BENEFIT-COST EVALUATION OF THE BTD TRAFFIC SIGNAL RETIMING PROGRAM FY 2010-2012

TETRA TECH

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BTD
BOSTON
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DEPARTMENT

Benefit-Cost Evaluation of the BTD Traffic Signal Retiming Program FY 2010-2012

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One Grant Street
Framingham, MA 01702
Tel 508.903.2000 Fax 508.903.2001

Table of Contents

List of Tables

List of Figures

List of Appendices

Executive Summary

Consistent with Mayor Thomas Menino's vision to create an environmentally-friendly and sustainable Boston for the 21st century, the Boston Transportation Department (BTD) embarked on a signal retiming initiative in 2007 to improve traffic signal operations and safety throughout the City of Boston. One of the principal goals of this initiative was to reduce vehicle delays at the City's traffic signals, and in doing so, also realize reductions in vehicle emissions and fuel consumption. From 2007 to 2012, the BTD has implemented traffic signal retiming improvements at 410 intersections city-wide, which represents approximately 50 percent of all the City's 845 traffic signals.

This report summarizes the improvements implemented by the BTD at 132 intersections that were completed as part of the 2010 – 2012 signal retiming program. The signal retiming improvements were undertaken with the assistance of the consulting firm Tetra Tech, Inc. under Contract #29623. The improvements were made through the efforts of 10 separate work orders at intersections located throughout the City. Approximately 20 different roadway "corridors" were analyzed, and separate reports were prepared for each work order. Those reports included documentation of existing conditions and recommendations for signal-related improvements to be implemented by the BTD. The recommendations were primarily changes to signal timing and phasing, but also included items such as loop detector repairs, signal equipment maintenance, and geometric or lane use changes.

The appropriate design, operation, and maintenance of traffic signals can return significant economic, environmental, and social benefits, all of which contribute to the Mayor's vision of a greener and more livable city. These benefits include reductions in driver delays, travel times, vehicular crashes, fuel consumption, and vehicle emissions. The benefits of the recommendations were quantified as part of the analysis prepared for each individual work order and compared to the costs of implementing the improvements. Comparative results were reported in a Benefit-Cost Analysis document prepared for each work order.

Building on the Benefit-Cost reports that were submitted for each of the work orders, this report examines the overall benefits of the signal retiming improvements made between 2010 and 2012 by the BTD. Some of the benefits, in terms of expected reductions in congestion metrics, are summarized in Table E-1 and described in further detail within the report text. The percent improvement over existing conditions for each performance metric is also presented in Table E-1.

Overall, the signal retiming improvements implemented at the 132 intersections between 2010 and 2012 are expected to:

- Reduce driver delays by 23.6%
- Reduce travel times up to 25.0%.
- Reduce vehicular emissions by 12.0%,
- Reduce fuel consumption is by 12.2%.
- Reduce vehicle crashes by 8%

Table E-1 2010-2012 Signal Retiming Program Benefits

	Expected Benefits (Reductions per day)		
Work Order	Vehicular Delay (hours/day)	Vehicular Emissions (kg/day)	Fuel Consumption (gallons/day)
1	-29 [-20.0%]	-1.66 [-4.7%]	-17 [-4.8%]
2	-200 [-25.4%]	-13.08 [-12.8%]	-131 [1-2.8%]
3	-54 [-10.5%]	-4.65 [-5.3%]	-46 [-5.2%]
4	-573 [-40.2%]	-44.81 [-24.4%]	-449 [-24.4%]
5	-94 [-12.7%]	-8.04 [-5.2%]	-80 [-5.1%]
6	-136 [-23.9%]	-11.00 [-13.9%]	-110 [-13.8%]
7	-24 [-5.9%]	-4.82 [-5.0%]	-49 [-5.1%]
8	-60 [-15.1%]	-5.53 [-9.2%]	-56 [-9.3%]
9	-153 [-37.6%]	-14.08 [-20.2%]	-163 [-23.2%]
10	-62 [-13.1%]	-5.05 [-7.0%]	-51 [-7.1%]
Total	-1,385 [-23.6%]	-112.72 [-12.0%]	1,152 [12.2%]

Notes:
1. *Expected daily reductions represent the total of 3 peak hours evaluated (AM, PM & Midday)*
2. *Emission reductions = reductions of Co + NOx + VOC*

The performance measures in Table E-1 (among others) were used to quantify the benefits, in monetary terms, of the signal retiming improvements. The monetary benefits of the improvements were compared to the costs associated with implementing the improvements. In this fashion, the relative value of the improvements to the City can be determined.

The annualized benefits of the recommended signal retiming improvements are estimated to be approximately $11,700,000, while the annualized costs of implementing the signal retiming improvements are estimated to be $271,000. This yields a benefit-cost ratio of approximately 43 to 1, meaning that the value of the benefits is 43 times greater than the costs to implement the improvements. Given this high rate-of-return, the costs to implement the signal retiming improvements are clearly a worthwhile investment of capital funds by the City, with the benefits accruing for both the roadway users and the citizens of the City of Boston. The benefit-cost analysis is summarized in Table E-2.

Table E-2 2010-2012 Retiming Program: Summary of Benefit-Cost Analysis

	Annualized Benefits & Costs
Signal Improvement Benefits	$11,711,587
Costs to Implement Improvements	$271,174
Benefit to Cost Ratio	43 to 1

The following report describes in detail the analyses, methodologies, and calculations used to quantify the benefit-cost ratio for the BTD's 2010 – 2012 signal retiming program.

1.0 Introduction

The Boston Transportation Department (BTD) retained Tetra Tech, Inc. to evaluate potential signal timing improvements under the 2010 – 2012 Signal Retiming Program (Contract #29623). This work was completed between September 2010 and November 2012 and was comprised of 10 work orders that included 132 intersections throughout the City of Boston (shown on Figures 1 through 10).

The work orders evaluated under this contract are as follows:

- Work Order #1 – Beacon Street/Charles Street/Washington Street, Boston Proper
- Work Order #2 – Commonwealth Avenue/Brighton Avenue, Brighton (vicinity of Harvard Avenue)
- Work Order #3 – Tremont Street/Shawmut Avenue/Washington Street/Harrison Avenue, Boston Proper
- Work Order #4 – Columbus Avenue, Roxbury
- Work Order #5 – Chelsea Street/Huntington Avenue/Various Locations
- Work Order #6 – Blue Hill Avenue, Roxbury
- Work Order #7 – Centre Street/Washington Street, West Roxbury
- Work Order #8 – Washington Street/Hyde Park Avenue, Jamaica Plain
- Work Order #9 – Commonwealth Avenue, Brighton (vicinity of Lake Street)
- Work Order #10 – Massachusetts Avenue/Albany Street, Roxbury/Boston Proper

As part of the evaluation performed for each of these work orders, the following deliverables were prepared by Tetra Tech, Inc. for the BTD:

- Existing Conditions Analysis/Report
- Recommendations Analysis/Report
- Revised Signal Operations Schedules
- Benefit-Cost Analysis/Report

Although this report provides a summary of the items conducted for each of the work orders, the primary focus of the report is the benefit-cost analyses prepared for each of the work orders. The benefit-cost analyses considered the costs incurred in designing, implementing, and testing the improvements as compared to the benefits realized from these improvements. The incurred costs include the engineering costs involved in developing proposed signal timings and construction costs involved in providing enhancements to intersections. The benefits that were realized from these improvements were measured using parameters such as reduced delays and travel times, decreased fuel consumption and vehicular emissions, and potential reductions to crashes.

The benefit and cost values were evaluated for the morning, midday, and afternoon peak hours on a typical weekday. To present a conservative analysis, the benefits that could be realized during other hours of a

weekday and during weekends were not considered in this analysis. The dollar values of the benefits and costs per year (Annual Value) were used to calculate the benefit-cost ratio. The benefits calculated per day were multiplied by 260 work days in a year to obtain annual values. Similarly, engineering and equipment costs were annualized over an appropriate number of years to calculate an annual value.

2.0 Task Descriptions

The general process for each work order included examining existing conditions, developing recommendations for each intersection, implementing the recommendations, re-evaluating the intersections based on the changes, and conducting a benefit-cost analysis.

2.1 Review of Existing Conditions

The first step in the evaluation of each work order was data collection. 12-hour turning movement counts (7:00 a.m. to 7:00 p.m.) of cars, heavy vehicles, pedestrians, and bicycles were collected at each study intersection. Existing traffic signal data such as phasing, timings, coordination data, pedestrian actuations (where applicable), and pattern data (including split times) were obtained from the BTD.

At each intersection, peak hour observations (AM, Midday and PM) and data collection were conducted through field visits. Observations typically included vehicle queue lengths, transit interactions (mainly related to buses), illegal turns, double parked vehicles, and on-street delivery operations. Data related to posted speed limits, lane configuration/lengths, on-street parking regulations and use, locations of bus stops, signal timings, signal equipment, and pedestrian/ bicycle presence were collected as well.

Existing travel time studies were also conducted. The studies were conducted by driving vehicles through the study corridors and noting arrival times at each intersection along the corridor. Overall corridor times were recorded for each direction during the peak hours.

A detailed crash analysis was also performed for each of the study intersections. The latest three years of available data were analyzed, noting crash severity, type, weather conditions, and time of day. The crash rate for each intersection was calculated and compared to the Statewide and Massachusetts Department of Transportation (MassDOT) District 6 averages for other signalized intersections.

2.2 Analysis of Existing Conditions

A Synchro traffic analysis and optimization model for each work order was created and calibrated based on the information obtained from the BTD and observed in the field. The model was used to analyze existing conditions. These results served as a basis for comparison to the recommended conditions. The analysis results were provided to BTD as part of the Existing Conditions Report and included the following key Measures of Effectiveness (MOEs):

Traffic Modeling Measures of Effectiveness

Levels of Service (LOS): measure of the functionality of an intersection or a lane group within an intersection that is based on average delay per vehicle. Functionality is rated on a scale of A to F, with LOS A indicating the best operations (little or no delays/queuing) and LOS F indicating the worst operations (excessive delays/queuing).

Delays: average seconds of delay per vehicle expressed by lane group and for the overall intersection.

Volume-to-capacity ratios (v/c): measure of the traffic using an intersection as it relates to the capacity of the intersection. A v/c ratio in excess of 1.00 indicates an intersection that is over capacity (i.e., the volume using the intersection is greater than the intersection's capacity).

Queues: average and 95th % vehicular queues expressed in feet per lane group.

2.3 Development of Recommendations

The BTD collaborated with Tetra Tech, Inc. to develop a full set of recommendations for each intersection. The full set of recommended improvements included items such as more efficient intersection geometries or lane-use, signal equipment and timings, safety enhancements, and other items that could improve progression or operations. For some locations, interim recommendations generally related to signal timings were prepared. Both sets of recommendations (interim and final) were fully analyzed within the traffic models.

2.4 Implementation

The recommended signal timing changes were then implemented by BTD. Following the implementation, Tetra Tech, Inc. conducted initial travel time runs and field observations for each study corridor to ensure that the signal coordination was functioning as expected. Based on these initial observations, signal "fine-tuning" recommendations were made to the BTD. After implementation of the suggested "fine-tuning" adjustments, formal post-improvement travel time studies were performed by Tetra Tech, Inc. The post-improvement results were compared to the existing (i.e., pre-improvement) travel time results in order to quantify the travel time benefits of the signal retiming modifications.

3.0 Benefit-Cost Methodology

Generally, a benefit-cost ratio is an indicator of the monetary value of a project. The ratio is conveyed as the benefit relative to the cost. A ratio greater than 1.0 indicates that a project could be worth undertaking. A ratio less than 1.0 indicates that the project likely should not be pursued as the project costs will outweigh the benefits of the project. The benefit-cost calculations performed for the ten work orders are summarized below. The Benefit-Cost analyses for each work order are provided in Appendices A through J.

3.1 Benefits Calculations

Implementation of the recommended improvements result in benefits related to the following key metrics:

- Vehicle Delays
- Vehicle Travel Times
- Safety (Vehicle Crashes)
- Energy (Fuel Consumption)
- Air Quality (Vehicle Emissions)

During the course of preparing the benefit-cost analysis for each of the work orders, monetary constants from the *2010 Urban Mobility Report,* published by the Texas Transportation Institute, were used to calculate the benefits of reducing delays. The constants from that publication are based on 2009 dollars. For the purposes of this report, the 2009 values were increased to reflect 2012 dollars. The adjustments made to the 2009 values were based on Consumer Price Index (CPI), which indicates an inflationary escalation factor of 7.0 percent between 2009 and 2012. Therefore, the 2009 constants from the *2010 Urban Mobility Report* were increased by 7.0 percent.

Urban Mobility Report constants (2012 $)

Vehicle Occupancy	1.25 persons / vehicle
Average Cost of Time (2012)	$17.22 / person-hour
Commercial Vehicle Operating Cost (2012)	$113.68 / vehicle-hour

Delays. Vehicle delays were calculated for each work order using the Synchro traffic analysis and optimization software. For the purposes of the benefit-cost analysis, Total Vehicle Delay values were used, which represent the combination of "control" delay plus the "queue" delay for each vehicle at each intersection in the study network. The Total Vehicle Delay values were calculated for the AM, Midday, and PM peak hours and are expressed in hours per peak period. The Total Vehicle Delay results for the post-improvement conditions were compared to the Total Vehicle Delay results for the existing conditions to determine the delay reductions that would be realized from the signal timing improvements. Note: for this analysis, the reduction in Total Vehicle Delay for the AM, Midday, and PM peak hour were combined to represent "daily" delay reductions. This approach is conservative, as the off-peak period delays are not included, therefore, the benefits of the improvements would in actuality be greater than those described below.

The reductions in delay were then apportioned into passenger car delays and truck delays, based on the truck percentages observed in the field during the 12-hour count programs. The passenger car delays were then converted from vehicle-hours to person-hours by applying the Vehicle Occupancy constant of 1.25 persons/vehicle from the 2010 *Urban Mobility Report.* The daily reductions in delay to persons and trucks were multiplied by 260 workdays/year to obtain the annual reduction in delay (in hours). The cost per hour of travel delays from the *2010 Urban Mobility Report* (converted to corresponding 2012 dollar values) is $17.22 per person (in passenger cars) and $113.68 per vehicle for trucks. Multiplying the reduction in the number of hours of delay by the respective cost/hour constants, and by 260 days, results in the annualized benefits of the signal retiming improvements. Table 1 provides a summary of the annualized benefits for each work order, and for the 2010 - 2012 signal retiming program as a whole.

As shown in Table 1, in total, the 2010 – 2012 retiming program is expected to reduce person delay (passenger cars) by over 424,000 hours per year, and truck delays by over 20,000 hours per year. This equates to an annual benefit of approximately $9.6 million.

Table 1 2010-2012 Retiming Program: Annual Delay Reductions & Annual Benefits

Work Order	Person Delay (hours/year)	Truck Delay (hours/year)	Annual Benefits (2012 dollars)
1	-8,840	-520	$211,338
2	-62,660	-1,820	$1,285,903
3	-16,380	-1,040	$400,291
4	-174,460	-9,360	$4,068,246
5	-29,120	-1,040	$619,674
6	-41,340	-2,140	$955,150
7	-7,280	-290	$158,329
8	-17,940	-1,140	$438,522
9	-47,580	-1,670	$1,009,173
10	-18,460	-1,170	$450,887
Total	-424,060	-20,190	$9,597,512

Notes:
1. *Person delay = vehicular delay from Synchro traffic analysis and optimization models x 1.25 persons per vehicle*
2. *Annual Benefits = reduction in Person Delay (hours/year) x $17.22/hour + reduction in Truck Delay (hours/year) x $113.68/hour*
3. *Annual Benefits for each Work Order rounded to the nearest dollar.*

Travel Time. Travel time analyses along key roadway corridors were performed as part of each work order. The travel time data along the corridors were collected in the field by Tetra Tech, Inc. staff and was obtained at the beginning of the assignment, which reflected the existing or "before" conditions. A second set of travel time data was collected after the BTD implemented the recommended signal retiming improvements (i.e., the "post-improvement" conditions). A comparison of the two sets of data was made to determine the travel time reductions that were realized in the field after implementation of the signal retiming improvements.

During each of these periods, travel time data was collected for the AM, Midday, and PM peak periods. For each key corridor in the work order's study area, between three and six travel time runs were conducted during each peak period.

The results of the travel time analyses for each work order, and a total for the 2010-2012 retiming program as a whole, are summarized in Table 2. The travel time data presented in Table 2 represent the average of the cumulative travel times of all corridors examined under each work order. Data related to each individual travel time run are provided by corridor for each work order in Appendix K.

As noted in Table 2, the signal retiming improvements resulted in travel time reductions measured in the field averaged approximately 25 percent during the AM peak, 16 percent during the Midday peak, and 17 percent during the afternoon peak hour.

Table 2 2010-2012 Retiming Program: Travel Time Comparisons

	AM Peak Hour				Midday Peak Hour				PM Peak Hour			
Work Order	Pre-Improv.	Post-Improv.	Change	% Change	Pre-Improv.	Post-Improv.	Change	% Change	Pre-Improv.	Post-Improv.	Change	% Change
1	6:56	4:16	-2:40	-38%	7:31	4:54	-2:37	-35%	7:36	5:35	-2:01	-27%
2	13:18	9:19	-3:59	-30%	11:49	9:59	-1:50	-16%	14:25	9:52	-4:33	-32%
3	18:27	16:32	-1:55	-10%	22:56	17:17	-5:39	-25%	20:36	17:17	-3:19	-16%
4	19:40	13:43	-5:57	-30%	11:43	10:31	-1:12	-10%	17:34	15:00	-2:34	-15%
6	12:56	10:48	-2:08	-16%	12:10	12:22	+0:12	+2%	18:09	16:57	-1:12	-7%
7	8:15	6:49	-2:26	-17%	8:43	8:04	-0:39	-7%	9:13	8:56	-0:17	-3%
8	11:07	10:57	-0:10	-1%	8:03	5:31	-2:32	-31%	14:39	9:25	-5:14	-36%
9	11:39	11:13	-0:26	-4%	10:04	9:15	-0:49	-8%	10:07	10:37	+0:30	+5%
10	4:07	4:12	+0:05	+2%	5:48	4:59	-0:49	-14%	6:14	4:17	-1:57	-31%
Total	117:25	87:49	-29:36	-25%	98:47	82:52	-15:55	-16%	118:33	97:56	-20:37	-17%

Notes:
1. *Pre-Improv. = Travel times prior to implementation of signal timing improvement (minutes:seconds)*
2. *Post-Improv. = Travel times after implementation of signal timing improvement (minutes:seconds)*

Safety (Vehicular Crashes). For each work order, the three most recent years of available MassDOT crash data were reviewed and tabularized by intersection, crash type, and crash severity. Based on safety research performed for the American Association of State Highway and Transportation Officials (AASHTO), Crash Reduction Factors (CRF) have been developed that quantify the crash reductions that are expected if a certain improvement is implemented. These CRFs pertaining to intersection improvements can be found in Chapter 14 of the *Highway Safety Manual*, 1st Edition, Volume 3, AASHTO, 2010. The research indicates that implementing signal timing changes, specifically modifying the clearance intervals at the intersection to be in compliance with the latest signal standards, can reduce crashes (all types; all severities) by approximately eight percent.

In order to account for the expected crash reduction benefits in the benefit-cost analysis, a monetary value needs to be assigned to the crashes. Estimates for the cost to society of various crash severities are provided in *The Economic Impact of Motor Vehicle Crashes 2000,* prepared by the National Highway Traffic Safety Administration. The costs per crash contained in this reference source were increased to 2012 dollars in accordance with the rate of inflation tracked by the CPI.

Economic Costs by Crash Severity (2012 $)

Property Damage Crashes	$3,387 / crash
Injury Crashes	$20,085 / crash
Fatal Crashes	$4,502,544 / crash

The eight percent CRF was applied to those crashes from the MassDOT data that: (1) could be confirmed to have occurred at one of the subject intersections; and (2) the crash severity was identified (i.e., crashes that were identified as “other” or “unknown” were omitted from the benefit-cost analysis). Table 3 provides a summary of the expected crash reductions that will result from the signal retiming program, as well as the annual economic benefits associated with the reduction in crashes.

Table 3 2010-2012 Signal Retiming Program: Safety Benefits

	Property Damage Only		Personal Injury		Fatality		Annual Benefits
Work Order	Existing Crashes	Reduction (-8%)	Existing Crashes	Reduction (-8%)	Existing Crashes	Reduction (-8%)	2012 dollars
1	17	-2	5	-1	0	0	$26,859
2	27	-3	14	-2	0.33	-.026	$167,397
3	27	-3	12	-1	0.67	-.053	$268,881
4	20	-2	25	-3	0	0	$67,029
5	15	-2	14	-2	0.67	-.053	$285,579
6	7	-1	9	-1	0	0	$23,472
7	10	-1	7	-1	0	0	$23,472
8	5	-1	6	-1	0	0	$23,472
9	11	-1	6	-1	0	0	$23,472
10	16	-2	14	-2	0	0	$46,944
Total	155	-18	112	-15	1.67	-0.132	$956,577

Notes:
1. *Crashes = Average number of crashes per year at all of the intersections evaluated in the work order based on 3 years of data.*
2. *Annual Benefits = Expected reduction in Property Damage Only crashes x $3,387 per crash + expected reduction in Personal Injury crashes x $20,085 per crash + expected reduction in fatal crashes x $4,502,544 per crash.*
3. *Annual Benefits for each Work Order rounded to the nearest dollar.*

As noted in Table 3, the 2010 – 2012 signal retiming program is expected to reduce the total number of crashes at the 132 studied intersections by approximately 33 crashes per year (18 property damage only crashes plus 15 personal injury crashes). The economic benefits to society associated with the crash reductions is estimated to be approximate $957,000 per year.

Energy (Fuel Reduction). The Synchro traffic analysis and optimization software used to develop signal retiming improvements also calculates fuel consumption estimates. Fuel consumption estimates from the traffic analysis and optimization models are based on vehicle delay, vehicle miles traveled, and vehicle stops within the study traffic network that are calculated for each peak hour analyzed. For the purposes of this analysis, the three peak hours evaluated for each work order (AM, Midday, PM) represents daily fuel consumption. By comparing the pre-improvements fuel consumption to the post-improvement consumption levels, the reduction in daily fuel consumption was determined for each work order.

In order to determine the energy benefits of the signal retiming program (in monetary terms), the daily fuel reduction estimates from the traffic models were converted to annual reductions by multiplying the daily consumption estimates by 260 (annual work days). The annual fuel reductions were then multiplied by the cost of a gallon of gasoline to determine the economic benefit of the signal improvements. Over the course of the 2010 – 2012 signal retiming program, the cost of gasoline has varied significantly (between $2.42 and $3.91 per gallon). The annual economic benefits calculated for each work order were based on the approximate cost of fuel at the time of the work order. For the purposes of this report, a cost per gallon of fuel of $3.65 was used to calculate the annual economic benefits of the improvements. $3.65 represents the average cost of fuel per gallon in 2012 based on review of data published by the Massachusetts Executive Office of Energy and Environmental Affairs. A summary of the energy consumption benefits are presented in Table 4.

Table 4 2010-2012 Signal Retiming Program: Energy Benefits

Work Order	Pre-Improvement Fuel Consumption (gal/day)	Post-Improvement Fuel Consumption (gal/day)	Change in Fuel Consumption (gal/day)	Annual change in Fuel Consumption (gal/yr)	Annual Benefit (2012 $)
1	357	340	-17 [-4.8%]	-4,420	$16,133
2	1,025	894	-131 [-12.8%]	-34,060	$124,319
3	886	840	-46 [-5.2%]	-11,960	$43,654
4	1,843	1,394	-449 [-24.4%]	-116,740	$426,101
5	1,559	1,479	-80 [-5.1%]	-20,800	$75,920
6	795	685	-110 [-13.8%]	-28,600	$104,390
7	962	913	-49 [-5.1%]	-12,740	$46,501
8	601	545	-56 [-9.3%]	-14,560	$53,144
9	702	539	-163 [-23.2%]	-42,380	$154,687
10	720	669	-51 [-7.1%]	-13,260	$48,399
Total	9,450	8,298	-1,152 [-12.2%]	-299,520	$1,093,248

Notes:
1. *Annual change in fuel consumption = daily change in fuel consumption x 260 work day).*
2. *Annual Benefits = annual change in fuel consumption x $3.65 (average price of a gallon of gas in 2012).*
3. *Annual Benefits for each Work Order rounded to the nearest dollar.*

As noted in Table 4, the 2010 – 2012 signal retiming program is expected to reduce fuel consumption by more than 1,150 gallons per day, or nearly 300,000 gallons per year. This represents an approximate 12 percent reduction in fuel consumption as compared to the pre-improvement conditions and translates to an annual economic benefit of approximately $1.1 million.

