52	C	23.6	0.67	52	C	28.5	0.70	66
Dudley St – SE	LT	B	12.2	0.50	27	**B**	**12.0**	**0.50**	**27**	B	12.0	0.50	27	B	11.2	0.42	32
Dudley St – SE	**R**	**B**	**11.3**	**0.41**	**41**	B	11.2	0.41	40	**B**	**11.2**	**0.41**	**41**	**B**	**10.7**	**0.37**	**49**
Overall		**B**	**16.2**	**0.67**	**–**	B	16.1	0.67	**–**	**B**	**16.1**	**0.67**	**–**	**B**	**17.3**	**0.71**	**–**
Dudley at BHAve/Mt. Plsnt														OB–g.ext; IB–q. jump			
Magazine St – WB	LTR	D	54.4	0.72	82	E	70.9	0.84	86	E	63.5	0.79	86	F	42.6	1.04	131
Blue Hill Ave – NB	LTR	E	74.7	1.03	215	E	62.9	0.99	211	F	93.4	1.08	226	F	37.6	1.12	266
Dudley St – SB	**LT**	**C**	**31.0**	**0.59**	**123**	**C**	**29.6**	**0.57**	**121**	**C**	**27.8**	**0.54**	**118**	**C**	**23.9**	**0.52**	**124**
Dudley St – SB	TR	D	35.8	0.72	158	C	33.8	0.69	155	C	31.4	0.66	152	C	25.0	0.61	158
Dudley St – NW	LT	D	49.1	0.84	144	D	43.1	0.79	140	D	37.2	0.74	135	E	65.3	0.98	270
Dudley St – NW	**TR**	**D**	**42.2**	**0.79**	**156**	**D**	**39.2**	**0.76**	**153**	**D**	**35.7**	**0.72**	**150**	**C**	**21.0**	**0.22**	**43**
Overall		**D**	**53.0**	**0.88**	**–**	**D**	**48.4**	**0.88**	**–**	**E**	**56.5**	**0.86**	**–**	**E**	**72.6**	**1.04**	**–**
Dudley at E./W. Cottage						Existing timings optimal								OB–g.ext; IB–shared RT/QJ			
W. Cottage St – EB	LTR	C	25.8	0.40	52					**C**	**29.6**	**0.46**	**56**	C	28.9	0.43	52
E. Cottage St – WB	LTR	D	36.3	0.70	86					**D**	**46.7**	**0.79**	**92**	D	42.6	0.75	87
Dudley St – NB	**LTR**	**B**	**19.8**	**0.75**	**172**					B	16.7	0.71	158	**B**	**13.1**	**0.66**	**149**
Dudley St – NB	**R/QJ**	–	–	–	–					–	–	–	–	**A**	**7.5**	**0.06**	**0**
Dudley St – SB	**LTR**	**B**	**11.9**	**0.40**	**66**					**B**	**10.4**	**0.38**	**61**	**A**	**9.3**	**0.37**	**66**
Overall		**C**	**21.6**	**0.73**	**–**					**C**	**22.2**	**0.73**	**–**	**B**	**19.1**	**0.69**	**–**

TABLE D-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]
Dudley/Stghtn at Columbia														OB queue jump and sig. impr.			