Air Quality (Vehicle Emissions). The traffic models used to evaluate traffic operations for the pre- and post-signal improvement conditions also calculates vehicle emission levels for the traffic network analyzed for each work order. The Synchro traffic analysis and optimization software calculates emission levels based on fuel consumption estimates, which are a function of factors such as vehicle delay, vehicle miles traveled and vehicle stops that occur in the subject traffic network. By comparing emissions outputs for the pre- and post-improvement conditions, the expected reduction in emissions levels can be determined.

From an air quality perspective, the key vehicle emissions are Carbon Monoxide (CO), Nitrous Oxide (NOx), and Volatile Organic Compounds (VOC). The Synchro traffic analysis and optimization software provides outputs for each of these compounds in kilograms/day (kg/day). In order to determine the monetary value of the reduced emissions associated with the signal retiming improvements, the kg/day were first converted to metric tons per day, and then by multiplying that result by 260, converted to metric tons per year. Once converted to metric tons per year, a dollar value for each reduction could be determined based on cost factors developed by the Federal Highway Administration (Highway Economic Requirements System – State Version [HERS-ST 2.0] Technical Report US DOT/Federal Highway Administration, 2002) that were adjusted to 2012 dollars based upon Consumer Price Index data.

Economic Costs of Vehicle Emissions (2012 $)

Carbon Monoxide (CO)	$148 / metric ton
Nitrous Oxide (NOx)	$8,014 / metric ton
Volatile Organic Compounds (VOC)	$6,080 / metric ton

A summary of the emission reductions and associated air quality benefits are provided in Table 5 for Carbon Monoxide (CO), Table 6 for Nitrous Oxide (NOx), and Table 7 for Volatile Organic Compounds (VOC). Table 8 presents the air quality benefits (in economic terms) that are expected as a result of implementing the signal retiming improvements implemented under the BTD's 2010 – 2012 program.

As noted in Table 8, the signal retiming improvements implemented under the 2010 – 2012 program are expected to realize approximately $64,000 in air quality economic benefits on an annual basis. Additionally, an overall reduction of approximately 29 metric tons of emissions per year is anticipated to occur as a result of the implementation of the signal retiming improvements (20.52 metric tons of CO + 4.01 metric tons of NOx + 4.78 metric tons of VOC).

Table 5 2010-2012 Signal Retiming Program: Carbon Monoxide (CO) Reductions

Work Order	Existing Emissions (kg/day)	Emissions w/Improvements (kg/day)	Change in Emissions (kg/day)	Change in Emissions (%)	Annual Change in Emissions (metric tons/yr)	Annual Benefits (2012 $)
1	24.92	23.76	-1.16	-4.7%	-0.3016	$45
2	71.63	62.46	-9.17	-12.8%	-2.3842	$352
3	61.94	58.68	-3.26	-5.3%	-0.8476	$125
4	128.83	97.43	-31.40	-24.4%	-8.1640	$1,205
5	109.01	103.37	-5.64	-5.2%	-1.4664	$217
6	55.58	47.87	-7.71	-13.9%	-2.0046	$296
7	67.22	63.84	-3.38	-5.0%	-0.8788	$130
8	42.00	38.12	-3.88	-9.2%	-1.0088	$149
9	48.79	39.02	-9.77	-20.0%	-2.5402	$375
10	50.30	46.75	-3.55	-7.1%	-0.9230	$136
Total	660.22	581.30	-78.92	-11.9%	-20.5192	$3,037

Notes:
1. *Annual change in vehicular emissions = daily change in emission x 260 workdays x kilogram to metric ton conversion factor*
2. *Annual Benefits = annual change in emission levels x economic cost per metric ton of CO ($148/metric ton)*
3. *Annual Benefits for each Work Order rounded to the nearest dollar.*

Table 6 2010-2012 Signal Retiming Program: Nitrous Oxide (NOx) Reductions

Work Order	Existing Emissions (kg/day)	Emissions w/Improvements (kg/day)	Change in Emissions (kg/day)	Change in Emissions (%)	Annual Change in Emissions (metric tons/yr)	Annual Benefits (2012 $)
1	4.85	4.62	-0.23	-4.7%	-0.0598	$479
2	13.94	12.15	-1.79	-12.8%	-0.4654	$3,730
3	12.05	11.42	-1.63	-5.2%	-0.1638	$1,313
4	25.07	18.95	-6.12	-24.4%	-1.5912	$12,752
5	21.21	20.11	-1.10	-5.2%	-0.2860	$2,292
6	10.82	9.32	-1.50	-13.9%	-0.3900	$3,126
7	13.07	12.42	-0.65	-5.0%	-0.1690	$1,354
8	8.17	7.41	-0.76	-9.3%	-0.1976	$1,584
9	9.55	7.58	-1.97	-20.6%	-0.5122	$4,105
10	9.78	9.10	-0.68	-7.0%	-0.1768	$1,417
Total	128.51	113.08	-15.43	-12.8%	-4.0118	$32,151

Notes:
1. *Annual change in vehicular emissions = daily change in emission x 260 workdays x kilogram to metric ton conversion factor*
2. *Annual Benefits = annual change in emission levels x economic cost per metric ton of NOx ($8,014/metric ton).*
3. *Annual Benefits for each Work Order rounded to the nearest dollar.*

Table 7 2010-2012 Signal Retiming Program: Volatile Organic Compounds (VOC) Reductions

Work Order	Existing Emissions (kg/day)	Emissions w/Improvements (kg/day)	Change in Emissions (kg/day)	Change in Emissions (%)	Annual Change in Emissions (metric tons/yr)	Annual Benefits (2012 $)
1	5.77	5.50	-0.27	-4.7%	-0.0702	$427
2	16.60	14.48	-2.12	-12.8%	-0.5512	$3,351
3	14.36	13.60	-0.76	-5.3%	-0.1976	$1,201
4	29.86	22.57	-7.29	-24.4%	-1.8954	$11,524
5	25.26	23.96	-1.30	-5.1%	-0.3380	$2,055
6	12.88	11.09	-1.79	-13.9%	-0.4654	$2,830
7	15.59	14.80	-0.79	-5.1%	-0.2054	$1,277
8	9.73	8.84	-0.89	-9.1%	-0.2314	$1,407
9	11.38	9.04	-2.34	-20.6%	-0.6084	$3,699
10	11.66	10.84	-0.82	-7.0%	-0.2132	$1,296
Total	153.09	134.72	-18.37	-12.0%	-4.7762	$29,039

Notes:
1. *Annual change in vehicular emissions = daily change in emission x 260 workdays x kilogram to metric ton conversion factor*
2. *Annual Benefits = annual change in emission levels x economic cost per metric ton of VOC ($6,080/metric/ton).*
3. *Annual Benefits for each Work Order rounded to the nearest dollar.*

Table 8 2010-2012 Signal Retiming Program: Air Quality Benefits Summary

Work Order	Carbon Monoxide (CO)	Nitrous Oxide (NOx)	Volatile Organic Compounds (VOC)	Total Annual Benefits (2012 $)
1	$45	$479	$427	$951
2	$352	$3,730	$3,351	$7,433
3	$125	$1,313	$1,201	$2,639
4	$1,205	$12,752	$11,524	$25,481
5	$217	$2,292	$2,055	$4,564
6	$296	$3,126	$2,830	$6,252
7	$130	$1,354	$1,277	$2,761
8	$149	$1,584	$1,407	$3,140
9	$375	$4,105	$3,699	$8,179
10	$136	$1,417	$1,296	$2,849
Total	$3,037	$32,151	$29,039	$64,227

Notes:
1. *Total Annual Benefits = annual benefits of CO + NOx + VOC.*
2. *Annual Benefits (2012 dollars) for each Work Order rounded to the nearest dollar.*

Benefits Summary. A summary of the Delay (vehicular), Safety (crashes), Energy (fuel consumption), and Air Quality (vehicular emissions) benefits calculated for each of the work orders is shown in Table 9. The values in Table 9 reflect the value of the benefits adjusted to 2012 dollars. As shown in Table 9, the 2010 - 2012 signal retiming improvements are estimated to yield annual benefits worth more than $11,700,000.

Table 9 2010-2012 Signal Retiming Program: Total Benefits

Work Order	Delay (Vehicular)	Safety (Crashes)	Energy (Fuel Consumption)	Air Quality (Emissions)	Total Annualized Benefits (2012 $)
1	$211,338	$26,859	$16,133	$951	$255,281
2	$1,285,903	$167,397	$124,319	$7,433	$1,585,052
3	$400,291	$268,881	$43,654	$2,639	$715,465
4	$4,068,246	$67,029	$426,101	$25,481	$4,586,857
5	$619,674	$285,579	$75,920	$4,564	$985,737
6	$955,150	$23,472	$104,390	$6,252	$1,089,264
7	$158,329	$23,472	$46,501	$2,761	$231,063
8	$438,522	$23,472	$53,144	$3,140	$518,278
9	$1,009,173	$23,472	$154,687	$8,179	$1,195,511
10	450,887	$46,944	$48,399	$2,849	$549,079
Total	$9,597,512	$956,577	$1,093,248	$64,227	$11,711,587

Notes:
1. *Annual Benefits (2012 dollars) for each Work Order rounded to the nearest dollar.*

Table 10 provides a summary of the total benefits expected to be accrued as a result of implementing the recommended signal retiming improvements identified through the analyses performed for the BTD's 2010 – 2012 Signal Retiming Program.

Table 10 2010-2012 Signal Retiming Program: Benefits Summary

Work Order	Areas/Corridors	# of Intersections	Annualized Benefits
1	Beacon St/Charles St/ Washington St	10	$255,281
2	Commonwealth Ave/Brighton Ave	10	$1,585,052
3	Tremont St/Shawmut Ave/Washington St	25	$715,465
4	Columbus Ave	17	$4,586,857
5	Chelsea St/Huntington Ave/Various	24	$985,737
6	Blue Hill Ave	7	$1,089,264
7	Centre St/Washington St	14	$231,063
8	Washington St/Hyde Park Ave	8	$518,278
9	Commonwealth Ave	10	$1,195,511
10	Massachusetts Ave/Albany St	7	$549,079
Total		132	$11,711,587

Notes:
1. Annual Benefits (2012 dollars) for each Work Order rounded to the nearest dollar.

3.2 Cost Calculations

There are costs to the City associated with the implementation of the recommended signal retiming improvements that were undertaken during the 2010 – 2012 signal retiming program. Those costs fall into two general categories:

- Engineering Costs
- Construction Costs

Engineering Costs. Engineering costs are the costs incurred in developing the recommended intersection improvements. It was assumed that signal retiming projects similar to these current projects are typically conducted by BTD once every five years. Tetra Tech Inc.'s engineering costs were annualized over a period of five years using an inflation rate that varied by assignment, but was based on the rates published in the Consumer Price Index (CPI) by United States Department of Labor. Those rates ranged from 1.6 percent to 4.85 percent/year. The costs associated with time spent by BTD professionals on the project are estimated to be $45,000 per year.

Construction Costs. The construction costs associated with implementing intersection improvements include items such as adding pavement markings, installing new traffic signs, upgrading signal equipment, etc. The construction cost associated with intersection improvements was estimated and is summarized in Appendices A through J. The list of proposed intersection improvements presented in the recommendations technical memorandum for each work order was used in estimating costs. In accordance with guidance provided by the BTD, items in the table such as ADA ramp improvements, repairs to signal equipment, etc., were not considered in the cost calculations. It was determined that these improvements would not directly improve traffic flow/operations, nor will they be part of regular BTD capital improvements

and/or signal maintenance contracts. Therefore, those improvements were not considered for the benefit-cost analysis presented in this report for the 2010 – 2012 signal retiming program.

Costs associated with implementing signal timing and phasing changes by BTD contractors were estimated based on data provided by the BTD. The contractor costs would include the time needed for implementing the clearance timing changes (assumed to be 0.5 hours per intersection) and two hours of travel time. It was assumed that the contractor would be paid $125 per hour. In addition, the BTD recommended using an estimated cost of $2,500 per intersection where a signal phasing change is to be implemented.

Based on guidance from the BTD, it was assumed that pavement markings/signs and signal equipment will have an average lifespan of five years and 15 years, respectively. Therefore, the marking/sign costs were annualized over a five-year period and the signal equipment related costs were annualized over a 15-year period using an inflation rates from the Consumer Price index (as was previously described). For the purposes of this analysis, a conservative assumption that all the non-signal retiming improvements will last for only one year was made. Details of engineering cost and BTD contractor cost calculations are also provided in Appendices A through J.

Cost Summary. A summary of the annualized costs calculated for each of the work orders is provided in the benefit-cost memoranda included in Appendices A through J, and is summarized in Table 11. The values noted in Table 11 include the applicable engineering and construction costs for the set of improvements recommended for each work order.

As presented in Table 11, the total annualized cost of implementing the improvements recommended as part of the 2010 – 2012 signal retiming program is estimated to be approximately $271,000 (2012 dollars).

Table 11 2010-2012 Signal Retiming Program: Costs Calculated

Work Order	Areas/Corridors	# of Intersections	Annualized Cost (2012 $)
N/A	Annual Labor Cost (BTD)		$45,000
1	Beacon St/Charles St/ Washington St	10	$14,080
2	Commonwealth Ave/Brighton Ave	10	$17,021
3	Tremont St/Shawmut Ave/Washington St	25	$29,247
4	Columbus Ave	17	$20,724
5	Chelsea St/Huntington Ave/Various	24	$77,837
6	Blue Hill Ave	7	$9,777
7	Centre St/Washington St	14	$18,442
8	Washington St/Hyde Park Ave	8	$13,965
9	Commonwealth Ave	10	$12,665
10	Massachusetts Ave/Albany St	7	$12,416
Total		132	$271,174

Notes:
1. *Annualized costs for each Work Order rounded to the nearest dollar.*

4.0 Benefit-Cost Ratios

The total benefits and costs associated with the signal retiming improvements implemented through the 10 work orders completed as part of the 2010 – 2012 signal retiming program (Contract #29623) are summarized in Table 12. The value of the benefits realized by the improvements was calculated to be approximately 43 times greater than the costs incurred to implement the improvements. Based on the benefit-cost analysis presented in this report, it is clearly evident that the 2010 – 2012 signal retiming program is beneficial to both the City of Boston and the users of the City's roadway system.

Table 12 2010-2012 Retiming Program: Summary of Benefit-Cost Analysis

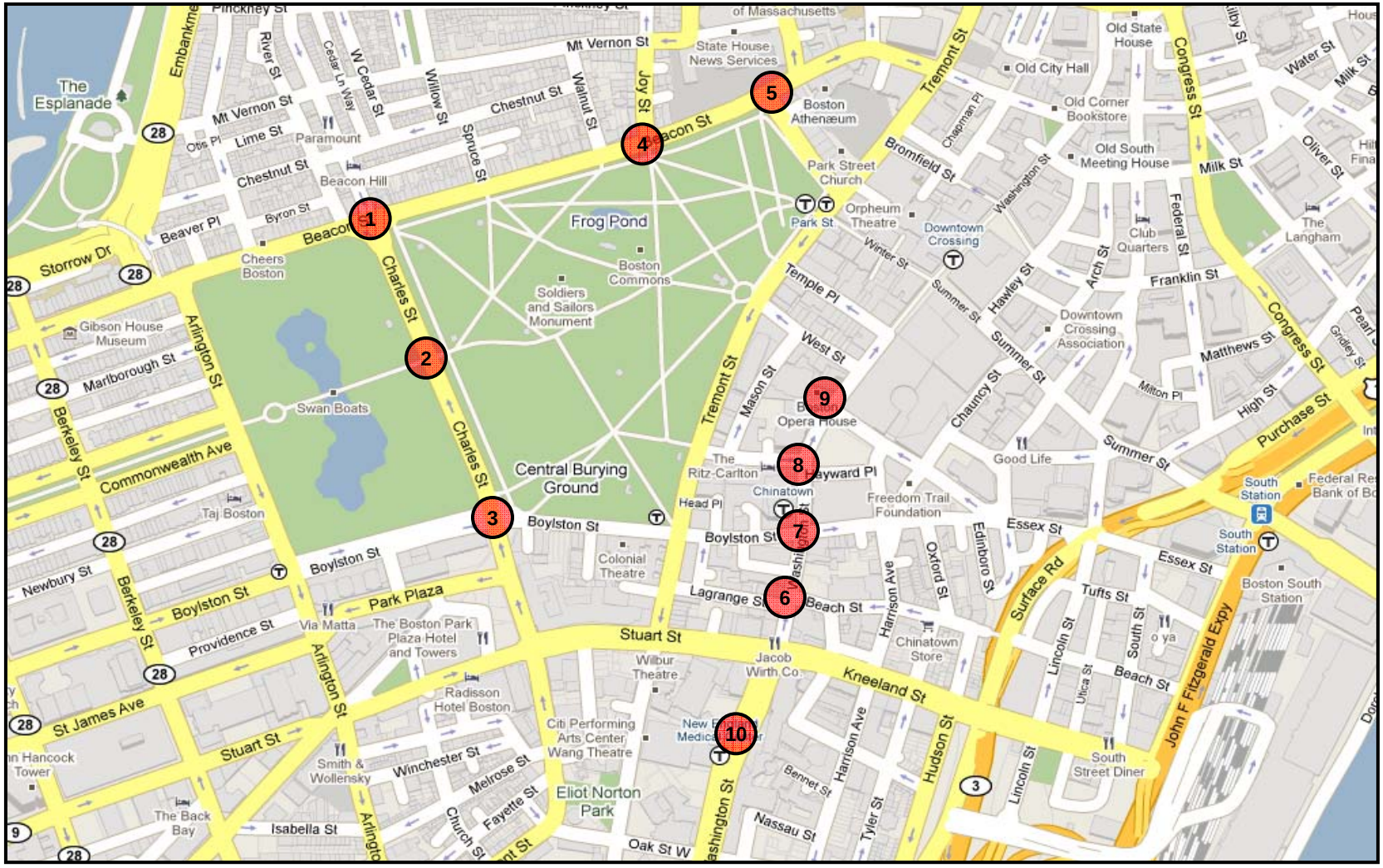
	Annualized Benefits & Costs
Signal Improvement Benefits	$11,711,587
Costs to Implement Improvements	$271,174
Benefit - Cost Ratio	43 to 1

Notes:

1. *Annualized benefits and costs rounded to the nearest dollar.*

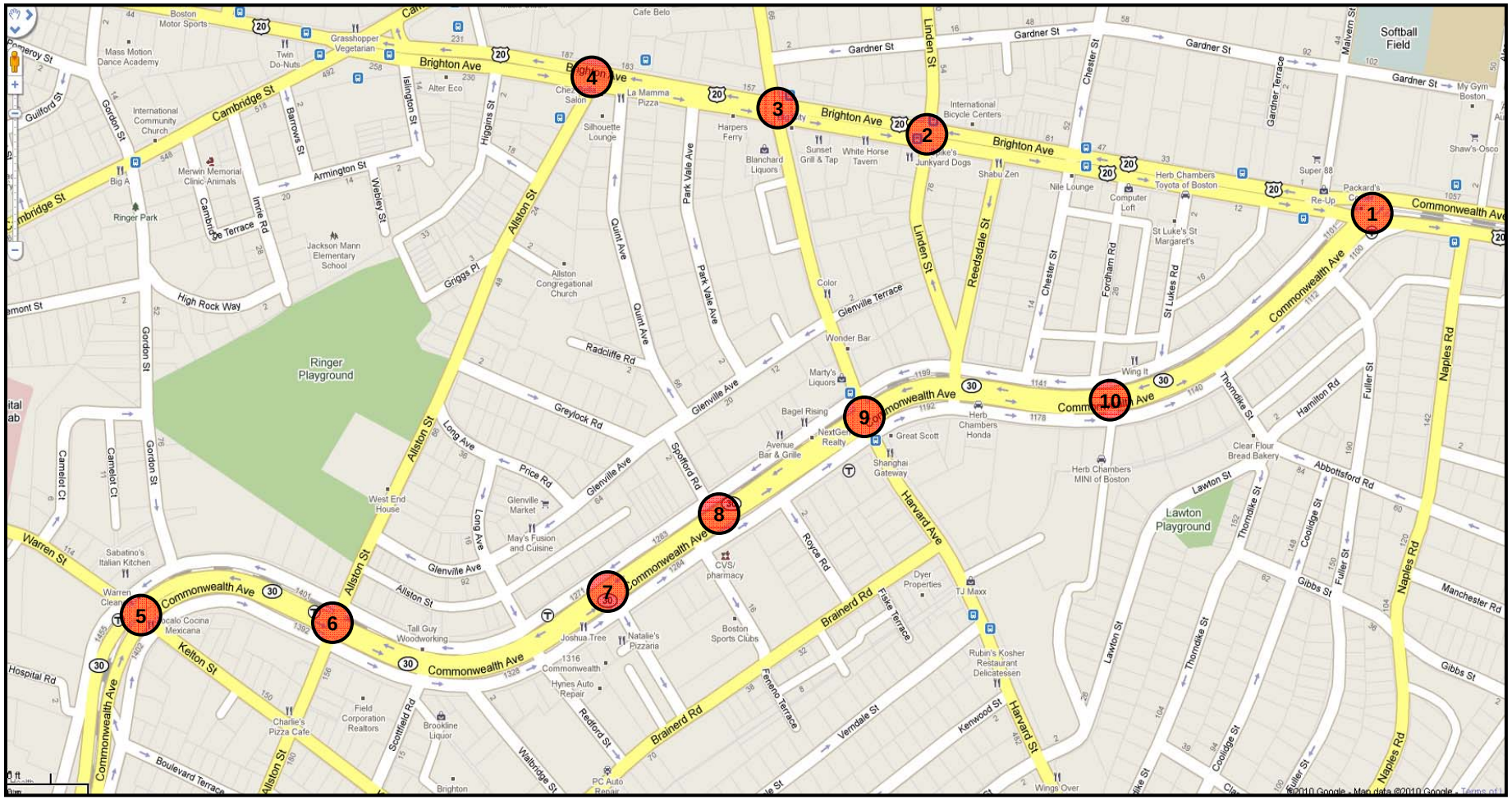
List of Intersections – Work Order 1

1. Beacon St & Charles St
2. Charles St & Center Gate (ctr of park)
3. Boylston St & Charles St
4. Beacon St & Joy St
5. Beacon St & Park St
6. Beach St & Lagrange St & Washington St
7. Boylston St, Essex St & Washington St
8. Avery St & Washington St
9. Ave DeLafayette & Washington St
10. Washington St at Tufts NE Medical Center

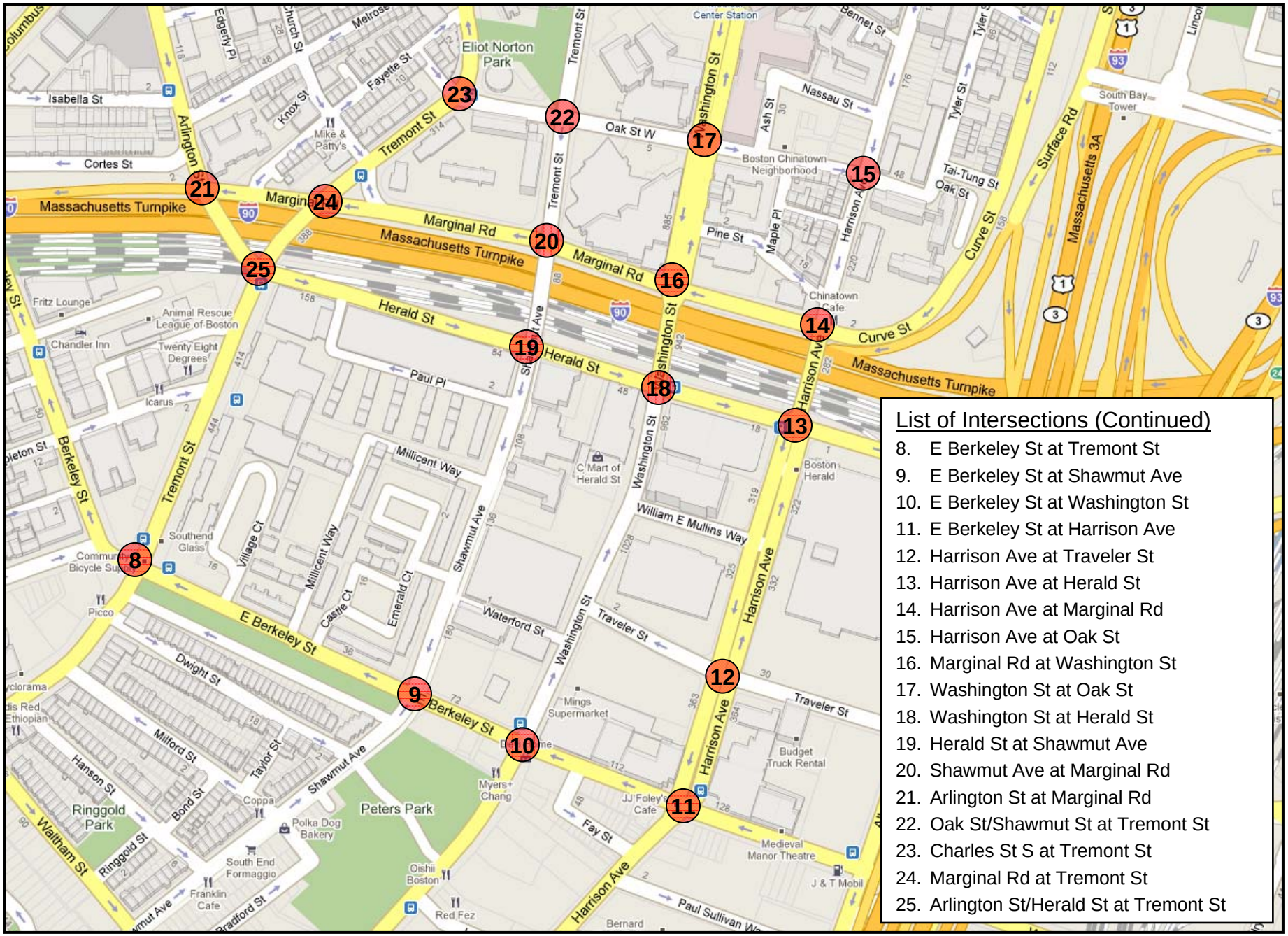


List of Intersections – Work Order 2

1. Brighton Ave & Commonwealth Ave
2. Brighton Ave & Linden St
3. Brighton Ave & Harvard Ave
4. Brighton Ave & Allston St
5. Commonwealth Ave & Warren St
6. Commonwealth Ave & Allston St
7. Commonwealth Ave & Griggs St
8. Commonwealth Ave & Spofford St
9. Commonwealth Ave & Harvard Ave
10. Commonwealth Ave & Fordham St

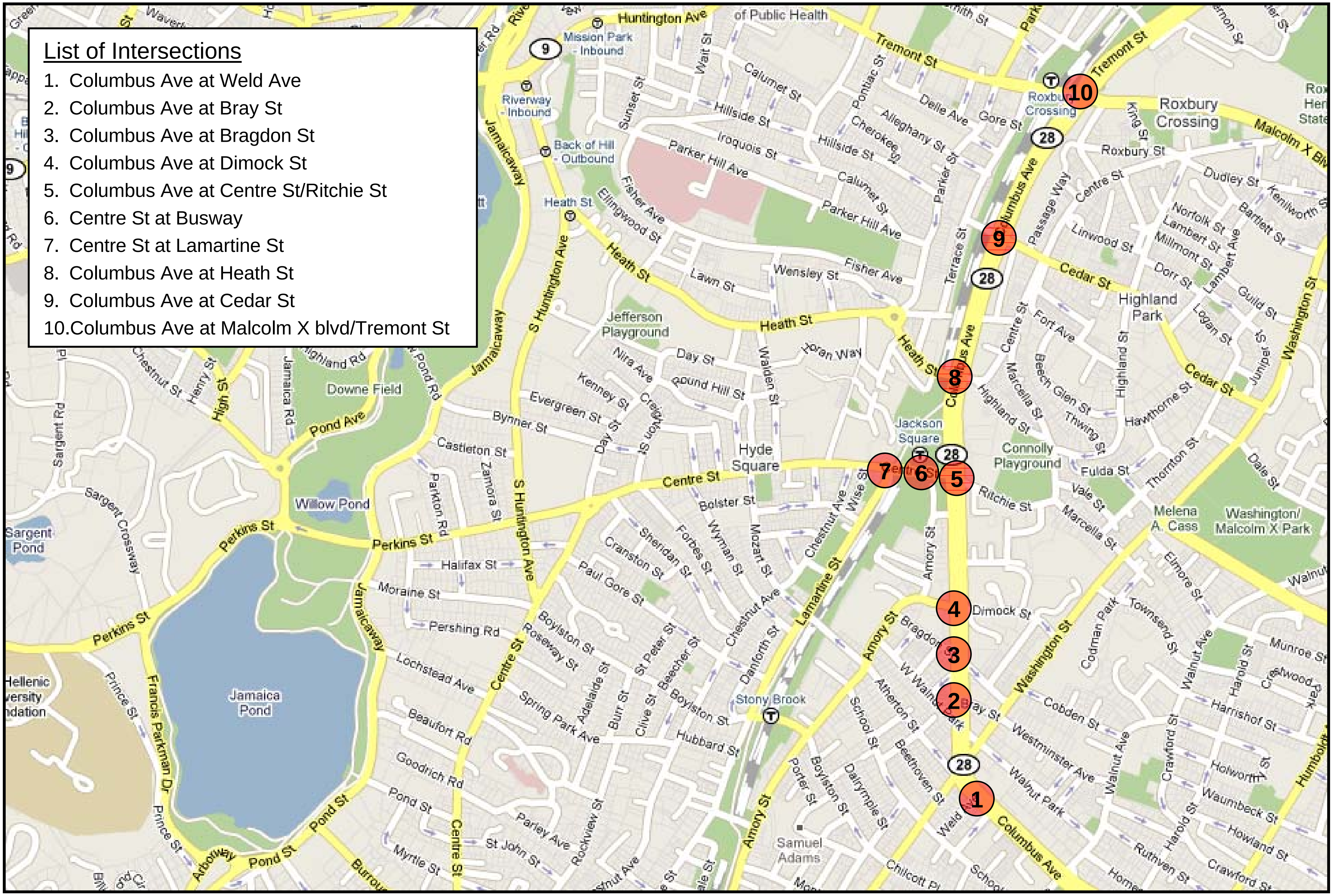



List of Intersections W.O. #3
1. Beacon St/School St at Tremont St
2. Bromfield St at Tremont St
3. Park/Winter St at Tremont St
4. Temple Place at Tremont St
5. West St at Tremont St
6. Avery St at Tremont St
7. Boylston St at Tremont St
Boston Common
Frog Pond
Central Burying Ground



List of Intersections (Continued)

8. E Berkeley St at Tremont St
9. E Berkeley St at Shawmut Ave
10. E Berkeley St at Washington St
11. E Berkeley St at Harrison Ave
12. Harrison Ave at Traveler St
13. Harrison Ave at Herald St
14. Harrison Ave at Marginal Rd
15. Harrison Ave at Oak St
16. Marginal Rd at Washington St
17. Washington St at Oak St
18. Washington St at Herald St
19. Herald St at Shawmut Ave
20. Shawmut Ave at Marginal Rd
21. Arlington St at Marginal Rd
22. Oak St/Shawmut St at Tremont St
23. Charles St S at Tremont St
24. Marginal Rd at Tremont St
25. Arlington St/Herald St at Tremont St


List of Intersections
1. Columbus Ave at Weld Ave
2. Columbus Ave at Bray St
3. Columbus Ave at Bragdon St
4. Columbus Ave at Dimock St
5. Columbus Ave at Centre St/Ritchie St
6. Centre St at Busway
7. Centre St at Lamartine St
8. Columbus Ave at Heath St
9. Columbus Ave at Cedar St
10.Columbus Ave at Malcolm X blvd/Tremont St


List of Intersections
11. Tremont St at Terrance St
12. Tremont St at Parker St
13. Tremont St at Prentiss St
14. Tremont St at Ruggles St/Whittier St
15. Ruggles St at Busway
16. Ruggles St at Leon St
17. Tremont St at Access Drive
11
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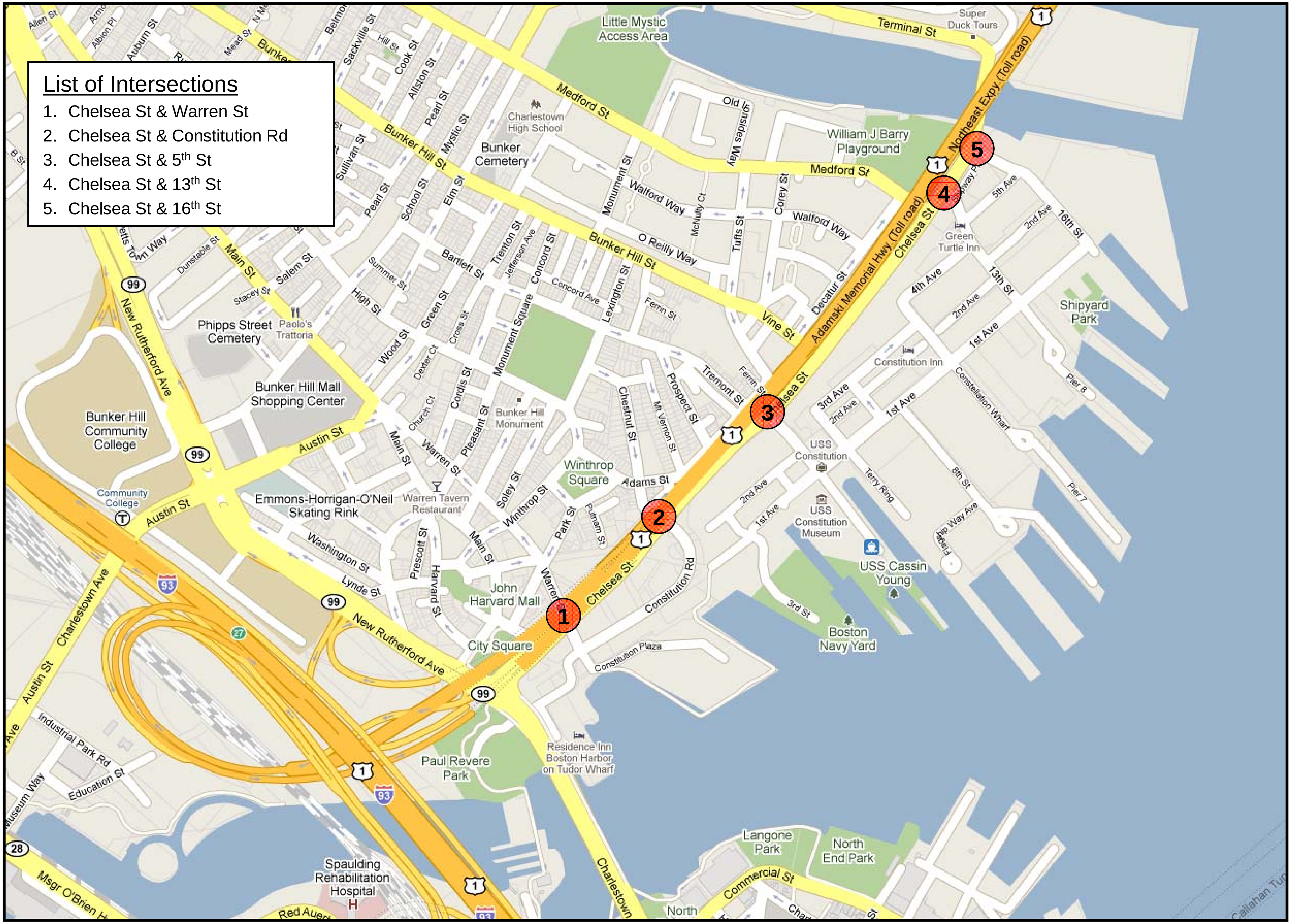
16
17
Tremont St
Parker St
Ruggles St
Whittier St
Prentiss St
Schroeder Plaza
Malcolm X Blvd
Melnea Cass Blvd
Columbus Ave
SW Corridor Park
Southwest Corridor
Annunciation Rd
Albert St
Leon St
McGreevey Way
Horadan Way
Smith St
Station St
Gurney St
Halleck St
Mindoro St
Vernon St
Cabot St
Downing St
Elmwood St
King St
Roxbury St
Gore St
Delle Ave
Ruggles Station (Mbta Orange Line)
Roxbury Crossing Station
Reggie Lewis Track and Athletic Center
Boston Housing Authority
International Village
Renaissance Park
White Fund Playground # 31
Jeep Jones Park
Roxbury Heritage State Park
King St Play Area
John D O'Bryant School
Good Shepherd Church of God
St Katharine Drexel Parish Center
Ryder Hall
Boston Center For Youth Family
ABCD Parker Hill Fenway
Mission Work
Bates Tire Repair
Fuentes Market
General Shoe Repair Store
Dominos Pizza
Ruggles Gilday

WORK ORDER #5


List of Intersections
1. Chelsea St & Warren St
2. Chelsea St & Constitution Rd
3. Chelsea St & 5th St
4. Chelsea St & 13th St
5. Chelsea St & 16th St
1
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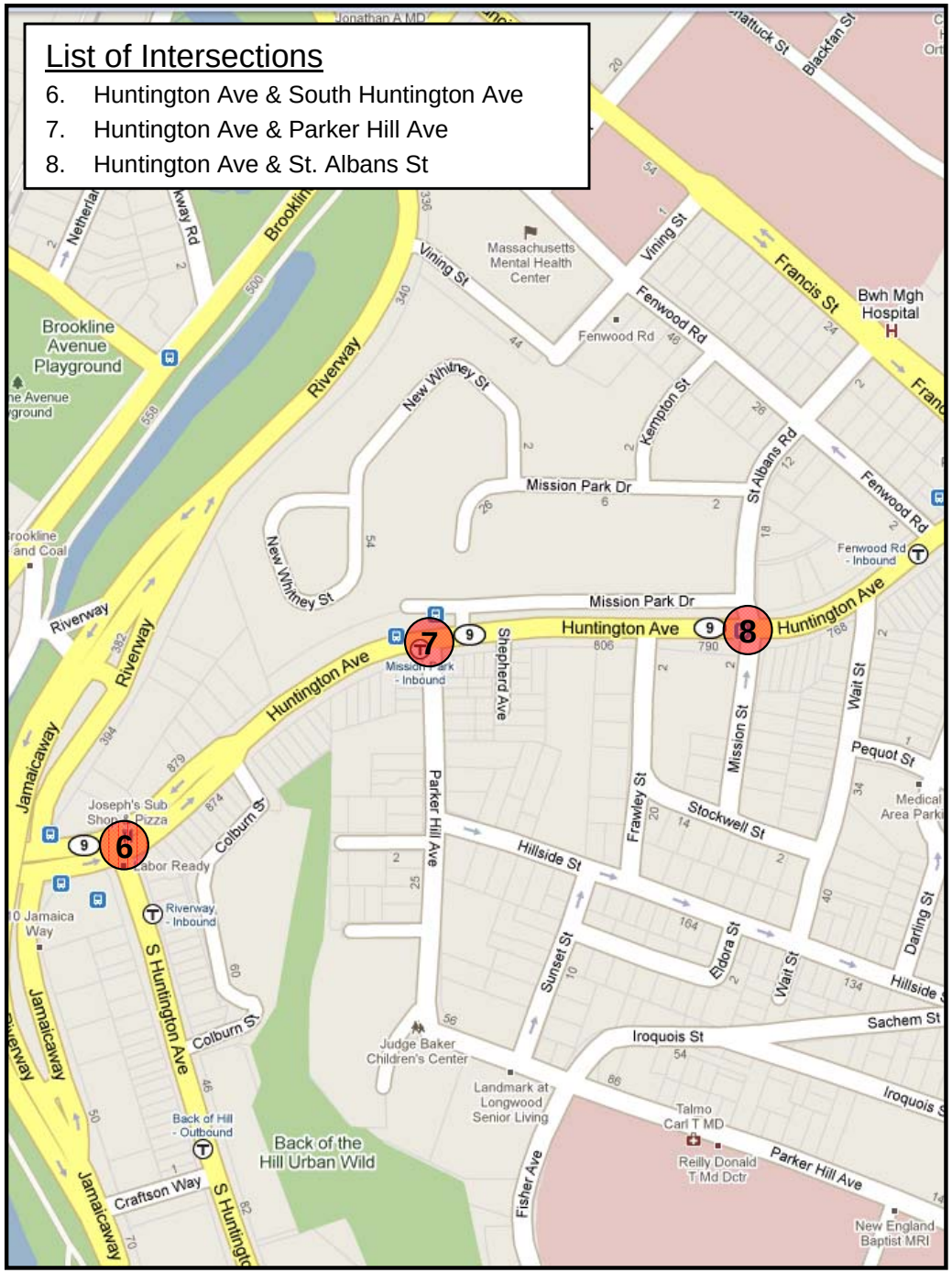
Medford St
Bunker Hill St
Terminal St
Little Mystic Access Area
Super Duck Tours
Charlestown High School
Bunker Cemetery
William J Barry Playground
Walford Way
O Reilly Way
Vine St
Adamski Memorial Hwy (Toll road)
Northeast Expy (Toll road)
Chelsea St
Green Turtle Inn
Shipyard Park
Constitution Inn
Phipps Street Cemetery
Paolo's Trattoria
Bunker Hill Mall Shopping Center
Bunker Hill Community College
Bunker Hill Monument
Winthrop Square
Austin St
New Rutherford Ave
Emmons-Horrigan-O'Neil Skating Rink
Warren Tavern Restaurant
Washington St
Lynde St
John Harvard Mall
City Square
Constitution Rd
Constitution Plaza
USS Constitution
USS Constitution Museum
USS Cassin Young
Boston Navy Yard
Residence Inn Boston Harbor on Tudor Wharf
Paul Revere Park
Charlestown Ave
Industrial Park Rd
Education St
Spaulding Rehabilitation Hospital
Langone Park
North End Park
Commercial St
Msgr O'Brien Hwy


List of Intersections
6. Huntington Ave & South Huntington Ave
7. Huntington Ave & Parker Hill Ave
8. Huntington Ave & St. Albans St
Brookline Avenue Playground
Massachusetts Mental Health Center
Bwh Mgh Hospital
Francis St
Vining St
Fenwood Rd
Riverway
New Whitney St
Kempton St
St Albans Rd
Mission Park Dr
Huntington Ave
Shepherd Ave
Wait St
Mission St
Pequot St
Parker Hill Ave
Hillside St
Stockwell St
Frawley St
Colburn St
Jamaicaway
S Huntington Ave
Craftson Way
Back of Hill - Outbound
Riverway - Inbound
Fenwood Rd - Inbound
Mission Park - Inbound
Joseph's Sub Shop & Pizza
Labor Ready
Judge Baker Children's Center
Landmark at Longwood Senior Living
Talmo Carl T MD
Reilly Donald T Md Dctr
New England Baptist MRI
Back of the Hill Urban Wild
Iroquois St
Sachem St
Darling St
Eldora St
Sunset St
Fisher Ave
Medical Area Park
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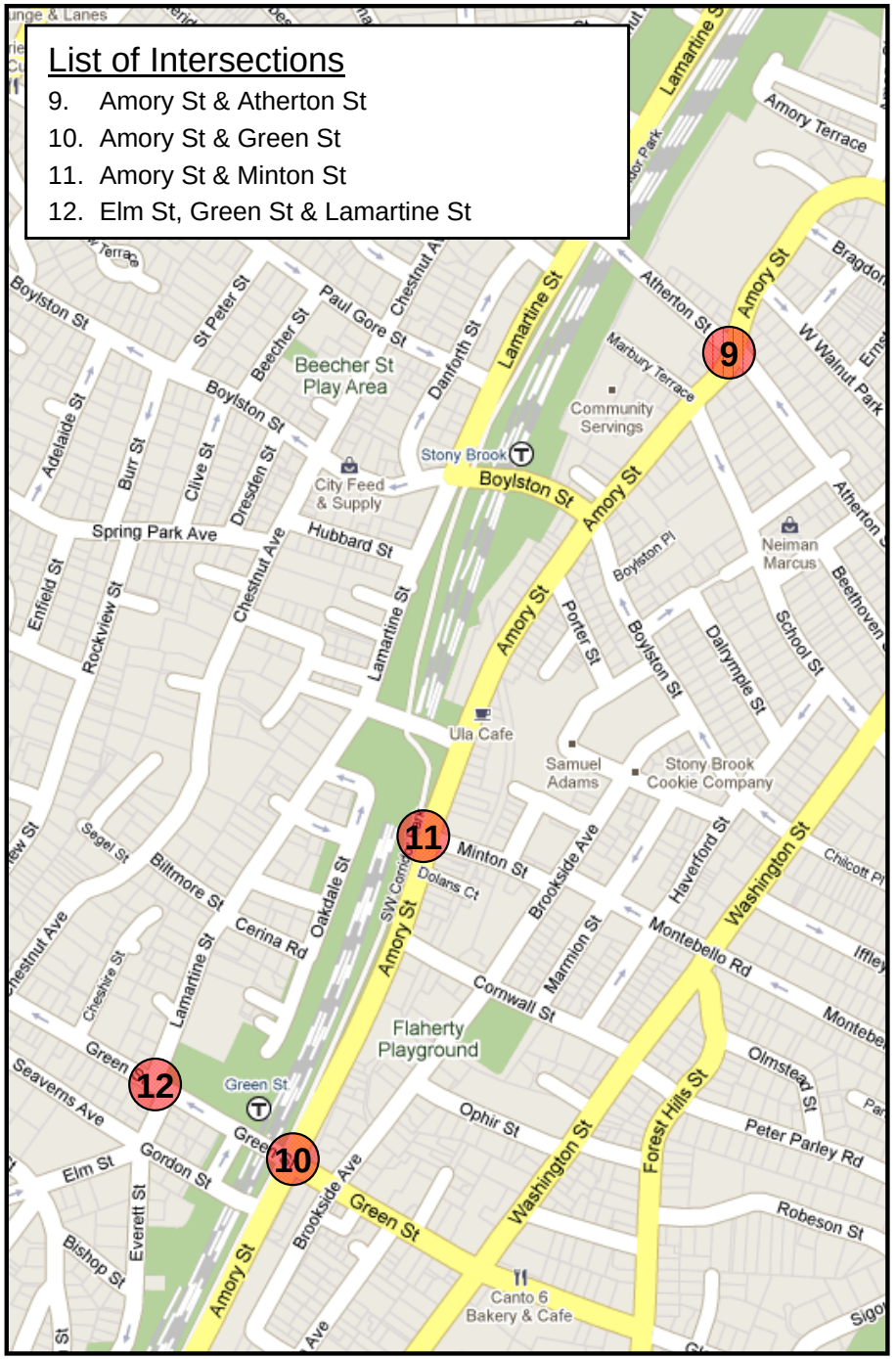
List of Intersections
9. Amory St & Atherton St
10. Amory St & Green St
11. Amory St & Minton St
12. Elm St, Green St & Lamartine St
Amory St
Lamartine St
Boylston St
Atherton St
Beecher St Play Area
Community Servings
Stony Brook
City Feed & Supply
Spring Park Ave
Hubbard St
Chestnut Ave
Enfield St
Rockview St
Adelaide St
Burr St
Clive St
Dresden St
Danforth St
Paul Gore St
St Peter St
Beecher St
Ula Cafe
Samuel Adams
Stony Brook Cookie Company
Neiman Marcus
Porter St
Dalrymple St
School St
Minton St
Dolans Ct
Brookside Ave
Marmion St
Haverford St
Montebello Rd
Cornwall St
Oakdale St
Biltmore St
Segel St
Cerina Rd
Cheshire St
Flaherty Playground
Green St
Seaverns Ave
Gordon St
Elm St
Everett St
Bishop St
Ophir St
Peter Parley Rd
Robeson St
Olmstead St
Forest Hills St
Washington St
Canto 6 Bakery & Cafe
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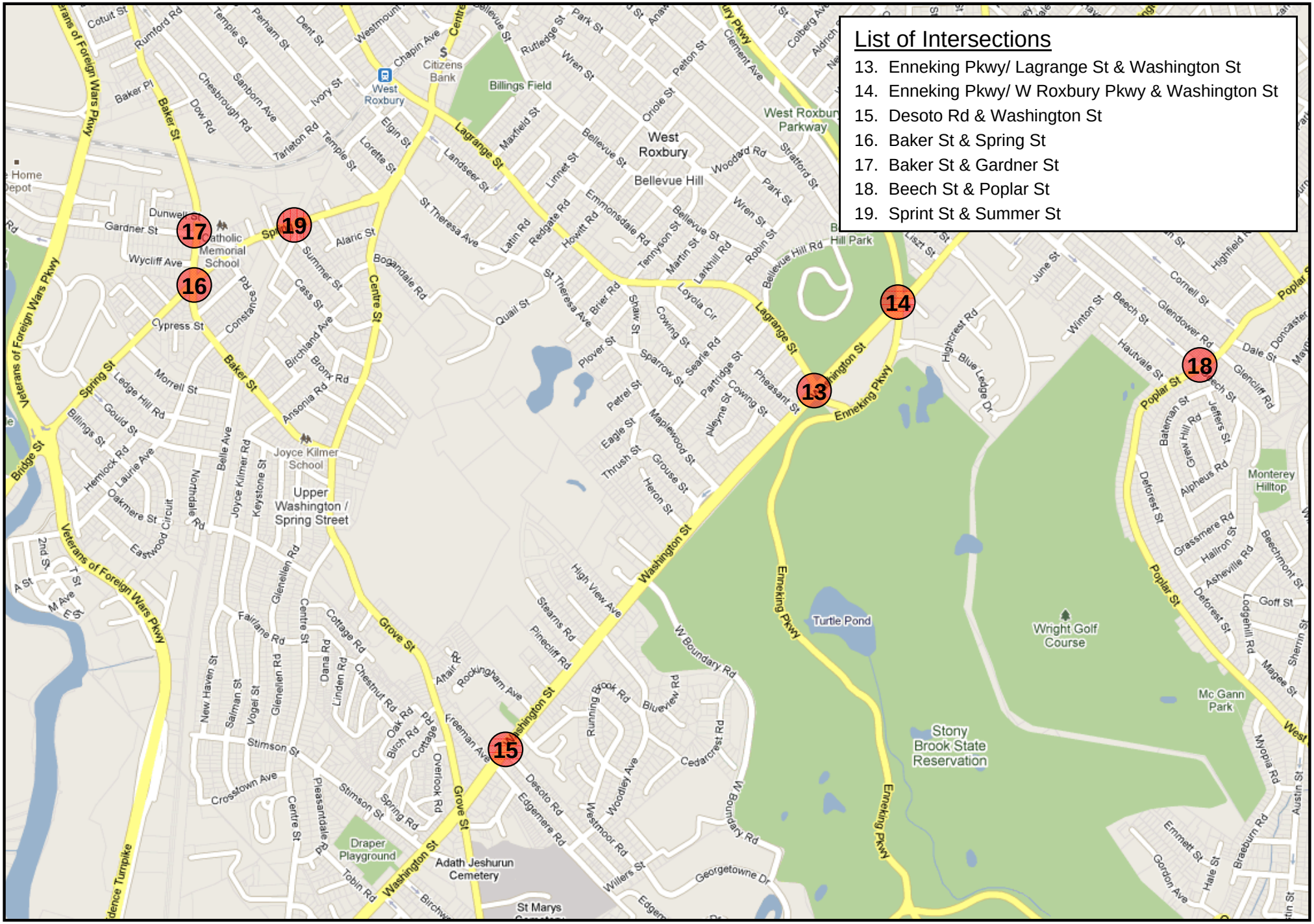
List of Intersections
13. Enneking Pkwy/ Lagrange St & Washington St
14. Enneking Pkwy/ W Roxbury Pkwy & Washington St
15. Desoto Rd & Washington St
16. Baker St & Spring St
17. Baker St & Gardner St
18. Beech St & Poplar St
19. Sprint St & Summer St
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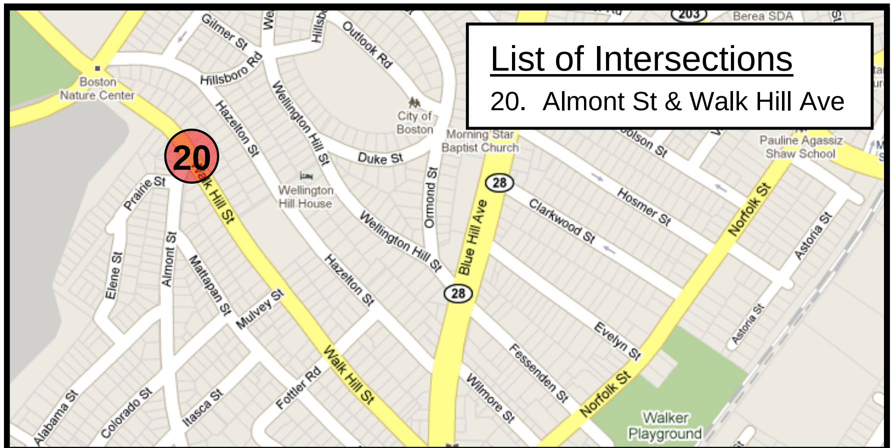
Lagrange St
Enneking Pkwy
Washington St
Baker St
Spring St
Grove St
Poplar St
Centre St
Veterans of Foreign Wars Pkwy
West Roxbury
Billings Field
Bellevue Hill
Upper Washington / Spring Street
Joyce Kilmer School
Turtle Pond
Wright Golf Course
Stony Brook State Reservation
Mc Gann Park
Monterey Hilltop
Draper Playground
Adath Jeshurun Cemetery
St Marys