Dudley St – EB	LT	F	207.3	1.30	246	E	75.7	0.94	183	E	59.7	0.87	175	F	91.5	1.00	186
Dudley St – EB	**R**	**C**	**30.8**	**0.20**	**22**	**C**	**25.4**	**0.16**	**14**	C	24.0	0.16	13	**B**	**17.5**	**0.19**	**37**
Stoughton St – WB	LTR	D	39.5	0.64	120	C	32.2	0.57	128	C	30.1	0.54	123	C	29.9	0.53	100
Columbia Rd – NB	**L**	**C**	**22.8**	**0.62**	**67**	**C**	**31.5**	**0.72**	**79**	D	35.4	0.75	83	**C**	**22.0**	**0.70**	**79**
Columbia Rd – NB	TR	D	52.5	0.98	493	D	40.8	0.93	468	D	47.8	0.96	484	D	50.5	0.97	497
Columbia Rd – SB	L	C	24.6	0.42	28	F	80.8	0.87	33	F	84.6	0.88	34	C	26.9	0.61	33
Columbia Rd – SB	TR	C	28.0	0.64	236	C	34.6	0.73	260	D	37.3	0.76	268	C	32.9	0.70	259
Overall		**D**	**52.9**	**1.04**	**–**	**D**	**40.5**	**0.94**	**–**	**D**	**42.6**	**0.93**	**–**	**D**	**42.3**	**0.98**	**–**
Hancock at Columbia														Signal retimed			
Columbia Rd – NB	T	C	28.3	0.71	222	D	38.0	0.82	257	C	33.3	0.77	242	D	36.3	0.80	252
Columbia Rd – NB	R	B	17.7	0.04	8	C	22.0	0.05	9	C	20.1	0.05	8	C	21.4	0.05	9
Columbia Rd – SB	**(L)**	**E**	**63.5**	**0.96**	**58**	**E**	**70.1**	**0.96**	**75**	**E**	**62.8**	**0.95**	**62**	**D**	**41.0**	**0.82**	**63**
Columbia Rd – SB	T	D	39.3	0.92	324	D	54.7	0.98	366	D	46.4	0.95	345	D	39.3	0.92	324
Hancock St – NW	L	D	40.8	0.32	42	D	36.3	0.27	40	D	38.4	0.29	41	D	37.8	0.32	42
Hancock St – NW	**R**	**F**	**230.3**	**1.36**	**266**	**F**	**143.5**	**1.15**	**234**	**F**	**180.4**	**1.24**	**250**	**C**	**29.6**	**0.68**	**166**
Overall		**E**	**64.8**	**1.06**	**–**	**E**	**61.5**	**1.04**	**–**	**E**	**61.6**	**1.04**	**–**	**D**	**36.6**	**0.89**	**–**

1. Route 15 approaches are shown in bold.
2. Delay is measured in seconds.
3. 50th percentile queue, measured in feet.

TABLE D-2 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]
Tremont at Prentiss														Green extension			
Prentiss St – EB	LR	F	139.5	1.14	228	F	99.9	1.03	207	F	198.7	1.29	248	F	165.4	1.20	194
Tremont St – NB	**LTR**	**B**	**16.7**	**0.68**	**241**	**B**	**17.5**	**0.70**	**244**	**B**	**15.5**	**0.65**	**239**	**B**	**12.2**	**0.65**	**95**
Tremont St – SB	**LTR**	**C**	**32.8**	**0.75**	**370**	**C**	**34.0**	**0.77**	**371**	**C**	**30.9**	**0.72**	**353**	**B**	**16.4**	**0.71**	**202**
Overall		**D**	**38.3**	**0.84**	**–**	**C**	**34.4**	**0.84**	**–**	**D**	**44.2**	**0.84**	**–**	**C**	**32.6**	**0.82**	**–**
Malcolm X at Shawmut														OB queue jump			
Malcolm X Blvd – EB	**QJ**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**B**	**13.8**	**0.02**	**3**
Malcolm X Blvd – EB	**LTR**	**B**	**15.6**	**0.37**	**96**	**B**	**15.8**	**0.37**	**102**	**B**	**15.6**	**0.37**	**96**	**B**	**17.3**	**0.38**	**93**
Dudley St – WB	**LTR**	**A**	**9.9**	**0.31**	**30**	**A**	**3.8**	**0.31**	**14**	**A**	**6.3**	**0.31**	**17**	**B**	**12.0**	**0.32**	**26**
Shawmut St – NB	L	F	143.9	1.15	135	F	124.1	1.12	125	D	146.9	1.15	135	F	143.6	1.15	134
Shawmut St – NB	TR	B	19.5	0.29	55	B	19.8	0.29	56	C	21.7	0.29	64	B	19.8	0.29	51