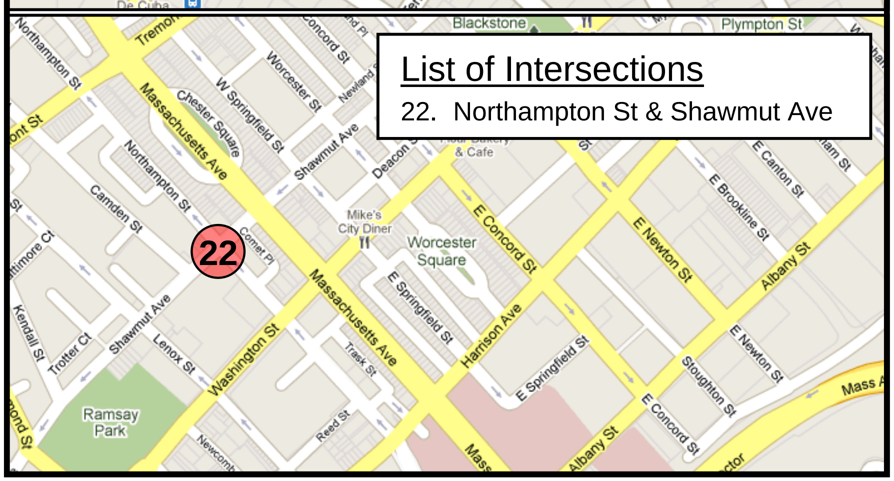


List of Intersections

20. Almont St & Walk Hill Ave

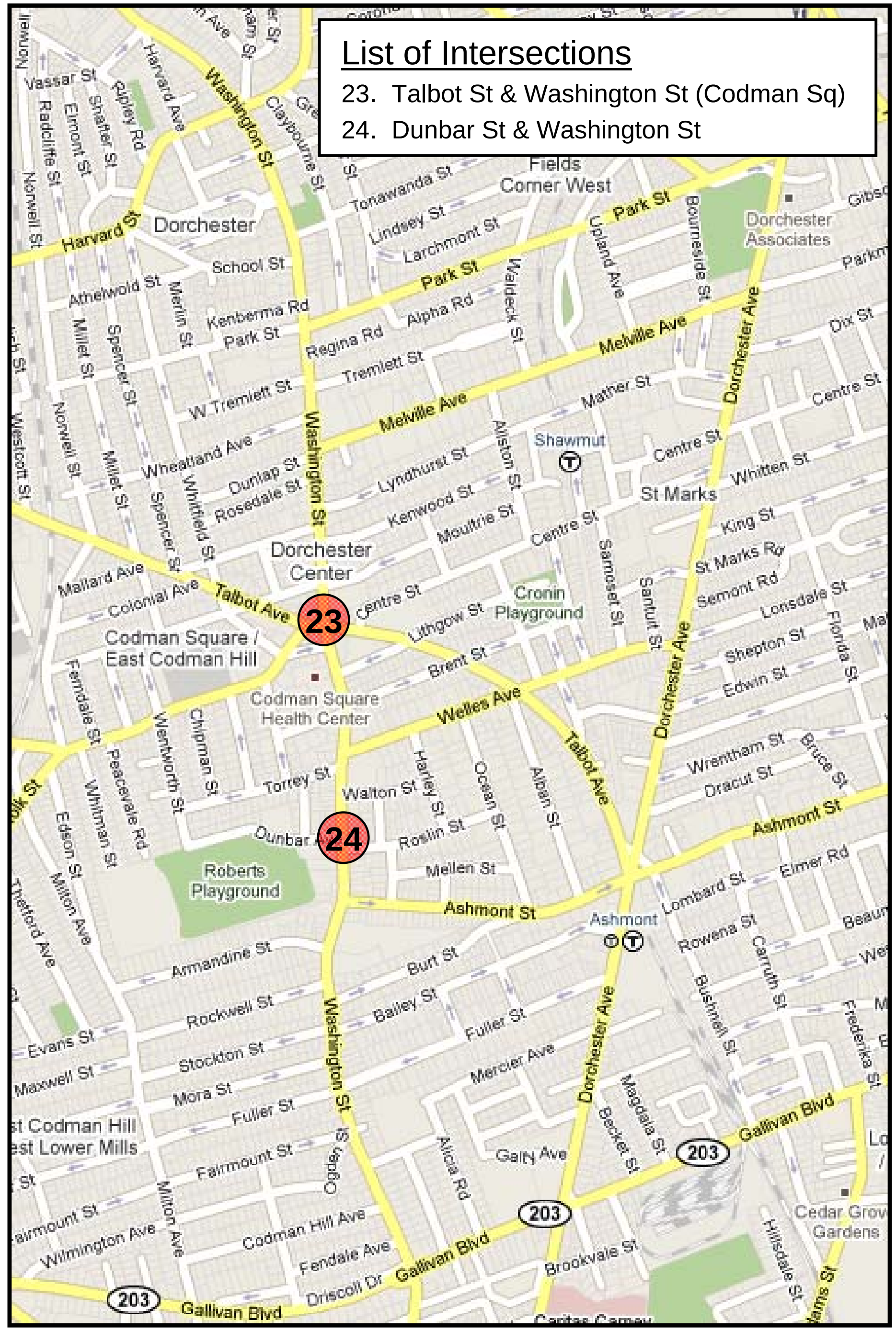
List of Intersections

21. Center St, Creighton St & Forbes St



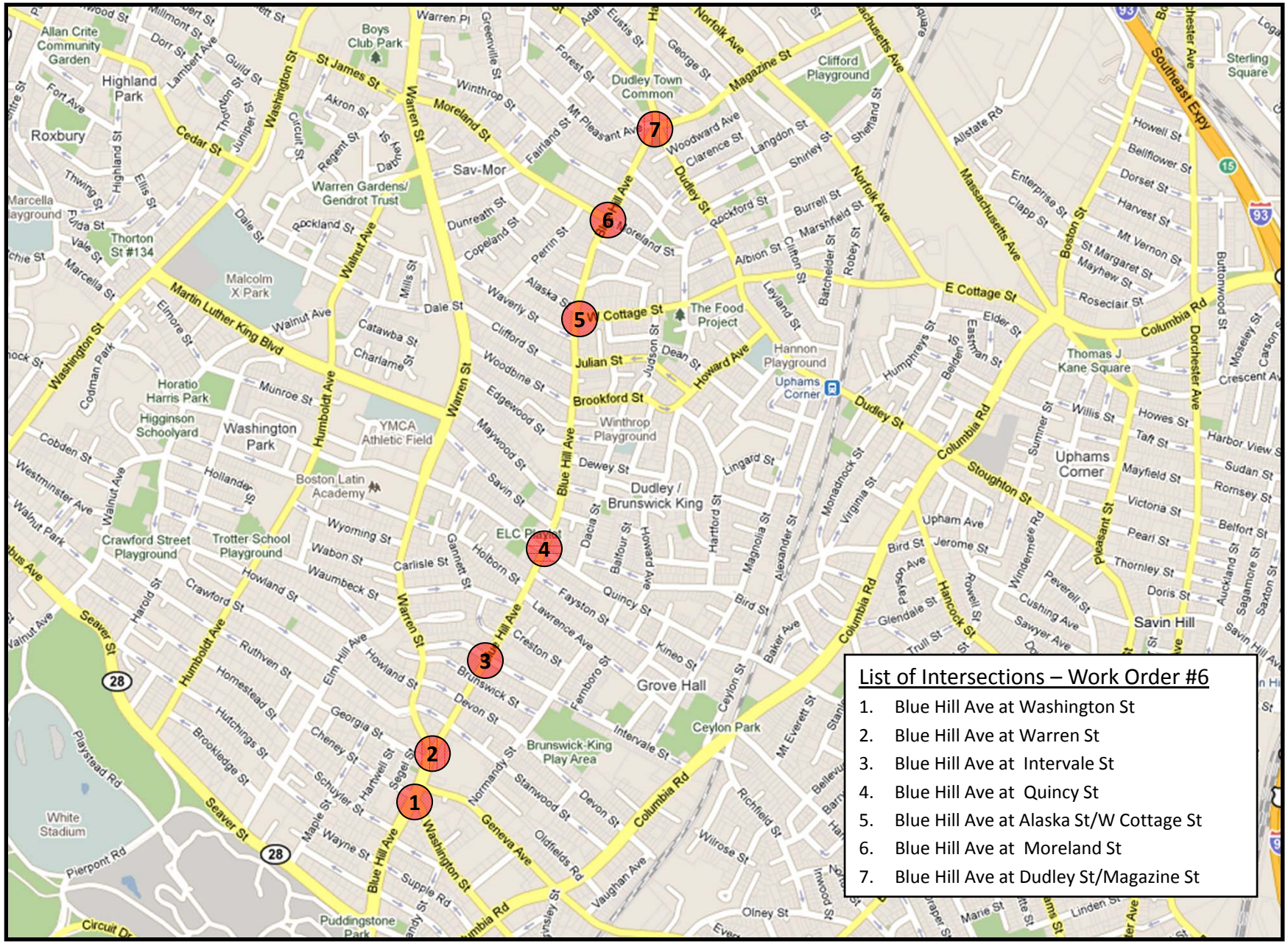
List of Intersections

22. Northampton St & Shawmut Ave



List of Intersections

23. Talbot St & Washington St (Codman Sq)
24. Dunbar St & Washington St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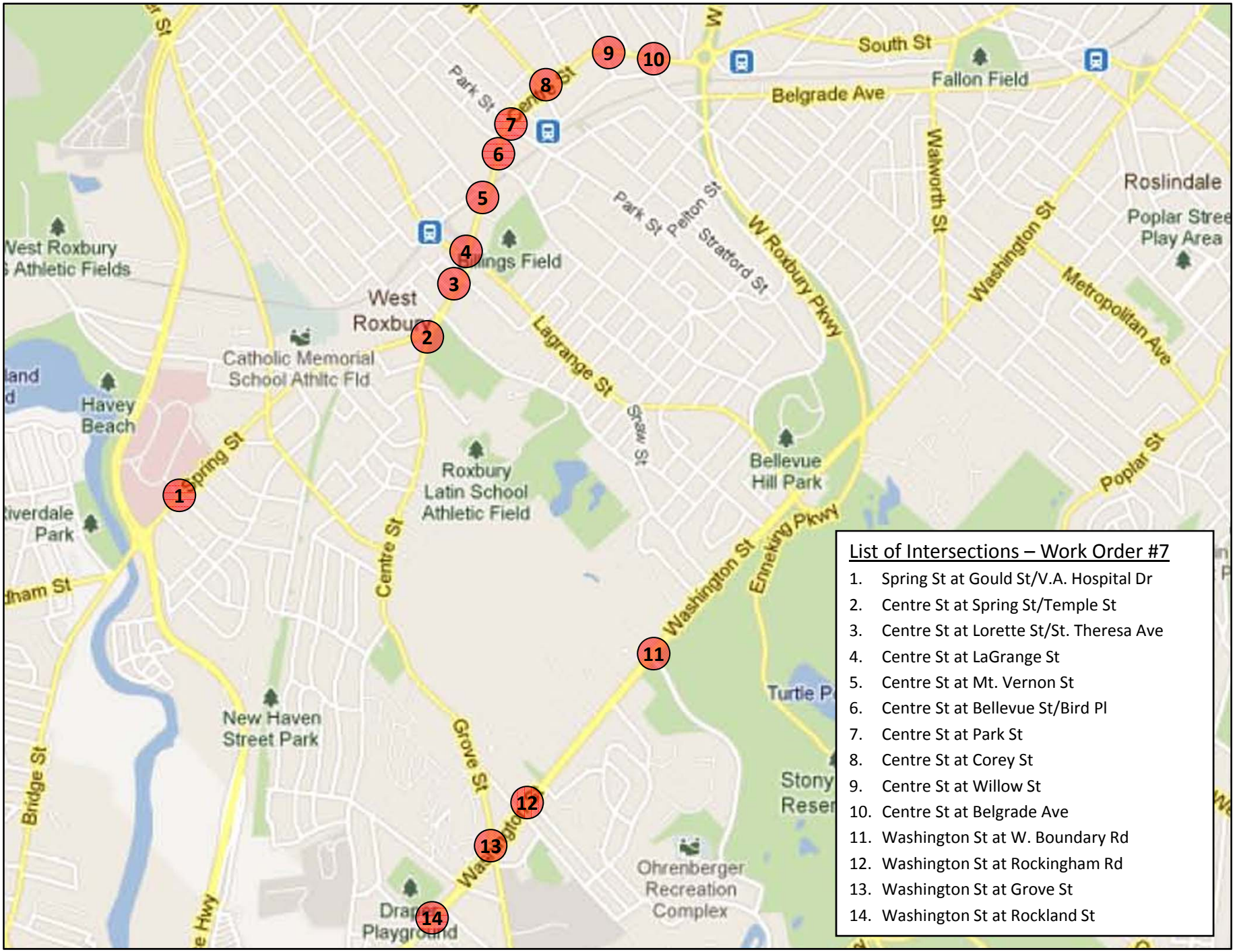
List of Intersections – Work Order #6
1. Blue Hill Ave at Washington St
2. Blue Hill Ave at Warren St
3. Blue Hill Ave at Intervale St
4. Blue Hill Ave at Quincy St
5. Blue Hill Ave at Alaska St/W Cottage St
6. Blue Hill Ave at Moreland St
7. Blue Hill Ave at Dudley St/Magazine St



List of Intersections – Work Order #7

1. Spring St at Gould St/V.A. Hospital Dr
2. Centre St at Spring St/Temple St
3. Centre St at Lorette St/St. Theresa Ave
4. Centre St at LaGrange St
5. Centre St at Mt. Vernon St
6. Centre St at Bellevue St/Bird Pl
7. Centre St at Park St
8. Centre St at Corey St
9. Centre St at Willow St
10. Centre St at Belgrade Ave
11. Washington St at W. Boundary Rd
12. Washington St at Rockingham Rd
13. Washington St at Grove St
14. Washington St at Rockland St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List of Intersections – Work Order #8
1. Washington St at New Washington St/Arborway
2. New Washington at Arborway
3. Washington St at South St/Forest Hills Bus Exit
4. Washington St at Forest Hills Bus Entrance
5. Washington St at Ukraine Way
6. Hyde Park Ave at Forest Hills Bus Entrance
7. Hyde Park Ave at Tower St/Bus Exit
8. Hyde Park Ave at Ukraine Way
Arborway
New Washington St
Msgr William Casey Hwy
Forest Hills Overpass
South St
Washington St
Hyde Park Ave
Tower St
Morton St
Ukraine Way
Hampstead Rd
Spalding St
Anson Street Garden
St Mark St
South Street Community Garden
Forest Hills Station Mall Park
Public Health Dept
Forest Hills Station
Bussey Brook Meadow
Arnold Arboretum
Forest Hills Preserve
Yang's Martial Arts Association
Tomorrow's Antiques
Pope Instrument Repair
Wellsmere Monumental Works
Forest Hills Greenspace
Morgan Variety
NACA Boston Office


List of Intersections – Work Order #9
1. Commonwealth Ave at Summit Ave
2. Commonwealth Ave at Washington St
3. Commonwealth Ave at Colborne Rd
4. Commonwealth Ave at Kinross/Wallingford Rd
5. Commonwealth Ave at Chiswick Rd
6. Commonwealth Ave at Chestnut Hill Ave
7. Commonwealth Ave at South St
8. Commonwealth Ave (North) at Greycliff St
9. Commonwealth Ave (South) at Greycliff St
10. Commonwealth Ave at Lake St/St Thomas Moore
Warren St
St Elizabeth's Medical Center
Washington St
Chestnut Hill Ave
Commonwealth Ave
South St
Lake St
Beacon St
Jackson Square
Boston College - Brighton Campus
Chestnut Hill Reservoir Garden
Evergreen Cemetery
1
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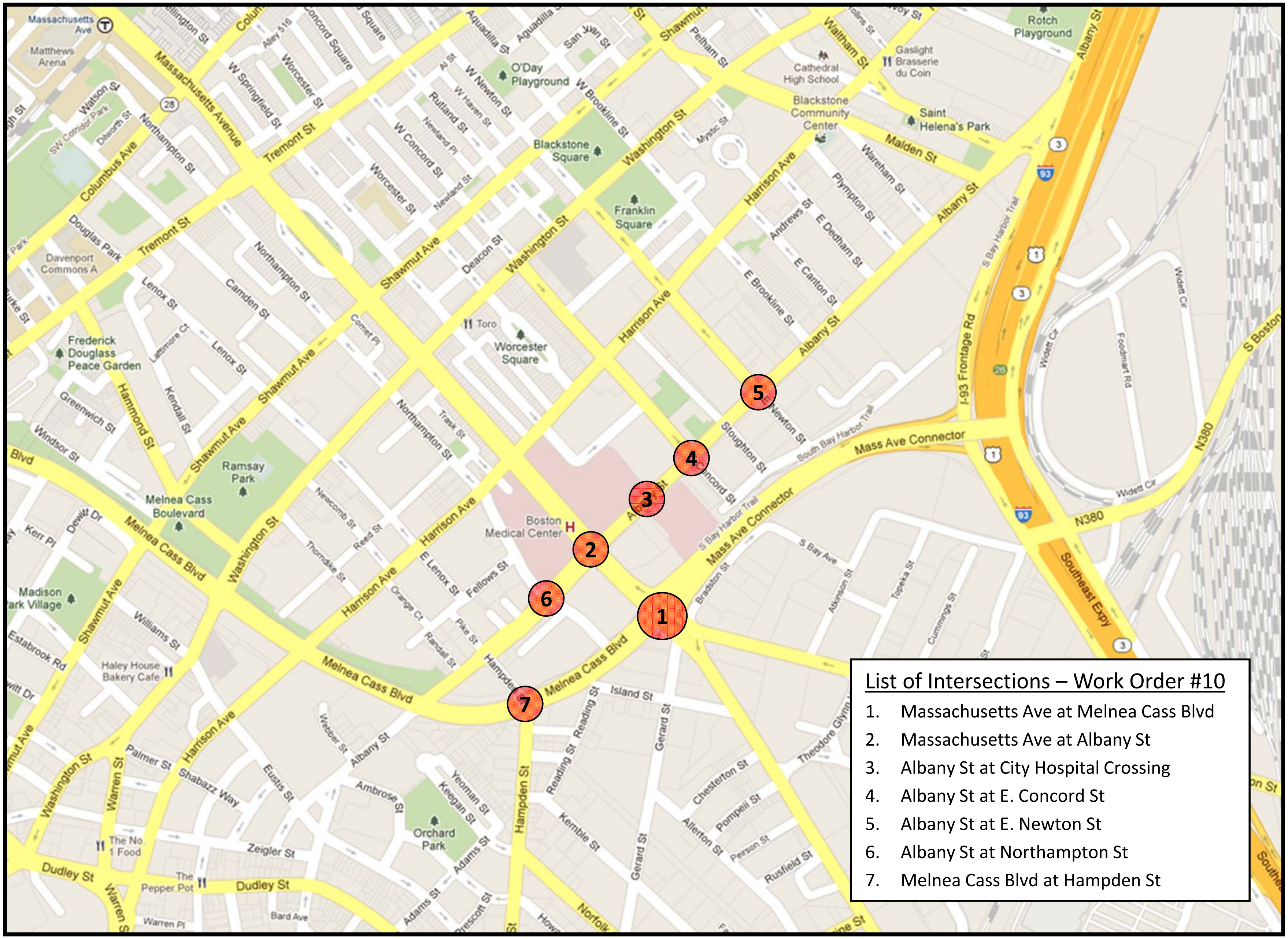

List of Intersections – Work Order #10

1. Massachusetts Ave at Melnea Cass Blvd
2. Massachusetts Ave at Albany St
3. Albany St at City Hospital Crossing
4. Albany St at E. Concord St
5. Albany St at E. Newton St
6. Albany St at Northampton St
7. Melnea Cass Blvd at Hampden St

Appendix A

Benefit Cost Analysis – Work Order #1

DATA

Data from Network MOE Summary Tables Submitted in Recommendations Technical memorandum

	AM Peak Hour		Midday Peak Hour		PM Peak Hour		Difference	% Difference
	Existing	Improved	Existing	Improved	Existing	Improved		
Total Delay (Hr.)	42	38	38	30	65	48	**29**	20.0%
Stops/Vehicle	0.51	0.43	0.51	0.44	0.53	0.45		
Average Speed (mph)	14	15	14	16	12	15		
Fuel Consumed (gal)	111	110	100	95	146	135	**17**	4.8%
Fuel Economy (mpg)	11.9	13	11.9	13.3	11	12.8		
CO Emissions (Kg)	7.74	7.65	6.99	6.65	10.19	9.46	**1.16**	4.7%
NOx Emissions (Kg)	1.51	1.49	1.36	1.29	1.98	1.84	**0.23**	4.7%
VOC Emissions (Kg)	1.79	1.77	1.62	1.54	2.36	2.19	**0.27**	4.7%

Truck Percentages

Location	AM	MD	PM	Average
Charles at Beacon	6.9%	5.4%	2.7%	5.0%
Charles at Boston Common	7.3%	5.8%	3.3%	5.5%
Charles at Boylston	6.5%	7.6%	3.3%	5.8%
Beacon at Joy	6.3%	6.4%	3.5%	5.4%
Beacon at Park	7.2%	10.9%	4.9%	7.7%
Washington at Lagrange	9.9%	11.3%	7.3%	9.5%
Washington at Boylston	8.9%	10.8%	4.8%	8.2%
Washington at Avery	9.3%	10.7%	4.4%	8.1%
Washington at Ave De Lafayette	10.7%	12.0%	4.6%	9.1%
Washington at NE Medical Center	10.8%	7.7%	9.0%	9.2%
Average				**7.3%**

Crash Data

	Location (BTD Intersection Numbers)									
Severity	**65**	**66**	**406**	**9**	**16**	**17**	**18**	**3076**	**Total**	**per Year**
Property Damage	26	9	3	3	1	6	1	1	50	**17**
Personal Injury	6	4	0	1	0	1	0	2	14	**5**
Fatality	0	0	0	0	0	0	0	0	0	**0.00**
Other	7	6	2	3	0	0	1	0	19	6
Total	39	19	5	7	1	7	2	3	83	28

Benefits Performance Measures values

Category	Performance Measures	Unit of measure	Value per unit in 2009 dollars	Value per unit in 2012 dollars
Delay	Intersection Delay	Person Hours (Cars)	$16.09	$17.22
	Intersection Delay	Person Hours (Trucks)	$106.24	$113.68
Crashes	Property Damage Only (PDO) Crash	Number of Crashes	$3,165	$3,387
	Minor Injury Crash	Number of Crashes	$18,771	$20,085
	Moderate Injury Crash	Number of Crashes	$392,755	$420,248
	Severe Injury Crash	Number of Crashes	$3,003,746	$3,214,008
	Fatality Crash	Number of Crashes	$4,207,985	$4,502,544
Emissions	Carbon Monoxide (CO)	Metric ton	$138	$148
	Nitrous Oxide (Nox)	Metric ton	$7,490	$8,014
	Volatile Organic Compounds (VOC)	Metric ton	$5,682	$6,080
Energy	Fuel	Gallon	$2.64	$3.65

Consumer Price Index increased from 2009 to 2012 by 7.0%. Hence all values are increase by 7.0% to calculate equivalent 2012 values.

BENEFIT CALCULATIONS

Calculation of Delay Reduction Per Year

Assuming

Truck Percentage: 7.3%

Vehicle Occupancy 1.25

Delay decreased by: 29 Vehicle hours per weekday

	Veh. Hours Per Day	Passenger Hours Per Day			Hours Per Year	Cost per Hour	Benefit per Year
Vehicle and Passenger Car Delay (96.6%)	27 hrs.	34	x	260 days/year =	**8,840**	$17.22	$152,192
Truck Delay (3.4%)	2 hrs.		x	260 days/year =	**520**	$113.68	$59,112

Calculation of Crash Reduction Per Year

Assume 8 % crash reduction factor for signal retiming

	Total Accidents	Reduction	Annual Reduction	Cost per Crash	Benefit per Year
Property Damage Accidents	17	0.08	**2.00**	$3,387	$6,773
Personal Injury Accidents	5	0.08	**1.00**	$20,085	$20,085
Fatality Accidents	0.00	0.08	**-**	$4,502,544	$0

Calculation of Emissions Reductions from Kilograms to Metric Tons to Annual Metric Tons

	KG per day	Metric Tons per day			Reduction	Cost per Ton	Benefit per Year
CO Reduction	1.16	0.00116	x	260 days/year =	**0.3016**	$148	$45
Nox Reduction	0.23	0.00023	x	260 days/year =	**0.0598**	$8,014	$479
VOC Reduction	0.27	0.00027	x	260 days/year =	**0.0702**	$6,080	$427

Calculation of Fuel Reduction Per Year

	Gal. per day			Annual Reduction	Cost per Gal.	Benefit per Year
Phase II fuel reduction in gallons =	17	x	260 days/year =	**4,420**	$3.65	$16,133

Benefits Summary

Category	Performance Measure	Unit	Value per Unit in 2012 Dollars	Benefits in Appropriate Units	Benefits Value
Delay	Intersection Delay	Person Hours (Cars)	$17.22	8840	$152,192
		person Hours (Trucks)	$113.68	520	$59,112
Crashes	Property Damage Only (PDO) Crash	Number of Crashes	$3,387	2	$6,773
	Minor Injury Crash	Number of Crashes	$20,085	1	$20,085
	Moderate Injury Crash	Number of Crashes	$420,248	0	$0
	Severe Injury Crash	Number of Crashes	$3,214,008	0	$0
	Fatality Crash	Number of Crashes	$4,502,544	0.00	$0
Emissions	Carbon Monoxide (CO)	Metric ton	$148	0.3016	$45
	Nitrous Oxide (Nox)	Metric ton	$8,014	0.0598	$479
	Volatile Organic Compounds (VOC)	Metric ton	$6,080	0.0702	$427
Energy	Fuel	Gallon	$3.65	4420	$16,133
TOTAL					**$255,246**

COST CALCULATIONS

Intersection Improvements Cost Calculations			
Intersection	Needed Items	Cost Estimate	
Beacon St/Charles St	Remove & Stack 4 signal heads		$800
	4 Rt & 2 Lt Arrows, 6 ONLY pav mark, 2 R3-8 signs		$2,500
	4 Rt & 4 Lt Arrows, 8 ONLY pav mark, 2 R3-8 signs		$3,500
	About 250' of white Thermoplastic		$400
	Relocate pedestrian signal head		$800
Charles St/ Center Gate	2 Pedestrian audio equipment		$1,000
Charles St/ Boylston St	2 Rt,4 Lt, 4 Th Arrows, 10 Only mark, 5 R3-8 signs		$2,700
	1 R5-1 do not enter & 1 R6-1 one way sign		$200
Beacon St/Joy St	1 R6-1 one way sign		$50
Beacon St/ Park St	Remove 8" signal heads (two)		$800
	2 New 12" signal heads 1 new head & post		$6,000
Washington Street/Lagrange / Beach Street	None		
Washington St / Ave DeLafayette	2 Rt turn Arrow, 2 ONLY pav mark, 2 R3-8 signs		$1,500
Washington St / New England Medical center	None		
Signal Equipment Cost that can be annualized over 15 years			**$7,000**
Signing and Pavement Marking Cost that can be annualized over 5 years			**$10,850**
Costs that cannot be annualized			**$2,400**

NOTE - Improvements considered above are based on Table 1 of Recommendations Technical memorandum

BTD Contractor Costs For implementing Signal timing and phasing improvements	
10 intersections with clearance time changes (0.5 hour per intersection at $125 per hour)	$625
Travel time for Contractor (2 hours at $125 per hour)	$250
BTD's estimated cost for phasing changes	$0
Total BTD Contractor costs =	**$875**

COST CALCULATIONS (Continued)

Engineering Costs, Signs and Pavement Marking Costs	
Engineering Fee for Work Order 1	$33,000
Signs and Pavement marking Costs	$10,850
BTD Contractor costs	$875
Sum of above costs	$44,725
Assume BTD retimes signals every 5 years	
Assume signs and pavement markings are replaced every 5 years	
Annualized Cost Per Year =P{ [i*(1+i)^n] / [(1+i)^n - 1] }	
P = Present Worth	$44,725
Assume i=7.0 (CPI)	
N = 5	
Numerator = 0.07*(1+0.07)^5 =	$0
Denominator = (1+0.07)^5 -1 =	$0
A = P *(Numerator/Denominator)	$10,908
Total Annual Engineering/Signs/Markings Cost =	**$10,908**

Signal Equipment Costs	
Signal equipment costs	$7,000
Assume signal equipment has a life time of fifteen years	
Annualized Cost Per Year =P{ [i*(1+i)^n] / [(1+i)^n - 1] }	
P= Present worth	$7,000
Assume i=7.0 (CPI) N= 15	
Numerator = 0.07*(1+0.07)^15 =	$0
Denominator = (1+0.07)^15 -1 =	$2
A = P *(Numerator/Denominator)	$769
Total Annual Signal Equipment Costs =	**$769**

Annual Cost Summary	
Type	
Engineering/Signs/Pavement markings	$10,910
Signal Equipment	$770
Other Non-Annualized Costs	$2,400
Total	**$14,080**

BENEFIT COST RATIO CALCULATIONS

Benefit	$255,246	
Cost	$14,080	
Ratio		**18 to 1**

Improvement Costs		
Intersection	Needed Items	Cost Estimate
Beacon St/Charles St	Remove & Stack 4 signal heads	$800
	4 Rt & 2 Lt Arrows, 6 ONLY pav mark, 2 R3-8 signs	$2,500
	4 Rt & 4 Lt Arrows, 8 ONLY pav mark, 2 R3-8 signs	$3,500
	About 250' of white Thermoplastic	$400
	Relocate pedestrian signal head	$800
Charles St/ Center Gate	2 Pedestrian audio equipment	$1,000
Charles St/ Boylston St	Maintenance, N/A	
	2 Rt,4 Lt, 4 Th Arrows, 10 Only mark, 5 R3-8 signs	$2,700
	1 R5-1 do not enter & 1 R6-1 one way sign	$200
	Maintenance, N/A	
Beacon St/Joy St	N/A	
	1 R6-1 one way sign	$50
	N/A	
Beacon St/ Park St	N/A	
	Remove 8" signal heads (two)	$800
	2 New 12" signal heads 1 new head & post	$6,000
	Maintenance, N/A	
Washington Street/Lagrange / Beach Street	N/A	
	N/A	
	Maintenance, N/A	
Washington St / Ave DeLafayette	Maintenance, N/A	
	2 Rt turn Arrow, 2 ONLY pav mark, 2 R3-8 signs	$1,500
	N/A	
Washington St / New England Medical center	N/A	
	N/A	

Signal Equipment Cost that can be annualized over 15 years	**$7,000**
Signing and Pavement Marking Cost that can be annualized over 5 years	**$10,850**
Costs that cannot be annualized	**$2,400**

Recommended Improvements

- Charles St Southbound approach – Circular red signal is shown on top of arrow red indication on all of the signal heads on this approach. The circular indications can be removed.
- Charles St Southbound approach – Lane designation should be shown using signs and pavement makings.
- Charles St Northbound approach - Lane designation should be shown using signs and pavement makings.
- Beacon St Westbound approach - Add Gore markings to the median island west of the intersection in the merger/weave departure area. Lane designation should be shown using signs and pavement makings.
- The pedestrian head on the southeast corner of the intersection can be relocated for better visibility from northeast corner of the intersection. Renovate the bituminous ADA ramps on the southeast corner of the inte

- Could consider adding pedestrian audio signals to reduce pedestrian start-up delays

- Majority of the pedestrian signal heads were not fully lighted and parts of the walk/FDW signs were not visible. Update equipment
- Lane designation pavement markings and signs can be added on all approaches to the intersection
- Only one DO NOT ENTER sign is provided on the eastbound approach; a second sign is recommended.
- Crosswalk markings are worn out on all approaches and need to be restriped.

- Even though there are less than 250 conflicting vehicles per hour, due to presence of high pedestrian volumes it is recommended that the existing exclusive pedestrian phase should continue to operate as an exclusiv
- One-Way sign was posted only on west side of Joy St. another sign should be added on the east side.
- The curb at the ADA ramp on the Boston Common side is not flush with Pavement and hinders access to crosswalk.

- Crosswalk on the west side of Beacon St is not accessible as ADA ramps are not provided and the curbs are raised.
- The 8" signal heads for the northbound Park St approach should be replaced with 12" signal heads
- Another set of signal indications should be provided for Park St northbound approach on the west side of intersection on top of the pedestrian signal post.
- The loop detection on Park St should be checked. During field observations, Park St phase was called every cycle even though no vehicles were present.

- Sliver line buses that stop just north of Beach St were observed to hinder Beach Street Operations. approach and blocks right turns out of Beach St. The presence of concurrent pedestrians on the crosswalk north of B
- The bus stop could be moved further north of Beach St. The buses stop short of the Archstone parking garage driveway which is located approximately 30' north of Beach St. Part of the bus usually extends into Beach S
- Tunnel visor was missing for Washington St northbound green arrow indication (post west of intersection). Replace to improve visibility.

- The pedestrian walk/don't walk indications on the west side of Washington St was not working and should be checked.
- Lane designation pavement markings and advance signs should use used on Ave DeLafayette, due to the turn restriction.
- Could consider eliminating the exclusive pedestrian phase and run concurrent phases as there are less than 250 conflicting vehicles per hour.

- The presence of a signal is not readily apparent to drivers. Visibility of the signal head is very poor. Pedestrians were observed to cross during green vehicular phases.
- Consider removing the signal or re-designing the signals to improve visibility and safety; perhaps with a flashing beacon.

Standard Item Costs

Item	Unit	cost
Signal head - 3 section one-way LED	Each	$1,000
3 section one-way programmable signal heads	Each	$2,000
Pedestrian signal head	Each	$1,500
8 Feet signal post & Foundation	Each	$2,500
10 Feet signal post & Foundation	Each	$3,000
Push Button and sign Assembly	Each	$500
Pedestrian Audio signals	Each	$500
Pullbox 12"X12" SD 2.031	Each	$750
Wiring & testing signal cable	per foot	$5
Wiring & testing pedestrian cable	per foot	$6
Existing Controller reprogramming	Each	$1,500
Remove & Stack signal post	Each	$200
Remove & Stack signal heads	Each	$200
Right turn Arrow Pav Marking	15.8 Sq Ft	$79
Left turn Arrow Pav Marking	15.8 Sq Ft	$79
Through Arrow Pav marking	15.8 Sq Ft	$79
ONLY Pav Marking	29.6 sq ft	$148
6"Reflectorized White Line (Thermoplastic)	1 ft	$1
R3-8 lane use Regulatory sign	30'X30' = 6.25 sq ft	$69
R3-5 Mandatory lane use Regulatory sign	30"x36" = 7.5 sq ft	$83
R10-12 Left Turn yield on Green ball sign	30"x36" = 7.5 sq ft	$83
R5-1 DO NOT ENTER sign	30"x30" = 6.25 sq ft	$69
R6-1 ONE-WAY sign	36"x12" = 3 sq ft	$33
R3-2 NO LEFT TURN sign	24"x24" = 4 sq ft	$44
R1-1 STOP sign	30"x30" = 6.25 sq ft	$69

Note - signs were assumed to be $300 each for the sign plate, post, installation etc.

Appendix B

Benefit Cost Analysis – Work Order #2

DATA

Data from Network MOE Summary Tables Submitted in Recommendations Technical memorandum

	AM Peak Hour		Midday Peak Hour		PM Peak Hour		Difference	% Difference
	Existing	Improved	Existing	Improved	Existing	Improved		
Total Delay (Hr.)	272	204	165	123	352	262	**200**	25.3%
Stops/Vehicle	0.55	0.59	0.52	0.55	0.59	0.58		
Average Speed (mph)	7	9	9	11	6	8		
Fuel Consumed (gal)	348	303	248	222	429	369	**131**	12.8%
Fuel Economy (mpg)	7.4	8.6	9	10.3	6.8	8.2		
CO Emissions (Kg)	24.31	21.21	17.31	15.49	30.01	25.76	**9.17**	12.8%
NOx Emissions (Kg)	4.73	4.13	3.37	3.01	5.84	5.01	**1.79**	12.8%
VOC Emissions (Kg)	5.63	4.92	4.01	3.59	6.96	5.97	**2.12**	12.8%

Truck Percentages

Location	AM	MD	PM	Average
Comm. Ave at Brighton	5.2%	5.0%	2.0%	4.1%
Brighton at Linden	5.5%	5.2%	3.1%	4.6%
Brighton at Harvard	7.1%	5.6%	2.8%	5.2%
Brighton at Allston	7.0%	4.4%	3.1%	4.8%
Comm. Ave at Warren	2.6%	4.2%	1.0%	2.6%
Comm. Ave at Allston	3.9%	3.2%	1.0%	2.7%
Comm. Ave at Griggs	3.3%	2.2%	1.3%	2.3%
Comm. Ave at Spofford	2.9%	2.1%	1.0%	2.0%
Comm. Ave at Harvard	4.8%	4.1%	1.4%	3.4%
Comm. Ave at Fordham	3.4%	3.3%	0.7%	2.5%
Average				**3.4%**

Crash Data

	Location (BTD Intersection Numbers)										
Severity	**179**	**185**	**1441**	**1808**	**323**	**335**	**459**	**181**	**845**	**Total**	**per Year**
Property Damage	4	14	9	5	5	13	2	29	0	81	**27**
Personal Injury	0	4	4	2	7	12	0	13	1	43	**14**
Fatality	0	0	0	1	0	0	0	0	0	1	**0.33**
Other	3	6	2	1	3	10	2	14	0	41	14
Total	7	24	15	9	15	35	4	56	1	166	55

Benefits Performance Measures values

Category	Performance Measures	Unit of measure	Value per unit in 2009 dollars	Value per unit in 2012 dollars
Delay	Intersection Delay	Person Hours (Cars)	$16.09	$17.22
	Intersection Delay	person Hours (Trucks)	$106.24	$113.68
Crashes	Property Damage Only (PDO) Crash	Number of Crashes	$3,165	$3,387
	Minor Injury Crash	Number of Crashes	$18,771	$20,085
	Moderate Injury Crash	Number of Crashes	$392,755	$420,248
	Severe Injury Crash	Number of Crashes	$3,003,746	$3,214,008
	Fatality Crash	Number of Crashes	$4,207,985	$4,502,544
Emissions	Carbon Monoxide (CO)	Metric ton	$138	$148
	Nitrous Oxide (Nox)	Metric ton	$7,490	$8,014
	Volatile Organic Compounds (VOC)	Metric ton	$5,682	$6,080
Energy	Fuel	Gallon	$2.64	$3.65

Consumer Price Index increased from 2009 to 2012 by 7.0%. Hence all values are increased by 7.0% to calculate equivalent 2012 values.

BENEFIT CALCULATIONS

Calculation of Delay Reduction Per Year

Assuming

Truck Percentage: 3.4%

Vehicle Occupancy 1.25

Delay decreased by: 200 Vehicle hours per weekday

	Veh. Hours Per Day	Passenger Hours Per Day			Hours Per Year	Cost per Hour	Benefit per Year
Vehicle and Passenger Car Delay (96.6%)	193 hrs.	241	x	260 days/year =	**62,660**	$17.22	$1,078,773.36
Truck Delay (3.4%)	7 hrs.		x	260 days/year =	**1,820**	$113.68	$206,891.78

Calculation of Crash Reduction Per Year

Assume 8 % crash reduction factor for signal retiming

	Total Accidents	Reduction	Annual Reduction	Cost per Crash	Benefit per Year
Property Damage Accidents	27	0.08	**3.00**	$3,387	$10,159.65
Personal Injury Accidents	14	0.08	**2.00**	$20,085	$40,169.94
Fatality Accidents	0.33	0.08	**0.03**	$4,502,544	$120,067.84

Calculation of Emissions Reductions from Kilograms to Metric Tons to Annual Metric Tons

	KG per day	Metric Tons per day			Annual Reduction	Cost per Ton	Benefit per Year
CO Reduction	9.17	0.00917	x	260 days/year =	**2.3842**	$148	$352.05
Nox Reduction	1.79	0.00179	x	260 days/year =	**0.4654**	$8,014	$3,729.86
VOC Reduction	2.12	0.00212	x	260 days/year =	**0.5512**	$6,080	$3,351.15
							$7,433.06

Calculation of Fuel Reduction Per Year

	Gal. per day			Annual Reduction	Cost per Gal.	Benefit per Year
Phase II fuel reduction in gallons =	131	x	260 days/year =	**34,060**	$3.65	$124,319.00

Benefits Summary

Category	Performance Measure	Unit	Value per Unit in 2012 Dollars	Benefits in Appropriate Units	Benefits Value
Delay	Intersection Delay	Person Hours (Cars)	$17.22	62660	$1,078,773
		Person Hours (Trucks)	$113.68	1820	$206,892
Crashes	Property Damage Only (PDO) Crash	Number of Crashes	$3,387	3	$10,160
	Minor Injury Crash	Number of Crashes	$20,085	2	$40,170
	Moderate Injury Crash	Number of Crashes	$420,248	0	$0
	Severe Injury Crash	Number of Crashes	$3,214,008	0	$0
	Fatality Crash	Number of Crashes	$4,502,544	0.03	$120,068
Emissions	Carbon Monoxide (CO)	Metric ton	$148	2.3842	$352
	Nitrous Oxide (Nox)	Metric ton	$8,014	0.4654	$3,730
	Volatile Organic Compounds (VOC)	Metric ton	$6,080	0.5512	$3,351
Energy	Fuel	Gallon	$3.65	34060	$124,319.00
TOTAL					**$1,587,815**

COST CALCULATIONS

Intersection Improvements Cost Calculations		
Intersection	Needed Items	Cost Estimate
Brighton Avenue at Commonwealth Avenue	3 arrow signal heads	$1,000.00
	2 Rt Arrows, 2 ONLY pav mark, 2 R3-8 signs	$1,100.00
	1 Ped signal, 1 post, 1 button, 2 pull box, 60' wire	$6,300.00
Brighton Avenue at Linden Street	None	
Brighton Avenue at Harvard Avenue	None	
Brighton Avenue at Allston Street	controller reprogramming	$1,000.00
Commonwealth Avenue at Warren Street	2 Lt Arrows, 2 ONLY pav mark, 2 R3-5 signs	$1,100.00
	2 signal heads, 1 R10-12 sign	$2,800.00
	10 programmable heads, controller reprogramming	$21,500.00
	2 R5-1 (do not enter) & 2 R6-1 (one way) signs	$1,500.00
Commonwealth Avenue at Allston Street	1 R5-1 do not enter & 1 R6-1 one way sign	$600.00
	1 R6-1 one way sign	$300.00
	1 R3-2 No left turn sign	$300.00
Commonwealth Avenue at Griggs Street	1 Ped signal, 1 post, 1 button, 2 pull box, say 100' wire	$6,500.00
	2 R1-1 STOP signs	$600.00
Commonwealth Avenue at Spofford Street	None	
Commonwealth Avenue at Harvard Avenue	1 R5-1 do not enter & 1 R6-1 one way sign	$600.00
	1 Ped signal, 1 post, 1 button, 2 pull box, say 60' wire	$6,500.00
Commonwealth Avenue at Fordham Road	R & S 4 signal Heads & 3 signal posts	$1,800.00
Signal Equipment Cost that can be annualized over 15 years		**$44,600**
Signing and Pavement Marking Cost that can be annualized over 5 years		**$8,900**
Costs that cannot be annualized		**$0**

NOTE - Improvements considered above are based on Table 1 of Recommendations Technical memorandum

BTD Contractor Costs For implementing Signal timing and phasing improvements	
9 intersections with clearance time changes (0.5 hour per intersection at $125 per hour)	$562.50
Travel time for Contractor (2 hours at $125 per hour)	$250.00
BTD's estimated cost for phasing change at Comm. Ave/Warren St/Kelton St intersection	$2,500.00
Total BTD Contractor costs =	**$3,312.50**

COST CALCULATIONS (Continued)

Engineering Costs, Signs and Pavement Marking Costs	
Engineering Fee for Work Order 2	$37,500.00
Signs and Pavement marking Costs	$8,900
BTD Contractor costs	$3,313
Sum of above costs	$49,712.50
Assume BTD retimes signals every 5 years	
Assume signs and pavement markings are replaced every 5 years	
Annualized Cost Per Year =P{ [i*(1+i)^n] / [(1+i)^n - 1] }	
P = Present Worth	$49,713
Assume i=7.0 (CPI)	
N = 5	
Numerator = 0.07*(1+0.07)^5 =	$0.10
Denominator = (1+0.07)^5 -1 =	$0.40
A = P *(Numerator/Denominator)	$12,124.42
Total Annual Engineering/Signs/Markings Cost =	**$12,124.42**

Signal Equipment Costs	
Signal equipment costs	$44,600
Assume signal equipment has a life time of fifteen years	
Annualized Cost Per Year =P{ [i*(1+i)^n] / [(1+i)^n - 1] }	
P= Present worth	$44,600
Assume i=7.0 (CPI) N= 15	
Numerator = 0.07*(1+0.07)^15 =	$0.19
Denominator = (1+0.07)^15 -1 =	$1.76
A = P *(Numerator/Denominator)	$4,897
Total Annual Signal Equipment Costs =	**$4,897**

Annual Cost Summary	
Type	
Engineering/Signs/Pavement markings	$12,124.42
Signal Equipment	$4,897
Other Non-Annualized Costs	$0
Total	**$17,021**