Shawmut St – SB	L	C	25.4	0.37	93	C	25.1	0.36	89	C	25.4	0.37	93	C	25.4	0.37	93
Shawmut St – SB	T	D	35.1	0.76	244	C	34.4	0.76	234	D	35.1	0.76	244	D	35.1	0.76	244
Shawmut St – SB	R	D	35.6	0.76	206	D	35.1	0.75	197	D	35.6	0.76	206	D	35.6	0.76	206
Overall		**C**	**31.7**	**0.68**	**–**	**C**	**29.5**	**0.67**	**–**	**C**	**31.1**	**0.68**	**–**	**C**	**32.5**	**0.71**	**–**
Dudley at Harrison														Green extension			
Dudley St – EB	L	C	23.0	0.49	30	C	27.4	0.60	37	B	15.3	0.47	30	C	24.9	0.52	66
Dudley St – EB	**TR**	**A**	**5.5**	**0.17**	**17**	**A**	**6.0**	**0.19**	**13**	**A**	**3.4**	**0.16**	**10**	**B**	**12.5**	**0.16**	**42**
Dudley St – WB	L	C	29.3	0.33	51	C	29.3	0.33	51	C	24.8	0.28	47	C	25.4	0.30	51
Dudley St – WB	**TR**	**D**	**45.7**	**0.79**	**192**	**D**	**45.7**	**0.79**	**192**	**C**	**34.6**	**0.68**	**176**	**C**	**34.3**	**0.71**	**192**
Harrison Ave – NB	LT	B	14.2	0.56	78	B	11.1	0.50	62	B	16.9	0.61	90	C	30.0	0.59	168
Harrison Ave – NB	R	A	6.2	0.16	3	A	5.0	0.15	3	A	7.1	0.18	5	C	22.0	0.18	27
Harrison Ave – SB	L	C	21.2	0.23	20	B	17.6	0.19	17	C	23.8	0.26	22	C	24.3	0.25	24
Harrison Ave – SB	TR	D	36.9	0.86	228	C	27.2	0.76	215	D	47.6	0.93	244	D	50.1	0.90	305
Overall		**C**	**27.8**	**0.77**	**–**	**C**	**24.6**	**0.75**	**–**	**C**	**28.4**	**0.75**	**–**	**C**	**34.1**	**0.77**	**–**

TABLE D-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]
Dudley at Dearbrn/Mt. Plsnt						Existing timings optimal								Green extension			
Dudley St – EB	**LT**	**A**	**6.5**	**0.32**	**31**					**A**	**6.3**	**0.31**	**34**	**A**	**5.5**	**0.31**	**34**
Dudley St – WB	**TR**	**A**	**8.1**	**0.48**	**56**					**A**	**7.9**	**0.46**	**62**	**A**	**6.3**	**0.46**	**62**
Mt. Pleasant Ave – NB	LTR	C	27.5	0.45	33					C	29.9	0.47	36	C	30.3	0.47	33
Dearborn St – SB	LR	D	37.6	0.69	43					D	44.5	0.74	49	D	40.7	0.73	45
Overall		**B**	**14.3**	**0.52**	**–**					**B**	**15.5**	**0.52**	**–**	**B**	**14.6**	**0.52**	**–**
Dudley at Hampden						Existing timings optimal								Green extension			
Dudley St – NB	**L**	**B**	**13.5**	**0.49**	**75**					**B**	**15.2**	**0.52**	**76**	**B**	**13.5**	**0.45**	**78**
Dudley St – NB	TR	B	13.0	0.44	69					B	14.5	0.46	70	B	14.4	0.53	99
Hampden St – SB	LTR	C	26.8	0.75	96					C	23.3	0.68	83	C	28.1	0.74	85
Dudley St – SE	LT	C	20.1	0.72	77					C	27.7	0.79	80	B	18.5	0.67	85
Dudley St – SE	**R**	**B**	**15.6**	**0.61**	**93**					**B**	**17.9**	**0.65**	**94**	**B**	**15.5**	**0.59**	**103**
Overall		**B**	**19.1**	**0.73**	**–**					**C**	**20.1**	**0.75**	**–**	**B**	**19.3**	**0.70**	**–**
Dudley at BHAve/Mt. Plsnt														OB–g.ext; IB–q. jump			
Magazine St – WB	LTR	F	136.7	1.13	154	F	92.4	1.00	137	F	176.8	1.23	167	F	136.0	1.15	184
Blue Hill Ave – NB	LTR	D	37.0	0.74	136	F	103.2	1.09	158	D	40.2	0.78	141	F	101.4	1.08	151
Dudley St – SB	**LT**	**E**	**79.7**	**1.03**	**260**	**D**	**40.4**	**0.86**	**228**	**E**	**56.7**	**0.95**	**250**	**D**	**43.4**	**0.89**	**250**
Dudley St – SB	TR	F	225.4	1.41	479	F	121.5	1.17	420	F	175.0	1.29	459	F	138.6	1.21	460