BENEFIT COST RATIO CALCULATIONS

Benefit	$1,587,815	
Cost	$17,021	
Ratio		**93 to 1**

Improvement Costs		
Intersection	Needed Items	Cost Estimate
Brighton Avenue at Commonwealth Avenue	3 arrow signal heads	$1,000
	N/A	
	2 Rt Arrows, 2 ONLY pav mark, 2 R3-8 signs	$1,100
	1 Ped signal, 1 post, 1 button, 2 pull box, 60' wire	$6,300
Brighton Avenue at Linden Street	Maintenance, N/A	
	N/A	
	N/A	
Brighton Avenue at Harvard Avenue	N/A	
Brighton Avenue at Allston Street	Maintenance, N/A	
	controller reprogramming	$1,000
Commonwealth Avenue at Warren Street	Maintenance, N/A	
	2 Lt Arrows, 2 ONLY pav mark, 2 R3-5 signs	$1,100
	2 signal heads, 1 R10-12 sign	$2,800
	10 programmable heads, controller reprogramming	$21,500
	2 R5-1 (do not enter) & 2 R6-1 (one way) signs	$1,500
Commonwealth Avenue at Allston Street	Maintenance, N/A	
	Maintenance, N/A	
	1 R5-1 do not enter & 1 R6-1 one way sign	$600
	1 R6-1 one way sign	$300
	1 R3-2 No left turn sign	$300
Commonwealth Avenue at Griggs Street	1 Ped signal, 1 post, 1 button, 2 pull box, say 100' wire	$6,500
	N/A	
	2 R1-1 STOP signs	$600.00
Commonwealth Avenue at Spofford Street	N/A	
	N/A	
Commonwealth Avenue at Harvard Avenue	1 R5-1 do not enter & 1 R6-1 one way sign	$600
	1 Ped signal, 1 post, 1 button, 2 pull box, say 60' wire	$6,500
Commonwealth Avenue at Fordham Road	N/A	
	R & S 4 signal Heads & 3 signal posts	$1,800
Signal Equipment Cost that can be annualized over 15 years		**$44,600**
Signing and Pavement Marking Cost that can be annualized over 5 years		**$8,900**
Costs that cannot be annualized		**$0**

Recommended Improvements

- Consider using Right Arrows for yellow signals for Commonwealth Ave northbound approach.
- Provide ADA ramp on northern end of crosswalk across Brighton Ave.
- Add Right turn only pavement markings and signs on Commonwealth Ave northbound approach.
- Consider adding pedestrian signals on the MBTA platform to reduce pedestrian crossing distance across Commonwealth Ave on the southern side of the intersection.
- Two of the pedestrian pushbuttons located on the signal poles on the north side of the intersection did not activate the pedestrian phase.
- Fix cracked concrete at ADA ramps on the northeast and southeast corners.
- Provide ADA ramp for crosswalk across Brighton Ave on the southwest corner
- Consider relocating bus stops on Brighton Ave from the approach to departure side
- The LED hand symbol on the pedestrian signal located north of Brighton Ave was not being displayed completely. Replace the LED panel.
- The northbound Allston St Phase starts at the "0" second pedestrian signal display. Reprogram to provide all-red after pedestrian phase, check cabinet.
- Pedestrian signals across eastbound Commonwealth Ave on the departure/receiving legs were not operating. The pushbuttons did not activate the signal and the signal heads were blanked out.
- The geometry on the westbound departure side of Commonwealth Ave results in conflicts between westbound vehicles from Commonwealth Ave and westbound vehicles from the service road.
- Add left turn only Pavement marking and signs on the EB approach of the two-way Service Rd located N of the intersection. Per BTD's request, change signal head for the EB left turn approach to permissive left tur
- Per BTD's request, revise signal phasing - Move EB and WB Service Rd movements to Phase 2. Add programmable signal heads at appropriate locations. Change MBTA signal heads to trolley signal heads. Move con
- Add DO NOT ENTER and ONE WAY signs on both sides of the southwestbound one-way service road located west of the intersection. Change signal head for permissive only left –turns.
- Pedestrian signal head on the median on Commonwealth Ave westbound is not working.
- The walk symbols on the pedestrian signals across Commonwealth Ave eastbound approach remain blank during the pedestrian phase.
- Add DO NOT ENTER and ONE WAY signs on the north side of the eastbound service road
- Add ONE WAY sign on the south side of the westbound service road.
- Add NO LEFT TURN sign on eastbound service road.
- Pedestrian signals and ADA ramps are not provided on the crosswalk that is located on the east side of the intersection. Consider adding signal and ADA ramps or removing the crosswalk striping.
- The crosswalk located on the west side of the intersection needs to be restriped to match ADA ramp on the northwest corner.
- Add STOP sign to eastbound service road.
- Commonwealth Ave median break does not align with the crosswalk. Provide median openings along crosswalk for ADA compatibility.
- Provide three ADA ramps south of Commonwealth Ave – on the southern side of the crosswalk across Commonwealth Ave and on both sides of the crosswalk across the eastbound service road. .
- Install a DO NOT ENTER and ONE WAY sign on the south side of the westbound service Road.
- Provide a pedestrian signal head for pedestrians headed north on the crosswalk that is across Commonwealth Ave westbound approach.
- The Fordham Rd MBTA station has been closed since April 2004. The pedestrian pushbuttons are not accessible as they are wedged into the pushbutton holders.
- Consider removing the crosswalk and all signal equipment or provide fully operational pedestrian signals and pushbuttons, or change the signal to an enhanced crossing with flashing pedestrian beacons.

Standard Item Costs

Item	Unit	cost
Signal head - 3 section one-way LED	Each	$1,000
3 section one-way programmable signal heads	Each	$2,000
Pedestrian signal head	Each	$1,500
8 Feet signal post & Foundation	Each	$2,500
Push Button and sign Assembly	Each	$500
Pullbox 12"X12" SD 2.031	Each	$750
Wiring & testing signal cable	per foot	$5
Wiring & testing pedestrian cable	per foot	$6
Existing Controller reprogramming	Each	$1,500
Remove & Stack signal post	Each	$200
Remove & Stack signal heads	Each	$200
Right turn Arrow Pav Marking	15.8 Sq Ft	$79
Left turn Arrow Pav Marking	15.8 Sq Ft	$79
ONLY Pav Marking	29.6 sq ft	$148
R3-8 lane use Regulatory sign	30'X30' = 6.25 sq ft	$69
R3-5 Mandatory lane use Regulatory sign	30"x36" = 7.5 sq ft	$83
R10-12 Left Turn yield on Green ball sign	30"x36" = 7.5 sq ft	$83
R5-1 DO NOT ENTER sign	30"x30" = 6.25 sq ft	$69
R6-1 ONE-WAY sign	36"x12" = 3 sq ft	$33
R3-2 NO LEFT TURN sign	24"x24" = 4 sq ft	$44
R1-1 STOP sign	30"x30" = 6.25 sq ft	$69

Note - signs were assumed to be $300 each for the sign plate, post, installation etc.

Appendix C

Benefit Cost Analysis – Work Order #3

DATA

Data from Network MOE Summary Tables Submitted in Recommendations Technical memorandum

	AM Peak Hour		Midday Peak Hour		PM Peak Hour		Difference	% Difference
	Existing	Improved	Existing	Improved	Existing	Improved		
Total Delay (Hr.)	183	157	166	126	163	175	**54**	10.5%
Stops/Vehicle	0.5	0.47	0.49	0.45	0.47	0.49		
Average Speed (mph)	9	10	9	10	10	10		
Fuel Consumed (gal)	301	279	269	236	316	325	**46**	5.2%
Fuel Economy (mpg)	8.3	8.9	8.1	9.2	9.3	9		
CO Emissions (Kg)	21.05	19.49	18.82	16.48	22.07	22.71	**3.26**	5.3%
NOx Emissions (Kg)	4.1	3.79	3.66	3.21	4.29	4.42	**0.63**	5.2%
VOC Emissions (Kg)	4.88	4.52	4.36	3.82	5.12	5.26	**0.76**	5.3%

Truck Percentages

Location	AM	MD	PM	Average
Beacon St./Tremont St.	8.1%	8.3%	3.8%	6.7%
Bromfield St./Tremont St.	11.3%	7.8%	4.3%	7.8%
Park St./Winter St./Tremont St.	11.5%	7.5%	4.0%	7.7%
Temple Place/Tremont St.	14.0%	8.1%	6.2%	9.4%
West St./Tremont St.	10.1%	7.5%	5.6%	7.7%
Avery St./Tremont St.	9.7%	6.6%	4.6%	7.0%
Boylston St./Tremont St.	8.9%	7.7%	5.1%	7.2%
Harrison Ave at Marginal Rd	3.4%	2.9%	1.4%	2.6%
Harrison Ave at Oak St	3.5%	4.6%	0.8%	3.0%
Washington St at Marginal Rd	9.5%	7.6%	7.8%	8.3%
Washington St at Oak St	8.1%	6.7%	8.7%	7.8%
Shawmut Ave at Marginal Rd	5.7%	3.5%	1.0%	3.4%
Arlington St at Marginal Rd	6.0%	6.7%	1.9%	4.9%
Shawmut/Tremont at Oak St	5.3%	3.1%	2.0%	3.5%
Tremont St at Charles St	7.2%	5.8%	4.2%	5.7%
Tremont St at Marginal Rd	5.8%	5.6%	2.3%	4.6%
Tremont St at E Berkeley St	7.4%	4.8%	3.2%	5.1%
Shawmut Ave at E Berkeley St	7.6%	7.1%	3.2%	6.0%
Washington St at E Berkeley St	10.0%	9.2%	6.6%	8.6%
Harrison Ave at E Berkeley St	7.4%	7.3%	2.8%	5.8%
Harrison Ave at Traveler St	8.2%	5.7%	3.2%	5.7%
Harrison Ave at Herald	5.3%	5.1%	2.3%	4.2%
Washington St at Herald	8.7%	6.6%	4.1%	6.5%
Shawmut Ave at Herald	4.9%	3.7%	2.1%	3.6%
Tremont/Arlington at Herald	6.2%	5.2%	2.6%	4.7%
Average				**5.9%**

DATA (Continued)

Crash Data

	Location (BTD Intersection Numbers)										
Severity	**11**	**10**	**8**	**6**	**5**	**4**	**3**	**86**	**87**	**365**	**366**
Property Damage	1	1	3	2	0	1	14	2	1	7	3
Personal Injury	0	0	2	2	1	2	2	2	1	0	0
Fatality	0	0	0	0	0	0	1	0	0	0	0
Other	0	0	0	0	2	1	4	0	0	2	0
Total	1	1	5	4	3	4	21	4	2	9	3

Crash Data

	Location (BTD Intersection Numbers)										
Severity	**1452**	**1122**	**395**	**299**	**1332**	**112**	**1127**	**447**	**1328**	**1331**	**1922**
Property Damage	3	4	1	1	3	3	6	5	2	7	0
Personal Injury	1	5	1	0	0	6	2	1	1	1	0
Fatality	0	0	0	0	0	0	0	0	0	0	1
Other	1	5	0	0	7	0	2	3	1	1	1
Total	5	14	2	1	10	9	10	9	4	9	2

Crash Data

	Location (BTD Intersection Numbers)				
Severity	**1783**	**1330**	**364**	**Total**	**per Year**
Property Damage	5	5	1	81	**27**
Personal Injury	0	5	0	35	**12**
Fatality	0	0	0	2	**0.67**
Other	2	4	3	39	13
Total	7	14	4	157	52

Benefits Performance Measures values

Category	Performance Measures	Unit of measure	Value per unit in 2009 dollars	Value per unit in 2012 dollars
Delay	Intersection Delay	Person Hours (Cars)	$16.09	$17.22
	Intersection Delay	Person Hours (Trucks)	$106.24	$113.68
Crashes	Property Damage Only (PDO) Crash	Number of Crashes	$3,165	$3,387
	Minor Injury Crash	Number of Crashes	$18,771	$20,085
	Moderate Injury Crash	Number of Crashes	$392,755	$420,248
	Severe Injury Crash	Number of Crashes	$3,003,746	$3,214,008
	Fatality Crash	Number of Crashes	$4,207,985	$4,502,544
Emissions	Carbon Monoxide (CO)	Metric ton	$138	$148
	Nitrous Oxide (Nox)	Metric ton	$7,490	$8,014
	Volatile Organic Compounds (VOC)	Metric ton	$5,682	$6,080
Energy	Fuel	Gallon	$2.64	$3.65

Consumer Price Index increased from 2009 to 2012 by 7.0%. Hence all values are increased by 7.0% to calculate equivalent 2012 values.

BENEFIT CALCULATIONS

Calculation of Delay Reduction Per Year

Assuming

Truck Percentage: 5.9%

Vehicle Occupancy 1.25

Delay decreased by: 54 Vehicle hours per weekday

	Veh. Hours Per Day	Passenger Hours Per Day			Hours Per Year	Cost per Hour	Benefit per Year
Vehicle and Passenger Car Delay (96.6%)	51 hrs.	63	x	260 days/year =	**16,380**	$17.22	$282,003
Truck Delay (3.4%)	4 hrs.		x	260 days/year =	**1,040**	$113.68	$118,224

Calculation of Crash Reduction Per Year

Assume 8 % crash reduction factor for signal retiming

	Total Accidents	Reduction	Annual Reduction	Cost per Crash	Benefit per Year
Property Damage Accidents	27	0.08	**3.00**	$3,387	$10,160
Personal Injury Accidents	12	0.08	**1.00**	$20,085	$20,085
Fatality Accidents	1	0.08	**0.05**	$4,502,544	$240,136

Calculation of Emissions Reductions from Kilograms to Metric Tons to Annual Metric Tons

	KG per day	Metric Tons per day			Annual Reduction	Cost per Ton	Benefit per Year
CO Reduction	3.26	0.00326	x	260 days/year =	**0.8476**	$148	$125
Nox Reduction	0.63	0.00063	x	260 days/year =	**0.1638**	$8,014	$1,313
VOC Reduction	0.76	0.00076	x	260 days/year =	**0.1976**	$6,080	$1,201
							$2,639

Calculation of Fuel Reduction Per Year

	Gal. per day			Annual Reduction	Cost per Gal.	Benefit per Year
Phase II fuel reduction in gallons =	46	x	260 days/year =	**11,960**	$3.65	$43,654

Benefits Summary

Category	Performance Measure	Unit	Value per Unit in 2012 Dollars	Benefits in Appropriate Units	Benefits Value
Delay	Intersection Delay	Person Hours (Cars)	$17.22	16380	$282,003
		person Hours (Trucks)	$113.68	1040	$118,224
Crashes	Property Damage Only (PDO) Crash	Number of Crashes	$3,387	3	$10,160
	Minor Injury Crash	Number of Crashes	$20,085	1	$20,085
	Moderate Injury Crash	Number of Crashes	$420,248	0	$0
	Severe Injury Crash	Number of Crashes	$3,214,008	0	$0
	Fatality Crash	Number of Crashes	$4,502,544	0.05	$240,136
Emissions	Carbon Monoxide (CO)	Metric ton	$148	0.8476	$125
	Nitrous Oxide (Nox)	Metric ton	$8,014	0.1638	$1,313
	Volatile Organic Compounds (VOC)	Metric ton	$6,080	0.1976	$1,201
Energy	Fuel	Gallon	$3.65	11960	$43,654
TOTAL					**$716,900**

COST CALCULATIONS

Intersection Improvements Cost Calculations			
Intersection	Needed Items	Cost Estimate	
Beacon Street/School Street/Tremont Street	1 R3-7, 1 R5-1 & 1 R6-1 sign		$300
Bromfield Street/ Tremont Street	2 R5-1 & 2 R6-1 sign		$400
Tremont Street/Park Street/Winter Street	Remove 8" heads and replace with 12" heads		$1,200
	2 R5-1 & 2 R6-1 sign		$400
Temple Place/ Tremont Street	Remove 8" heads and replace with 12" heads		$2,400
	2 R5-1 & 2 R6-1 sign		$400
Tremont Street/West Street	2 R5-1 & 2 R6-1 sign, replace green ball with arrow		$700
Avery Street/Tremont Street	2 R5-1 & 2 R6-1 and 1 R3-5 sign		$500
Boylston Street/Tremont Street	3 R5-1 & 2 R6-1 and relocate 1 sign		$500
E. Berkeley Street/Tremont Street	Relocate 1 sign		$200
	2 R3-5 signs, 2 Th, 2 TH-Rt Pav Markings		$1,400
E. Berkeley Street/Shawmut Avenue	1 R6-1 sign and relocate 2 signs		$400
E. Berkeley Street/ Washington Street	2 R6-1 signs		$200
E. Berkeley Street/ Harrison Avenue	None		
Harrison Avenue/Traveler Street	Replace 2 arrow heads with 2 balls		$2,500
Harrison Avenue/Herald Street	Remove R5-1 sign		$200
Harrison Avenue/ Marginal Road	2 R6-1 signs		$200
Harrison Avenue/ Oak Street	I ped bush button assembly		$500
	Say 100' of white Thermoplastic		$500
Washington Street/Marginal Road	Relocate sign		$200
Washington Street/Oak Street	None		
Washington Street/Herald Street	1 R6-1 sign		$50
Shawmut Avenue/Herald Street	I ped bush button assembly		$500
	500' thermoplastic, 1 R5-1 & 1 R 6-1 sign		$1,000
Shawmut Avenue/Marginal Road	1 R6 - 1 sign		$100
Arlington Street/Marginal Road	None		
Shawmut Avenue/Tremont Street/Oak Street	Reset post		$800
Tremont Street/Charles Street South	Replace 4 8" heads with 12" heads		$2,400
Tremont Street/Marginal Road	Reset post		$800
Tremont Street/Arlington Street/Herald Street	None		
Signal Equipment Cost that can be annualized over 15 years			**$7,700**
Signing and Pavement Marking Cost that can be annualized over 5 years			**$8,850**
Costs that cannot be annualized			**$2,200**

NOTE - Improvements considered above are based on Table 1 of Recommendations Technical memorandum

BTD Contractor Costs For implementing Signal timing and phasing improvements	
25 intersections with clearance time changes (0.5 hour per intersection at $125 per hour)	$1,563
Travel time for Contractor (6 hours at $125 per hour)	$750
BTD's estimated cost for phasing change at 5 intersections	$12,500
Total BTD Contractor costs =	**$14,813**

COST CALCULATIONS (Continued)

Engineering Costs, Signs and Pavement Marking Costs	
Engineering Fee for Work Order 3	$83,750
Signs and Pavement marking Costs	$8,850
BTD Contractor costs	$14,813
Sum of above costs	$107,413
Assume BTD retimes signals every 5 years	
Assume signs and pavement markings are replaced every 5 years	
Annualized Cost Per Year =P{ [i*(1+i)^n] / [(1+i)^n - 1] }	
P = Present Worth	$107,413
Assume i=7.0 (CPI)	
N = 5	
Numerator = 0.07*(1+0.07)^5 =	$0
Denominator = (1+0.07)^5 -1 =	$0
A = P *(Numerator/Denominator)	$26,197
Total Annual Engineering/Signs/Markings Cost =	**$26,197**

Signal Equipment Costs	
Signal equipment costs	$7,700
Assume signal equipment has a life time of fifteen years	
Annualized Cost Per Year =P{ [i*(1+i)^n] / [(1+i)^n - 1] }	
P= Present worth	$7,700
Assume i=7.0 (CPI) N= 15	
Numerator = 0.07*(1+0.07)^15 =	$0.19
Denominator = (1+0.07)^15 -1 =	$1.76
A = P *(Numerator/Denominator)	$845
Total Annual Signal Equipment Costs =	**$845**

Annual Cost Summary	
Type	
Engineering/Signs/Pavement markings	$26,197
Signal Equipment	$850
Other Non-Annualized Costs	$2,200
Total	**$29,247**

BENEFIT COST RATIO CALCULATIONS

Benefit	$716,900	
Cost	$29,247	
Ratio		**25 to 1**

Improvement Costs		
Intersection	Needed Items	Cost Estimate
Beacon Street/School Street/Tremont Street	Maintenance, N/A	
	1 R3-7, 1 R5-1 & 1 R6-1 sign	$300
Bromfield Street/ Tremont Street	Maintenance, N/A	
	2 R5-1 & 2 R6-1 sign	$400
Tremont Street/Park Street/Winter Street	Maintenance, N/A	
	Remove 8" heads and replace with 12" heads	$1,200
	2 R5-1 & 2 R6-1 sign	$400
Temple Place/ Tremont Street	Remove 8" heads and replace with 12" heads	$2,400
	2 R5-1 & 2 R6-1 sign	$400
Tremont Street/West Street	Maintenance, N/A	
	2 R5-1 & 2 R6-1 sign, replace green ball with arrow	$700
Avery Street/Tremont Street	N/A	
	2 R5-1 & 2 R6-1 and 1 R3-5 sign	$500
Boylston Street/Tremont Street	3 R5-1 & 2 R6-1 and relocate 1 sign	$500
	Relocate 1 sign	$200
	2 R3-5 signs, 2 Th, 2 TH-Rt Pav Markings	$1,400
E. Berkeley Street/Shawmut Avenue	Maintenance, N/A	
	1 R6-1 sign and relocate 2 signs	$400
E. Berkeley Street/ Washington Street	2 R6-1 signs	$200
E. Berkeley Street/ Harrison Avenue	Maintenance, N/A	
	Maintenance, N/A	
Harrison Avenue/Traveler Street	Maintenance, N/A	
	Replace 2 arrow heads with 2 balls	$2,500
Harrison Avenue/Herald Street	Remove R5-1 sign	$200
Harrison Avenue/ Marginal Road	2 R6-1 signs	$200
Harrison Avenue/ Oak Street	I ped bush button assembly	$500
	Say 100' of white Thermoplastic	$500
	Maintenance, N/A	
	Maintenance, N/A	
Washington Street/Marginal Road	Relocate sign	$200
Washington Street/Oak Street	Maintenance, N/A	
Washington Street/Herald Street	1 R6-1 sign	$50
Shawmut Avenue/Herald Street	I ped bush button assembly	$500
	Maintenance, N/A	
	500' thermoplastic, 1 R5-1 & 1 R 6-1 sign	$1,000
Shawmut Avenue/Marginal Road	1 R6 - 1 sign	$100
Arlington Street/Marginal Road	Maintenance, N/A	
Shawmut Avenue/Tremont Street/Oak Street	Reset post	$800
Tremont Street/Charles Street South	Replace 4 8" heads with 12" heads	$2,400
Tremont Street/Marginal Road	Maintenance, N/A	
	Reset post	$800
Tremont Street/Arlington Street/Herald Street	Maintenance, N/A	
Signal Equipment Cost that can be annualized over 15 years		**$7,700**
Signing and Pavement Marking Cost that can be annualized over 5 years		**$8,850**
Costs that cannot be annualized		**$2,200**

Recommended Improvements

- Reset the leaning signal post at northeast corner. Replace missing louvers on signal post at northeast corner. Update the handicap ramp at southeast corner. Update the handicap ramp at southeast corner.
- Install an advanced "Right Lane for Right Turn" sign on southbound Tremont Street. Install "Do Not Enter" and "One Way" signs on Tremont Street (east side). Enforce the No Parking zoning on southbound Tremont Street.
- Repair the LED in the pedestrian head on Bromfield Street facing north. Update wheelchair ramp at northeast corner.
- Install a handicap ramp on the east side of Tremont Street. Install "Do Not Enter" and "One Way" signs on Tremont Street. Enforce the No Parking zoning on southbound Tremont Street in front of the Nine Zero Hotel.
- Increase distance between Tremont St. mast arm and Stop line to 40 feet. Repair LED in red indication at southwest corner of Park Street. Reset leaning signal post at southeast corner of Winter Street.
- Replace the 8 inch signal indications facing Park Street with 12 inch indications. Install a handicap ramp on the east side of Tremont Street at Winter Street.
- Install "Do Not Enter" and "One Way" signs on Tremont Street at Park Street. Enforce the No Parking zone on southbound Tremont Street.
- Replace the 8 inch signal indications facing Temple Place with 12 inch indications. Relocate the signs blocking the pedestrian head on the northeast corner facing the south.
- Install a handicap ramp on the east side of Tremont Street. Install "Do Not Enter" and "One Way" signs on Tremont Street. Enforce the No Parking zone on southbound Tremont Street.
- Repair the LED in the pedestrian head on the north side of West Street facing south. Relocate the handicap ramps on Tremont Street, south of West Street to the center of the crosswalk.
- Install "Do Not Enter" and "One Way" signs on Tremont Street. Replace green ball signal 4A with green vertical arrow per BTD's suggestions.
- Relocate the handicap ramp on the east side of Tremont Street, to the center of the crosswalk.
- Install "Do Not Enter" and "One Way" signs on Tremont Street. Replace the existing lane use sign on the mast arm with a larger sign per MUTCD specifications.
- Install a handicap ramp on the east side of Tremont Street, north of Boylston Street. Relocate the No Left Turn sign facing Boylston Street to meet MUTCD mounting standards. Install a "Do Not Enter" and a "One Way" signs on Tremont Street – west side.
- Relocate the handicap ramp on the east side of Tremont Street, south of E. Berkley Street to the center of the crosswalk. Remove and reset the "No Right Turn on Red" sign located on the mast arm.
- Provide lane use signs and pavement markings for the E. Berkeley Street westbound approach.
- Reset the signal post at the northwest corner to be within 5 feet of the handicap ramp. Remove the abandoned signal post foundation at the northeast corner.
- Reset the "Do Not Enter" and "One Way" signs on Shawmut Ave to meet MUTCD sign mounting specifications. Install a "One Way" sign on southbound Shawmut Ave (west side). Install lane lines on Shawmut Street.
- Repair the pedestrian push button at the northeast corner. Install "One Way" signs on E. Berkeley Street. Remove exclusive pedestrian phase and use concurrent pedestrian phases
- Repair LEDs in the pedestrian heads on the northeast corner. The countdown in the head facing E. Berkeley Street is not working and the Don't Walk indication facing Harrison Avenue is not working.
- Repair the pedestrian push button at the northeast corner.
- Repair the pedestrian push buttons on the Harrison Avenue medians and at the northwest corner. Confirm loops in Traveler Street and in the northbound left lane are not working. Repair if needed.
- Remove northbound left turn phase, and make it a permissive phase. Replace left arrow signal heads (5A & 9A) with balls.
- Repair the LED in the pedestrian head located on the southerly Harrison Avenue median and facing west. Remove one of the "Do Not Enter" signs at southwest corner.
- Replace the old pedestrian signal head located at the southwest corner. Repair the pedestrian push button at the southwest corner. Install a "One Way" sign on the north leg of Harrison Avenue (west side).
- Install a pedestrian push button at the northwest corner, unless the Oak Street concurrent pedestrian phase (Harrison Avenue crosswalk) recall setting Note - signs were assumed to be $300 each for the sign plate, post, installation etc.
- Repair the pedestrian push button at the southwest corner. Update the handicap ramp at northeast corner. Install crosswalk markings on the eastbound Oak Street approach.
- The Oak Street concurrent pedestrian phase (Harrison Avenue crosswalk) is not activated as shown on signal plan. The controller needs to be programmed to include this concurrent phase.
- During the exclusive pedestrian phase, a WALK indication is not shown to the eastbound Oak Street crosswalk.
- Repair the pedestrian push button at the northwest corner. Reset the "Left Turn Sign" facing Marginal Road from the far left corner to improve its visibility.
- Repair the LED in the pedestrian head on the southwest corner facing Oak Street. Repair the pedestrian push buttons at the northeast and northwest corners and on the northerly median.
- Repair the LED in the pedestrian head on the southwest corner facing Washington Street. Install a "One-Way sign on Herald Street (east side).
- Replace the missing plunger on the pedestrian push button at the southwest corner. Repair the LED in the pedestrian head at the southeast corner facing Shawmut Avenue.
- Repair the pedestrian push button at the northwest corner. The Herald Street concurrent pedestrian phase was not getting activated. Reset controller settings.
- Install lane markings on Shawmut Avenue. Install a "Do Not Enter" and a "One Way" sign on Herald Street (east side).
- Repair the LED in the pedestrian head at the southwest corner facing Shawmut Street. Repair/replace the cracked pedestrian signal head at the northwest corner (backside). Install a "One-Way" sign on Marginal Road (north side).
- Repair the pedestrian push buttons at the northwest and southwest corners. Install a handicap ramp at the southwest corner.
- Reset the leaning signal post at the northeast corner.
- Replace the 8 inch signal indications facing Tremont Street and Jefferson Street with 12 inch signal indications. Trim tree growth around the signal head on the southeast corner. Repair the pedestrian push button at the southeast corner.
- Repair the pedestrian push button at the southwest corner.
- Remove and reset the signal post and pedestrian push button at the northwest corner to be within 5 feet of the handicap ramp serving the Tremont Street crosswalk. The existing push button is approximately 17 feet from the ramp.
- Update the handicap ramp at southwest corner.

Standard Item Costs

Item	Unit	cost
Signal head - 3 section one-way LED	Each	$1,000
3 section one-way programmable signal heads	Each	$2,000
Pedestrian signal head	Each	$1,500
8 Feet signal post & Foundation	Each	$2,500
Push Button and sign Assembly	Each	$500
Pullbox 12"X12" SD 2.031	Each	$750
Wiring & testing signal cable	per foot	$5
Wiring & testing pedestrian cable	per foot	$6
Existing Controller reprogramming	Each	$1,500
Remove & Stack signal post	Each	$200
Remove & Stack signal heads	Each	$200
Right turn Arrow Pav Marking	15.8 Sq Ft	$79
Left turn Arrow Pav Marking	15.8 Sq Ft	$79
Through-Right Pav Marking	28.1 Sq Ft	$141
ONLY Pav Marking	29.6 sq ft	$148
6"Reflectorized White Line (Thermoplastic)	1 ft	$1
R3-8 lane use Regulatory sign	30'X30' = 6.25 sq ft	$69
R3-5 Mandatory lane use Regulatory sign	30"x36" = 7.5 sq ft	$83
R3-7 Right Lane Must turn Right sign	36"x36" = 9 sq ft	$99
R10-12 Left Turn yield on Green ball sign	30"x36" = 7.5 sq ft	$83
R5-1 DO NOT ENTER sign	30"x30" = 6.25 sq ft	$69
R6-1 ONE-WAY sign	36"x12" = 3 sq ft	$33
R3-2 NO LEFT TURN sign	24"x24" = 4 sq ft	$44
R1-1 STOP sign	30"x30" = 6.25 sq ft	$69

Appendix D

Benefit Cost Analysis – Work Order #4

DATA

Data from Network MOE Summary Tables Submitted in Recommendations Technical memorandum

	AM Peak Hour		Midday Peak Hour		PM Peak Hour		Difference	% Difference
	Existing	Improved	Existing	Improved	Existing	Improved		
Total Delay (Hr.)	626	350	232	164	569	340	**573**	40.2%
Stops/Vehicle	0.58	0.52	0.51	0.48	0.6	0.56		
Average Speed (mph)	6	9	10	12	6	8		
Fuel Consumed (gal)	747	530	392	337	704	527	**449**	24.4%
Fuel Economy (mpg)	5.7	8.1	8.8	10.3	5.9	8.3		
CO Emissions (Kg)	52.21	37.02	27.4	23.54	49.22	36.87	**31.4**	24.4%
NOx Emissions (Kg)	10.16	7.2	5.33	4.58	9.58	7.17	**6.12**	24.4%
VOC Emissions (Kg)	12.1	8.58	6.35	5.45	11.41	8.54	**7.29**	24.4%

Truck Percentages

Location	AM	MD	PM	Average
Tremont St. at Ruggles Access	6.9%	8.2%	5.8%	7.0%
Tremont St at Whittier/Ruggles	8.8%	8.2%	5.5%	7.5%
Ruggles at MBTA Access	15.1%	12.1%	10.6%	12.6%
Ruggles at Leon St	7.9%	6.3%	4.5%	6.2%
Tremont St. at Prentiss St	8.6%	9.3%	7.1%	8.3%
Tremont St. at Malcolm X Blvd	7.9%	8.7%	5.8%	7.5%
Tremont St. at Terrace St.	6.1%	5.1%	3.3%	4.8%
Tremont St. at Parker St.	5.7%	4.8%	2.2%	4.2%
Columbus Ave at Cedar St	3.9%	4.7%	2.1%	3.6%
Columbus Ave at Heath St	7.0%	6.9%	3.5%	5.8%
Columbus Ave at Centre/Richie	7.0%	5.8%	3.2%	5.3%
Centre St at MBTA Bus Access	8.2%	7.0%	4.0%	6.4%
Centre St at Lamartine St	5.7%	5.8%	4.2%	5.2%
Columbus Ave at Dimock St	6.6%	5.9%	5.0%	5.8%
Columbus Ave at Bragdon St	6.9%	5.0%	4.0%	5.3%
Columbus Ave at Bray St	7.5%	5.7%	4.8%	6.0%
Columbus Ave at Weld Ave	6.1%	3.8%	3.5%	4.5%
Average				**6.2%**

DATA (Continued)

Crash Data

	Location (BTD Intersection Numbers)								
Severity	**1831**	**3079**	**801**	**507**	**287**	**3067**	**805**	**196**	**1077**
Property Damage	1	2	2	2	4	1	1	12	10
Personal Injury	0	0	0	4	9	0	2	8	8
Fatality	0	0	0	0	0	0	0	0	0
Other	0	0	0	3	5	0	3	8	4
Total	1	2	2	9	18	1	6	28	22

Crash Data

	Location (BTD Intersection Numbers)								
Severity	**192**	**1972**	**610**	**4023**	**611**	**3068**	**1526**	**Total**	**Per Year**
Property Damage	10	1	2	2	7	1	1	59	**20**
Personal Injury	18	7	5	3	12	0	0	76	**25**
Fatality	0	0	0	0	0	0	0	0	**0.00**
Other	10	3	1	4	7	0	1	49	16
Total	38	11	8	9	26	1	2	184	61

Benefits Performance Measures values

Category	Performance Measures	Unit of measure	Value per unit in 2009 dollars	Value per unit in 2012 dollars
Delay	Intersection Delay	Person Hours (Cars)	$16.09	$17.22
	Intersection Delay	Person Hours (Trucks)	$106.24	$113.68
Crashes	Property Damage Only (PDO) Crash	Number of Crashes	$3,165	$3,387
	Minor Injury Crash	Number of Crashes	$18,771	$20,085
	Moderate Injury Crash	Number of Crashes	$392,755	$420,248
	Severe Injury Crash	Number of Crashes	$3,003,746	$3,214,008
	Fatality Crash	Number of Crashes	$4,207,985	$4,502,544
Emissions	Carbon Monoxide (CO)	Metric ton	$138	$148
	Nitrous Oxide (Nox)	Metric ton	$7,490	$8,014
	Volatile Organic Compounds (VOC)	Metric ton	$5,682	$6,080
Energy	Fuel	Gallon	$2.64	$3.65

Consumer Price Index increased from 2009 to 2012 by 7.0%. Hence all values are increased by 7.0% to calculate equivalent 2012 values.

BENEFIT CALCULATIONS

Calculation of Delay Reduction Per Year

Assuming

Truck Percentage: 6.2%

Vehicle Occupancy 1.25

Delay decreased by: 573 Vehicle hours per weekday

	Veh. Hours Per Day	Passenger Hours Per Day			Hours Per Year	Cost per Hour	Benefit per Year
Vehicle and Passenger Car Delay (96.6%)	537 hrs.	671	x	260 days/year =	**174,460**	$17.22	$3,003,556
Truck Delay (3.4%)	36 hrs.		x	260 days/year =	**9,360**	$113.68	$1,064,015

Calculation of Crash Reduction Per Year

Assume 8 % crash reduction factor for signal retiming

	Total Accidents	Reduction	Annual Reduction	Cost per Crash	Benefit per Year
Property Damage Accidents	20	0.08	**2.00**	$3,387	$6,773
Personal Injury Accidents	25	0.08	**3.00**	$20,085	$60,255
Fatality Accidents	0	0.08	**-**	$4,502,544	$0

Calculation of Emissions Reductions from Kilograms to Metric Tons to Annual Metric Tons

	KG per day	Metric Tons per day			Annual Reduction	Cost per Ton	Benefit per Year
CO Reduction	31.4	0.0314	x	260 days/year =	**8.1640**	$148	$1,205
Nox Reduction	6.12	0.00612	x	260 days/year =	**1.5912**	$8,014	$12,752
VOC Reduction	7.29	0.00729	x	260 days/year =	**1.8954**	$6,080	$11,524

Calculation of Fuel Reduction Per Year

	Gal. per day			Annual Reduction	Cost per Gal.	Benefit per Year
Phase II fuel reduction in gallons =	449	x	260 days/year =	**116,740**	$3.65	$426,101

Benefits Summary

Category	Performance Measure	Unit	Value per Unit in 2012 Dollars	Benefits in Appropriate Units	Benefits Value
Delay	Intersection Delay	Person Hours (Cars)	$17.22	174460	$3,003,556
		person Hours (Trucks)	$113.68	9360	$1,064,015
Crashes	Property Damage Only (PDO) Crash	Number of Crashes	$3,387	2	$6,773
	Minor Injury Crash	Number of Crashes	$20,085	3	$60,255
	Moderate Injury Crash	Number of Crashes	$420,248	0	$0
	Severe Injury Crash	Number of Crashes	$3,214,008	0	$0
	Fatality Crash	Number of Crashes	$4,502,544	0.00	$0
Emissions	Carbon Monoxide (CO)	Metric ton	$148	8.1640	$1,205
	Nitrous Oxide (Nox)	Metric ton	$8,014	1.5912	$12,752
	Volatile Organic Compounds (VOC)	Metric ton	$6,080	1.8954	$11,524
Energy	Fuel	Gallon	$3.65	116740	$426,101
TOTAL					**$4,586,181**

COST CALCULATIONS

Intersection Improvements Cost Calculations

Intersection	Needed Items	Cost Estimate
Columbus Avenue near Weld Street	About 255' of white thermoplastic	$500
Columbus Avenue at Bray Street	1 pedestrian signal head, post & push button	$4,500
	About 320' of white thermoplastic	$700
	2 R 3-2 signs, 2 Th arrow markings	$500
Columbus Avenue at Bragdon Street	2 new signal heads	$1,000
Columbus Avenue at Dimock Street	About 1000' of white thermoplastic	$2,500
Columbus Avenue at Centre Street/Ritchie Street	About 1300' of white thermoplastic	$3,000
Columbus Avenue at Busway	None	
Columbus Avenue at Lamartine Street	None	
Columbus Avenue at Cedar Street	None	
Columbus Avenue at Malcolm X Boulevard/Tremont S	About 2100' of white thermoplastic	$4,000
Tremont Street at Parker Street	Relocate street name post & sign	$400
Tremont Street at Ruggles Street/Whittier Street	None	
Ruggles Street at Busway	About 1000' white & 500' yellow thermoplastic	$2,750
Ruggles Street at Leon Street	About 1500' white & 500' yellow thermoplastic	$5,000
	2 Th-Lt, 2 LT, 2 RT arrow, 6 ONLY markings	$3,000
Signal Equipment Cost that can be annualized over 15 years		**$5,500**
Signing and Pavement Marking Cost that can be annualized over 5 years		**$21,950**
Costs that cannot be annualized		**$400**

NOTE - Improvements considered above are based on Table 1 of Recommendations Technical memorandum

BTD Contractor Costs For implementing Signal timing and phasing improvements	
17 intersections with clearance time changes (0.5 hour per intersection at $125 per hour)	$1,063
Travel time for Contractor (4 hours at $125 per hour)	$500
BTD's estimated cost for phasing change at Columbus/Tremont/Malcolm X Blvd intersection	$2,500
Total BTD Contractor costs =	**$4,063**

COST CALCULATIONS (Continued)

Engineering Costs, Signs and Pavement Marking Costs	
Engineering Fee for Work Order 4	$54,850
Signs and Pavement marking Costs	$21,950
BTD Contractor costs	$4,063
Sum of above costs	$80,863
Assume BTD retimes signals every 5 years	
Assume signs and pavement markings are replaced every 5 years	
Annualized Cost Per Year =P{ [i*(1+i)^n] / [(1+i)^n - 1] }	
P = Present Worth	$80,863
Assume i=7.0 (CPI)	
N = 5	
Numerator = 0.07*(1+0.07)^5 =	$0
Denominator = (1+0.07)^5 -1 =	$0
A = P *(Numerator/Denominator)	$19,722
Total Annual Engineering/Signs/Markings Cost =	**$19,720**

Signal Equipment Costs	
Signal equipment costs	$5,500
Assume signal equipment has a life time of fifteen years	
Annualized Cost Per Year =P{ [i*(1+i)^n] / [(1+i)^n - 1] }	
P= Present worth	$5,500
Assume i=7.0 (CPI) N= 15	
Numerator = 0.07*(1+0.07)^15 =	$0
Denominator = (1+0.07)^15 -1 =	$2
A = P *(Numerator/Denominator)	$604
Total Annual Signal Equipment Costs =	**$604**

Annual Cost Summary	
Type	
Engineering/Signs/Pavement markings	$19,720
Signal Equipment	$604
Other Non-Annualized Costs	$400
Total	**$20,724**

BENEFIT COST RATIO CALCULATIONS

Benefit	$4,586,181	
Cost	$20,724	
Ratio		**221 to 1**

Improvement Costs		
Intersection	Needed Items	Cost Estimate
Columbus Avenue near Weld Street	Maintenance, N/A	
	About 255' of white thermoplastic	$500
Columbus Avenue at Bray Street	1 pedestrian signal head, post & push button	$4,500
	About 320' of white thermoplastic	$700
	2 R 3-2 signs, 2 Th arrow markings	$500
Columbus Avenue at Bragdon Street	Maintenance, N/A	
	N/A	
	2 new signal heads	$1,000
	N/A	
	N/A	
Columbus Avenue at Dimock Street	Maintenance, N/A	
	About 1000' of white thermoplastic	$2,500
Columbus Avenue at Centre Street/Ritchie Street	About 1300' of white thermoplastic	$3,000
	N/A	
	Maintenance, N/A	
	N/A	
Columbus Avenue at Busway	N/A	
Columbus Avenue at Lamartine Street	N/A	
Columbus Avenue at Cedar Street	N/A	
Columbus Avenue at Malcolm X Boulevard/Tremont S	N/A	
	About 2100' of white thermoplastic	$4,000
Tremont Street at Parker Street	Relocate street name post & sign	$400
Tremont Street at Ruggles Street/Whittier Street	Maintenance, N/A	
Ruggles Street at Busway	About 1000' white & 500' yellow thermoplastic	$2,750
	N/A	
Ruggles Street at Leon Street	About 1500' white & 500' yellow thermoplastic	$5,000
	2 Th-Lt, 2 LT, 2 RT arrow, 6 ONLY markings	$3,000
Signal Equipment Cost that can be annualized over 15 years		**$5,500**
Signing and Pavement Marking Cost that can be annualized over 5 years		**$21,950**
Costs that cannot be annualized		**$400**

Recommended Improvements

- Pedestrian pushbuttons along Columbus Avenue on the southwest corner and on the median did not work during field observations. Repair as neede
- Restripe crosswalk pavement markings to improve visibility.

- The signal pole with the pedestrian pushbutton on the median was observed to be rusted and in poor condition. Please replace.
- Restripe crosswalk pavement markings to improve visibility.
- Post signs and provide pavement markings to indicate appropriate lane use. (No left/right turns onto Bray St)

- Trim vegetation to improve visibility of the signal head located on the southeast corner of the intersection.
- Crosswalks are provided without corresponding signal heads and pushbuttons.
- Add a far-side signal indication in the median on the existing posts for the Columbus Avenue northbound and southbound approaches.
- Add advanced warning signs for the Fire Station.
- Consider providing pedestrian phasing with pedestrian signals or remove crosswalks across Columbus Avenue.

- Field observations showed that all pedestrian pushbuttons within the intersection are malfunctioning. Please check and replace equipment as neede
- Restripe crosswalk pavement markings to improve visibility.

- Restripe crosswalk pavement markings to improve visibility.
- Consider replacing all the posts and mounting hardware/brackets.
- Check loops on Richie Street, they might be broken.
- Provide ADA ramp on the northeast corner for the northern crosswalk at the intersection.

- ADA ramp on the northeast corner does not match crosswalk location. Build new ramp and repair sidewalk.

- Repair ADA ramp on the southeast corner to fix the cracks in the concrete.

- Field observations showed that the left turn lanes on Columbus Ave are frequently being used by through vehicles as a receiving through lane is pro\

- Trim vegetation to improve visibility of signal head for Columbus Ave southbound movement.
- Restripe crosswalk pavement markings to improve visibility.

- The pedestrian signal head located on the northwest corner of the intersection is being blocked by the street name sign.
- Relocate the street name sign.

- Per comments from BTD, detector loops on Whittier St are broken. Loops are to be replaced.

- Field observations showed that the pavement markings at the intersection had faded. Restripe pavement markings.
- Provide ADA ramp on the eastern side of crosswalk across MBTA busway.

- Field observations showed that the pavement markings at the intersection had faded. Restripe pavement markings.

Standard Item Costs

Item	Unit	cost
Signal head - 3 section one-way LED	Each	$1,000
3 section one-way programmable signal heads	Each	$2,000
Pedestrian signal head	Each	$1,500
8 Feet signal post & Foundation	Each	$2,500
Push Button and sign Assembly	Each	$500
Pullbox 12"X12" SD 2.031	Each	$750
Wiring & testing signal cable	per foot	$5
Wiring & testing pedestrian cable	per foot	$6
Existing Controller reprogramming	Each	$1,500
Remove & Stack signal post	Each	$200
Remove & Stack signal heads	Each	$200
Right turn Arrow Pav Marking	15.8 Sq Ft	$79
Left turn Arrow Pav Marking	15.8 Sq Ft	$79
Through Arrow Pav Marking	15.8 Sq Ft	$79
Through-Right Pav Marking	28.1 Sq Ft	$141
ONLY Pav Marking	29.6 sq ft	$148
6"Reflectorized White Line (Thermoplastic)	1 ft	$1
6"Reflectorized Yellow Line (Thermoplastic)	1 ft	$1
R3-2 No Left/Right Turn sign	36'X36' = 9 sq ft	$99
R3-8 lane use Regulatory sign	30'X30' = 6.25 sq ft	$69
R3-5 Mandatory lane use Regulatory sign	30"x36" = 7.5 sq ft	$83
R3-7 Right Lane Must turn Right sign	36"x36" = 9 sq ft	$99
R10-12 Left Turn yield on Green ball sign	30"x36" = 7.5 sq ft	$83
R5-1 DO NOT ENTER sign	30"x30" = 6.25 sq ft	$69
R6-1 ONE-WAY sign	36"x12" = 3 sq ft	$33
R3-2 NO LEFT TURN sign	24"x24" = 4 sq ft	$44
R1-1 STOP sign	30"x30" = 6.25 sq ft	$69

Note - signs were assumed to be $300 each for the sign plate, post, installation etc.