Dudley St – NW	LT	F	151.0	1.16	111	D	36.5	0.68	75	E	67.3	0.89	88	C	29.4	0.71	162
Dudley St – NW	**TR**	**C**	**32.0**	**0.62**	**113**	**C**	**25.0**	**0.51**	**100**	**C**	**29.3**	**0.57**	**109**	**B**	**19.7**	**0.15**	**27**
Overall		**F**	**117.9**	**1.11**	**–**	**F**	**81.1**	**1.11**	**–**	**F**	**97.4**	**1.10**	**–**	**F**	**91.9**	**1.16**	**–**
Dudley at E./W. Cottage														OB–g.ext; IB–shared RT/QJ			
W. Cottage St – EB	LTR	D	51.2	0.87	121	F	94.5	1.05	130	F	156.6	1.21	158	E	59.3	0.91	120
E. Cottage St – WB	LTR	C	25.4	0.38	49	C	29.7	0.45	52	C	33.7	0.52	55	C	28.1	0.40	49
Dudley St – NB	**LTR**	**C**	**27.5**	**0.85**	**186**	**C**	**20.7**	**0.79**	**161**	**B**	**17.8**	**0.76**	**146**	**B**	**12.3**	**0.60**	**113**
Dudley St – NB	**R/QJ**	–	–	–	–	–	–	–	–	–	–	–	–	**A**	**8.0**	**0.14**	**0**
Dudley St – SB	**LTR**	**D**	**46.6**	**0.98**	**247**	**C**	**30.8**	**0.91**	**215**	**C**	**24.8**	**0.87**	**194**	**C**	**25.2**	**0.88**	**237**
Overall		**D**	**38.9**	**0.95**	**–**	**D**	**38.1**	**0.95**	**–**	**D**	**45.8**	**0.95**	**–**	**C**	**26.3**	**0.90**	**–**

TABLE D-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]
Dudley/Stghtn at Columbia														OB queue jump and sig. impr.			
Dudley St – EB	LT	D	41.7	0.62	147	D	51.9	0.72	157	D	38.6	0.58	143	E	60.0	0.83	165
Dudley St – EB	**R**	**C**	**32.5**	**0.29**	**23**	**D**	**37.4**	**0.34**	**32**	**C**	**30.8**	**0.27**	**20**	**C**	**28.6**	**0.44**	**107**
Stoughton St – WB	LTR	D	35.1	0.48	91	D	41.8	0.58	99	C	33.0	0.45	88	D	43.8	0.68	104
Columbia Rd – NB	**L**	**D**	**53.4**	**0.91**	**111**	**C**	**29.9**	**0.70**	**108**	**E**	**56.4**	**0.86**	**127**	**C**	**24.9**	**0.80**	**70**
Columbia Rd – NB	TR	C	27.9	0.64	248	C	33.3	0.71	270	C	29.9	0.67	256	C	22.6	0.57	233
Columbia Rd – SB	L	D	45.5	0.90	107	C	24.1	0.70	109	D	53.5	0.93	118	B	18.4	0.76	83
Columbia Rd – SB	TR	C	31.2	0.75	314	D	35.2	0.80	331	D	36.7	0.81	336	C	22.1	0.63	267
Overall		**C**	**34.8**	**0.80**	**–**	**D**	**35.2**	**0.73**	**–**	**D**	**37.5**	**0.80**	**–**	**C**	**27.5**	**0.84**	**–**
Hancock at Columbia														Signal retimed			
Columbia Rd – NB	T	C	23.2	0.48	133	D	50.5	0.84	195	C	30.2	0.58	156	D	43.2	0.76	186
Columbia Rd – NB	R	B	18.4	0.10	18	C	33.7	0.18	26	C	23.6	0.12	21	C	31.1	0.16	25
Columbia Rd – SB	**L**	**F**	**220.1**	**1.41**	**231**	**F**	**207.9**	**1.37**	**313**	**F**	**227.3**	**1.42**	**257**	**F**	**90.8**	**1.08**	**213**
Columbia Rd – SB	T	E	59.1	1.01	402	F	124.3	1.18	560	F	83.4	1.08	453	E	59.1	1.01	402
Hancock St – NW	L	D	43.1	0.41	56	C	32.9	0.29	48	D	38.0	0.35	52	D	43.1	0.41	56
Hancock St – NW	**R**	**F**	**408.2**	**1.77**	**402**	**F**	**183.5**	**1.27**	**331**	**F**	**286.6**	**1.51**	**370**	**C**	**26.5**	**0.70**	**188**
Overall		**F**	**140.8**	**1.44**	**–**	**F**	**126.5**	**1.27**	**–**	**F**	**130.3**	**1.38**	**–**	**D**	**54.3**	**0.97**	**–**

1. Route 15 approaches are shown in bold.
2. Delay is measured in seconds.
3. 50th percentile queue, measured in feet .