Appendix E

Benefit Cost Analysis – Work Order #5

DATA

Data from Network MOE Summary Tables Submitted in Recommendations Technical memorandum

	AM Peak Hour		Midday Peak Hour		PM Peak Hour		Difference	% Difference
	Existing	Improved	Existing	Improved	Existing	Improved		
Total Delay (Hr.)	280	242	152	139	309	266	**94**	12.7%
Stops/Vehicle	0.60	0.59	0.60	0.57	0.62	0.58		
Average Speed (mph)	12	13	14	15	12	13		
Fuel Consumed (gal)	561	532	385	373	613	574	**80**	5.1%
Fuel Economy (mpg)	11.2	11.8	12.6	13.0	11.1	11.8		
CO Emissions (Kg)	39.19	37.19	26.94	26.07	42.88	40.11	**5.64**	5.2%
NOx Emissions (Kg)	7.63	7.24	5.24	5.07	8.34	7.8	**1.1**	5.2%
VOC Emissions (Kg)	9.08	8.62	6.24	6.04	9.94	9.3	**1.3**	5.1%

Truck Percentages

Location	AM	MD	PM	Average
Chelsea St at Warren St	8.0%	18.9%	7.9%	11.6%
Chelsea St at Constitution Rd	9.0%	21.9%	9.4%	13.4%
Chelsea St at 5th St	9.4%	20.5%	9.9%	13.3%
Chelsea St at 13th St	20.7%	23.3%	12.1%	18.7%
Chelsea St at 16th St	38.8%	50.2%	29.5%	39.5%
Huntington Ave at S Huntington Ave	5.9%	4.5%	2.9%	4.4%
Huntington Ave at Parker Hill/Mission Park	6.9%	6.7%	3.4%	5.7%
Huntington Ave at St. Albans/Mission	8.1%	7.3%	3.8%	6.4%
Amory St at Atherton St	2.8%	5.5%	2.6%	3.6%
Amory St at Green St	2.6%	4.5%	3.3%	3.5%
Amory St at Minton St	2.3%	4.0%	2.8%	3.0%
Green St at Elm St/Lamartine St	2.3%	3.4%	0.7%	2.1%
Washington St at Lagrange St	6.0%	3.7%	2.7%	4.1%
Washington St at Enneking Pkwy/W Roxbury Pkwy	4.6%	3.4%	1.8%	3.3%
Washington St at Desoto Rd	5.6%	3.9%	2.3%	3.9%
Baker St at Spring St	7.7%	4.1%	2.4%	4.7%
Baker St at Gardner St	2.8%	7.8%	2.5%	4.4%
Beech St at Poplar St	5.8%	3.8%	2.1%	3.9%
Spring St at Summer St/Shaw's	5.3%	3.3%	1.6%	3.4%
Almont St at Walk Hill St	4.3%	3.8%	3.0%	3.7%
Centre St at Creighton St/Forbes St	6.1%	4.6%	4.4%	5.0%
Northampton St at Shawmut Ave	10.2%	4.5%	1.7%	5.5%
Washington St at Norfolk St/Talbot St	8.3%	5.6%	5.1%	6.3%
Washington St at Dunbar St/Roslin St	6.4%	5.8%	4.3%	5.5%
Average				**4.2%**

DATA (Continued)

Crash Data

	Location (BTD Intersection Numbers)								
Severity	**2339**	**4037**	**3038**	**3039**	**4053**	**206**	**613**	**3133**	**615**
Property Damage	1	0	0	1	0	6	3	3	0
Personal Injury	0	0	1	2	0	2	4	2	0
Fatality	1	0	1	0	0	0	0	0	0
Other	0	0	0	0	0	1	1	4	0
Total	2	0	2	3	0	9	8	9	0

Crash Data

	Location (BTD Intersection Numbers)								
Severity	**372**	**1883**	**435**	**255**	**254**	**1752**	**727**	**817**	**972**
Property Damage	1	1	0	3	11	3	3	1	1
Personal Injury	0	0	0	2	14	0	5	0	2
Fatality	0	0	0	0	0	0	0	0	0
Other	1	3	0	4	8	0	3	0	0
Total	2	4	0	9	33	3	11	1	3

Crash Data

	Location (BTD Intersection Numbers)							
Severity	**2056**	**719**	**1089**	**785**	**225**	**4029**	**Total**	**Per Year**
Property Damage	1	0	1	0	5	1	46	**15**
Personal Injury	0	0	0	0	7	1	42	**14**
Fatality	0	0	0	0	0	0	2	**0.67**
Other	1	0	1	1	4	0	32	11
Total	2	0	2	1	16	2	122	41

Benefits Performance Measures values

Category	Performance Measures	Unit of measure	Value per unit in 2009 dollars	Value per unit in 2012 dollars
Delay	Intersection Delay	Person Hours (Cars)	$16.09	$17.22
	Intersection Delay	Person Hours (Trucks)	$106.24	$113.68
Crashes	Property Damage Only (PDO) Crash	Number of Crashes	$3,165	$3,387
	Minor Injury Crash	Number of Crashes	$18,771	$20,085
	Moderate Injury Crash	Number of Crashes	$392,755	$420,248
	Severe Injury Crash	Number of Crashes	$3,003,746	$3,214,008
	Fatality Crash	Number of Crashes	$4,207,985	$4,502,544
Emissions	Carbon Monoxide (CO)	Metric ton	$138	$148
	Nitrous Oxide (Nox)	Metric ton	$7,490	$8,014
	Volatile Organic Compounds (VOC)	Metric ton	$5,682	$6,080
Energy	Fuel	Gallon	$2.64	$3.65

Consumer Price Index increased from 2009 to 2012 by 7.0%. Hence all values are increased by 7.0% to calculate equivalent 2012 values.

BENEFIT CALCULATIONS

Calculation of Delay Reduction Per Year

Assuming

Truck Percentage: 3.9%

Vehicle Occupancy 1.25

Delay decreased by: 94 Vehicle hours per weekday

	Veh. Hours Per Day	Passenger Hours Per Day			Hours Per Year	Cost per Hour	Benefit per Year
Vehicle and Passenger Car Delay (96.6%)	90 hrs.	112	x	260 days/year =	**29,120**	$17.22	$501,339
Truck Delay (3.4%)	4 hrs.		x	260 days/year =	**1,040**	$113.68	$118,224

Calculation of Crash Reduction Per Year

Assume 8 % crash reduction factor for signal retiming

	Total Accidents	Reduction	Annual Reduction	Cost per Crash	Benefit per Year
Property Damage Accidents	15	0.08	**2.00**	$3,387	$6,773
Personal Injury Accidents	14	0.08	**2.00**	$20,085	$40,170
Fatality Accidents	1	0.08	**0.05**	$4,502,544	$240,136

Calculation of Emissions Reductions from Kilograms to Metric Tons to Annual Metric Tons

	KG per day	Metric Tons per day			Annual Reduction	Cost per Ton	Benefit per Year
CO Reduction	5.64	0.00564	x	260 days/year =	**1.4664**	$148	$217
Nox Reduction	1.1	0.0011	x	260 days/year =	**0.2860**	$8,014	$2,292
VOC Reduction	1.3	0.0013	x	260 days/year =	**0.3380**	$6,080	$2,055

Calculation of Fuel Reduction Per Year

	Gal. per day			Annual Reduction	Cost per Gal.	Benefit per Year
Fuel reduction in gallons =	80	x	260 days/year =	**20,800**	$3.65	$75,920

Benefits Summary

Category	Performance Measure	Unit	Value per Unit in 2012 Dollars	Benefits in Appropriate Units	Benefits Value
Delay	Intersection Delay	Person Hours (Cars)	$17.22	29120	$501,339
		person Hours (Trucks)	$113.68	1040	$118,224
Crashes	Property Damage Only (PDO) Crash	Number of Crashes	$3,387	2	$6,773
	Minor Injury Crash	Number of Crashes	$20,085	2	$40,170
	Moderate Injury Crash	Number of Crashes	$420,248	0	$0
	Severe Injury Crash	Number of Crashes	$3,214,008	0	$0
	Fatality Crash	Number of Crashes	$4,502,544	0.05	$240,136
Emissions	Carbon Monoxide (CO)	Metric ton	$148	1.4664	$217
	Nitrous Oxide (Nox)	Metric ton	$8,014	0.2860	$2,292
	Volatile Organic Compounds (VOC)	Metric ton	$6,080	0.3380	$2,055
Energy	Fuel	Gallon	$3.65	20800	$75,920
TOTAL					**$987,125**

COST CALCULATIONS

Intersection Improvements Cost Calculations

Intersection	Needed Items	Cost Estimate
Chelsea Street at Warren Street	About 565' of 12" white thermoplastic	$1,130
	About 600' of 6" white thermoplastic	$600
	2 new signal heads	$2,000
	1 LT arrow, 1 TH-RT arrow, 1 LT-TH arrow, 1 RT arrow, 2 ONLY markings	$1,800
	New cabinet assembly-Type 8 DW-Includes all equipment and labor	$19,668
Chelsea Street at Constitution Road	About 165' of 12" white thermoplastic	$330
	New cabinet assembly-Type 4 DW-Includes all equipment and labor	$15,904
Chelsea Street at 5th Street	Replace red arrow head with red ball	$300
	About 345' of 12" white thermoplastic	$690
	New cabinet assembly-Type 4 DW-Includes all equipment and labor	$15,904
Chelsea Street at 13th Street	About 335' of 12" white thermoplastic	$670
	New cabinet assembly-Type 4 DW-Includes all equipment and labor	$15,904
Chelsea Street at 16th Street	About 305' of 12" white thermoplastic	$610
	About 370' of 6" yellow thermoplastic	$370
	New cabinet assembly-Type 4 DW-Includes all equipment and labor	$15,904
Huntington Avenue at South Huntington Avenue	About 1000' of 12" white thermoplastic	$2,000
	New cabinet assembly-Type 4 DW-Includes all equipment and labor	$15,904
Huntington Avenue at Parker Hill Avenue/Mission Park Drive	About 700' of 12" white thermoplastic	$1,400
	Provide pedestrian signal heads across Parker Hill Avenue	$6,000
	New cabinet assembly-Type 4 DW-Includes all equipment and labor	$15,904
Huntington Avenue at St. Albans Road/Mission Street	About 650' of 12" white thermoplastic	$1,300
	New cabinet assembly-Type 4 DW-Includes all equipment and labor	$15,904
Amory Street at Atherton Street	About 385' of 12" white thermoplastic	$770
	New cabinet assembly-Type 4 DW-Includes all equipment and labor	$15,904
Amory Street at Green Street	About 470' of white thermoplastic	$940
	Replace pedestrian signal head with LED	$1,500
	New cabinet assembly-Type 4 DW-Includes all equipment and labor	$15,904
Amory Street at Minton Street	Remove 8" heads and replace with 12" heads	$1,200
	About 250' of 12" white thermoplastic	$500
	Provide pedestrian signal heads across Minton Street	$6,000
	New cabinet assembly-Type 4 DW-Includes all equipment and labor	$15,904
Green Street at Elm Street/Lamartine Street	About 685' of 12" white thermoplastic	$1,370
	New cabinet assembly-Type 4 DW-Includes all equipment and labor	$15,904
Washington Street at West Roxbury Parkway/Enneking Parkway	About 1345' of 12" white thermoplastic	$2,690
	New cabinet assembly-Type 8 DW-Includes all equipment and labor	$19,668
Washington Street at Lagrange Street	About 810' of 12" white thermoplastic	$1,620
	Replace 3-section left turn heads with 5-section doghouse heads (3)	$6,600
	New cabinet assembly-Type 8 DW-Includes all equipment and labor	$19,668
Washington Street at Desoto Road	Replace 3-section left turn heads with 5-section doghouse heads (2)	$4,400
	New cabinet assembly-Type 4 DW-Includes all equipment and labor	$15,904
Baker Street at Spring Street	About 830' of 12" white thermoplastic	$1,660
	New cabinet assembly-Type 4 DW-Includes all equipment and labor	$15,904
Baker Street at Gardner Street	New cabinet assembly-Type 4 DW-Includes all equipment and labor	$15,904
Beech Street at Poplar Street	About 795' of 12" white thermoplastic	$1,590
	New cabinet assembly-Type 4 DW-Includes all equipment and labor	$15,904
Spring Street at Summer Street	About 480' of 12" white thermoplastic	$960
	Repair communication with Centre/Spring	$2,000
	Provide crosswalk across Shaw's Drive - about 230' of 12" white thermoplastic	$460
	Provide pedestrian signal heads and crosswalk across Shaw's Driveway	$6,000
	New cabinet assembly-Type 4 DW-Includes all equipment and labor	$15,904
Almont Street at Walk Hill Street	New cabinet assembly-Type 4 DW-Includes all equipment and labor	$15,904
Centre Street at Creighton Street/Forbes Street	About 300' of 6" yellow thermoplastic	$300
	About 325' of 12" white thermoplastic	$650
	New cabinet assembly-Type 4 DW-Includes all equipment and labor	$15,904
Northampton Street at Shawmut Avenue	Repair communication with Massachusetts Avenue/Shawmut Avenue	$2,000
	About 210' of 12" white thermoplastic	$420
	New cabinet assembly-Type 4 DW-Includes all equipment and labor	$15,904
Talbot Street at Washington Street/Norfolk Street	Replace one 3-section signal head with a 5-section head	$2,200
	About 1565' of 12" white thermoplastic	$3,130
	New cabinet assembly-Type 8 DW with master-Includes all equipment and labor	$23,168
Washington Street at Roslin Street/Dunbar Street	Provide pedestrian signal heads across Roslin Street and Dunbar Street	$12,000
	New cabinet assembly-Type 4 DW-Includes all equipment and labor	$15,904
Signal Equipment Cost that can be annualized over 15 years		**$452,452**
Signing and Pavement Marking Cost that can be annualized over 5 years		**$27,960**
Costs that cannot be annualized		**$0**

NOTE - Improvements considered above are based on Table 1 of Recommendations Technical memorandum

BTD Contractor Costs For implementing Signal timing and phasing improvements	
Assumed to be zero because controllers are being replaced at all intersections within this work order and will be built based on the Operations Schedules provided in the recommendations memo.	$0
Total BTD Contractor costs =	**$0**

Notes for New Cabinet Assembly Controller Costs:

1. Type 4 DW cost includes: 4 DW Controller, 2 Rack Mounted Loop Amplifiers, R&S Controller Cabinet Assembly, Install 4 DW Controller, and 1 Special Duty Police (8 hours)
2. Type 8 DW cost includes: 8 DW Controller, 4 Rack Mounted Loop Amplifiers, R&S Controller Cabinet Assembly, Install 8 DW Controller, and 2 Special Duty Police (8 hours each)
3. Type 8 DW with Master cost includes: 8 DW Controller with Closed Loop Master, 4 Rack Mounted Loop Amplifiers, R&S Controller Cabinet Assembly, Install 8 DW Controller, and 2 Special Duty Police (8 hours each)

COST CALCULATIONS (Continued)

Engineering Costs, Signs and Pavement Marking Costs		
Engineering Fee for Work Order 5		$87,500
Signs and Pavement marking Costs		$27,960
BTD Contractor costs		$0
Sum of above costs		$115,460
Assume BTD retimes signals every 5 years		
Assume signs and pavement markings are replaced every 5 years		
Annualized Cost Per Year =P{ [i*(1+i)^n] / [(1+i)^n - 1] }		
P = Present Worth		$115,460
Assume i=7.0 (CPI)		
N = 5		
Numerator = 0.07*(1+0.07)^5 =		$0
Denominator = (1+0.07)^5 -1 =		$0
A = P *(Numerator/Denominator)		$28,160
Total Annual Engineering/Signs/Markings Cost =		**$28,160**

Signal Equipment Costs		
Signal equipment costs		$452,452
Assume signal equipment has a life time of fifteen years		
Annualized Cost Per Year =P{ [i*(1+i)^n] / [(1+i)^n - 1] }		
P= Present worth		$452,452
Assume i=7.0 (CPI)	N= 15	
Numerator = 0.07*(1+0.07)^15 =		$0
Denominator = (1+0.07)^15 -1 =		$2
A = P *(Numerator/Denominator)		$49,677
Total Annual Signal Equipment Costs =		**$49,677**

Annual Cost Summary	
Type	
Engineering/Signs/Pavement markings	$28,160
Signal Equipment	$49,677
Other Non-Annualized Costs	$0
Total	**$77,837**

BENEFIT COST RATIO CALCULATIONS

Benefit	$987,125	
Cost	$77,837	
Ratio	**13**	**to 1**

Improvement Costs

Intersection	Needed Items	Cost Estimate
Chelsea Street at Warren Street	New cabinet assembly-Type 8 DW-Includes all equipment and labor	$19,668
	About 565' of 12" white thermoplastic	$1,130
	About 600' of 6" white thermoplastic	$600
	2 new signal heads	$2,000
	1 LT arrow, 1 TH-RT arrow, 1 LT-TH arrow, 1 RT arrow, 2 ONLY markings	$1,800
Chelsea Street at Constitution Road	New cabinet assembly-Type 4 DW-Includes all equipment and labor	$15,904
	Maintenance, N/A	$0
	Maintenance, N/A	$0
	About 165' of 12" white thermoplastic	$330
Chelsea Street at 5th Street	New cabinet assembly-Type 4 DW-Includes all equipment and labor	$15,904
	Replace red arrow head with red ball	$300
	About 345' of 12" white thermoplastic	$690
Chelsea Street at 13th Street	New cabinet assembly-Type 4 DW-Includes all equipment and labor	$15,904
	Maintenance, N/A	$0
	About 335' of 12" white thermoplastic	$670
Chelsea Street at 16th Street	New cabinet assembly-Type 4 DW-Includes all equipment and labor	$15,904
	About 305' of 12" white thermoplastic	$610
	About 370' of 6" yellow thermoplastic	$370
Huntington Avenue at South Huntington Avenue	New cabinet assembly-Type 4 DW-Includes all equipment and labor	$15,904
	Enforcement, N/A	$0
	About 1000' of 12" white thermoplastic	$2,000
Huntington Avenue at Parker Hill Avenue/Mission Park Drive	New cabinet assembly-Type 4 DW-Includes all equipment and labor	$15,904
	About 700' of 12" white thermoplastic	$1,400
	Maintenance, N/A	$0
	Modify signal phasing	$0
	Provide pedestrian signal heads across Parker Hill Avenue	$6,000
Huntington Avenue at St. Albans Road/Mission Street	New cabinet assembly-Type 4 DW-Includes all equipment and labor	$15,904
	Maintenance, N/A	$0
	About 650' of 12" white thermoplastic	$1,300
Amory Street at Atherton Street	New cabinet assembly-Type 4 DW-Includes all equipment and labor	$15,904
	Maintenance, N/A	$0
	About 385' of 12" white thermoplastic	$770
Amory Street at Green Street	New cabinet assembly-Type 4 DW-Includes all equipment and labor	$15,904
	About 455' of 12" white thermoplastic	$910
	About 15' of 12" white thermoplastic	$30
	Maintenance, N/A	$0
	Replace pedestrian signal head with LED	$1,500
Amory Street at Minton Street	New cabinet assembly-Type 4 DW-Includes all equipment and labor	$15,904
	Remove 8" heads and replace with 12" heads	$1,200
	N/A	$0
	About 250' of 12" white thermoplastic	$500
	Maintenance, N/A	$0
	Provide pedestrian signal heads across Minton Street	$6,000
Green Street at Elm Street/Lamartine Street	New cabinet assembly-Type 4 DW-Includes all equipment and labor	$15,904
	Maintenance, N/A	$0
	About 685' of 12" white thermoplastic	$1,370
Washington Street at West Roxbury Parkway/Enneking Parkway	New cabinet assembly-Type 8 DW-Includes all equipment and labor	$19,668
	About 1345' of 12" white thermoplastic	$2,690
Washington Street at Lagrange Street	New cabinet assembly-Type 8 DW-Includes all equipment and labor	$19,668
	Replace 3-section left turn heads with 5-section doghouse heads (3)	$6,600
	About 810' of 12" white thermoplastic	$1,620
Washington Street at Desoto Road	New cabinet assembly-Type 4 DW-Includes all equipment and labor	$15,904
	Replace 3-section left turn heads with 5-section doghouse heads (2)	$4,400
	Maintenance, N/A	$0
Baker Street at Spring Street	New cabinet assembly-Type 4 DW-Includes all equipment and labor	$15,904
	About 830' of 12" white thermoplastic	$1,660
Baker Street at Gardner Street	New cabinet assembly-Type 4 DW-Includes all equipment and labor	$15,904
	N/A	$0
Beech Street at Poplar Street	New cabinet assembly-Type 4 DW-Includes all equipment and labor	$15,904
	Maintenance, N/A	$0
	About 795' of 12" white thermoplastic	$1,590
Spring Street at Summer Street	New cabinet assembly-Type 4 DW-Includes all equipment and labor	$15,904
	About 480' of 12" white thermoplastic	$960
	Repair communication with Centre/Spring	$2,000
	Provide crosswalk across Shaw's Drive - about 230' of 12" white thermoplastic	$460
	Provide pedestrian signal heads and crosswalk across Shaw's Driveway	$6,000
Almont Street at Walk Hill Street	New cabinet assembly-Type 4 DW-Includes all equipment and labor	$15,904
	N/A	$0
Centre Street at Creighton Street/Forbes Street	New cabinet assembly-Type 4 DW-Includes all equipment and labor	$15,904
	Maintenance, N/A	$0
	About 300' of 6" yellow thermoplastic	$300
	About 325' of 12" white thermoplastic	$650
Northampton Street at Shawmut Avenue	New cabinet assembly-Type 4 DW-Includes all equipment and labor	$15,904
	Repair communication with Massachusetts Avenue/Shawmut Avenue	$2,000
	About 210' of 12" white thermoplastic	$420
Talbot Street at Washington Street/Norfolk Street	New cabinet assembly-Type 8 DW with master-Includes all equipment and labor	$23,168
	Maintenance, N/A	$0
	Replace one 3-section signal head with a 5-section head	$2,200
	About 1565' of 12" white thermoplastic	$3,130
Washington Street at Roslin Street/Dunbar Street	New cabinet assembly-Type 4 DW-Includes all equipment and labor	$15,904
	Maintenance, N/A	$0
	Provide pedestrian signal heads across Roslin Street and Dunbar Street	$12,000
Signal Equipment Cost that can be annualized over 15 years		**$452,452**
Signing and Pavement Marking Cost that can be annualized over 5 years		**$27,960**
Costs that cannot be annualized		**$0**

Recommended Improvements

- Controller type 8 DW (includes all equipment and labor)
- Restripe crosswalk pavement markings to improve visibility.
- Restripe Chelsea Street NB departure lane.
- Replace Chelsea Street LT signal heads with 3-section heads
- Consider formalizing lane use on Warren Street by providing pavement markings.
- Controller type 4 DW (includes all equipment and labor)
- Repair pedestrian signals.
- Repair green indication on bracket-mounted signal on Chelsea Street SB
- Restripe missing pavement markings on west side of Chelsea Street
- Controller type 4 DW (includes all equipment and labor)
- Consider replacing Chelsea Street SB red arrow with red ball to improve visibility
- Restripe crosswalk pavement markings to improve visibility.
- Controller type 4 DW (includes all equipment and labor)
- Rotate pedestrian signal head at southeast corner of the intersection so that it is visible to pedestrians in the crosswalk.
- Restripe crosswalk pavement markings to improve visibility.
- Controller type 4 DW (includes all equipment and labor)
- Restripe crosswalks and pavement markings to improve visibility

- Controller type 4 DW (includes all equipment and labor)
- Consider enforcing no stopping area on Huntington Ave WB
- Restripe crosswalk pavement markings to improve visibility.
- Controller type 4 DW (includes all equipment and labor)
- Restripe crosswalk pavement markings to improve visibility.
- Remove STOP signs to reduce driver confusion
- Provide split phasing for side streets because of offset distance.
- No pedestrian signal heads across Parker Hill Avenue. Consider providing pedestrian phasing with pedestrian signal heads.
- Controller type 4 DW (includes all equipment and labor)
- Remove STOP signs to reduce driver confusion
- Restripe crosswalks and pavement markings to improve visibility
- Controller type 4 DW (includes all equipment and labor)
- Repair loops on Atherton Street
- Restripe crosswalk pavement markings to improve visibility.

- Controller type 4 DW (includes all equipment and labor)
- Restripe crosswalk pavement markings to improve visibility.
- Add STOP bar on Green Street EB.
- Repair countdowns on two pedestrian signal heads.
- Add visor to pedestrian signal head to improve visibility or replace with LED to be consistent with other pedestrian heads at intersection.
- Controller type 4 DW (includes all equipment and labor)
- Consider upgrading signal heads to 12 inches.
- Replace visors on missing signal heads (assume this is being ignored since signal heads should be changed to 12" heads)
- Restripe crosswalk pavement markings to improve visibility.
- Repair loops on Minton Street.
- No pedestrian signal heads across Minton Street. Consider providing pedestrian phasing with pedestrian signal heads.
- Controller type 4 DW (includes all equipment and labor)
- Activate loops on Elm Street and Lamartine Street once loop installation is complete.
- Restripe crosswalks and pavement markings to improve visibility
- Controller type 8 DW (includes all equipment and labor)
- Restripe crosswalks and pavement markings to improve visibility
- Controller type 8 DW (includes all equipment and labor)
- Replace Washington Street 3-section LT signal heads with 5-section doghouse heads
- Restripe crosswalks and pavement markings to improve visibility
- Controller type 4 DW (includes all equipment and labor)

- Remove STOP signs to reduce driver confusion
- Controller type 4 DW (includes all equipment and labor)
- Restripe crosswalks and stop bars to improve visibility
- Controller type 4 DW (includes all equipment and labor)
- ADA ramps do not match crosswalk locations on all corners. Build new ADA ramps and repair sidewalk.
- Controller type 4 DW (includes all equipment and labor)
- Visors missing from some signal heads. Replace visors.
- Restripe crosswalks and stop bars to improve visibility
- Controller type 4 DW (includes all equipment and labor)
- Restripe crosswalks and stop bars to improve visibility
- Repair communication between Centre Street/Spring Street and this location.
- No crosswalk across Shaw's driveway. Consider providing crosswalk.
- No pedestrian signal heads across Shaw's Driveway. Consider providing pedestrian phasing with pedestrian signal heads.
- Controller type 4 DW (includes all equipment and labor)
- Provide ADA ramp on northern side of crosswalk across Walk Hill Street.
- Controller type 4 DW (includes all equipment and labor)
- Old crosswalks have not been fully removed and crosswalk location is ambiguous. Fully remove old crosswalk.
- Restripe pavement markings to improve visibility.

- Controller type 4 DW (includes all equipment and labor)
- Repair communication between Massachusetts Avenue/Shawmut Avenue and this location.
- Restripe crosswalk pavement markings to improve visibility.
- Controller type 8 DW with Master (includes all equipment and labor)
- Visors missing from some signal heads. Replace visors.
- Replace traffic signal head 7A with 5-section head.
- Restripe crosswalk pavement markings to improve visibility.
- Controller type 4 DW (includes all equipment and labor)
- Repair loops on side streets.
- No pedestrian signal heads across Roslin Street or Dunbar Street. Consider providing pedestrian phasing with pedestrian signal heads.

Standard Item Costs

Item	Unit	cost
Signal head - 3 section one-way LED	Each	$1,000
3 section one-way programmable signal heads	Each	$2,000
Pedestrian signal head	Each	$1,500
8 Feet signal post & Foundation	Each	$2,500
Push Button and sign Assembly	Each	$500
Pullbox 12"X12" SD 2.031	Each	$750
Wiring & testing signal cable	per foot	$5
Wiring & testing pedestrian cable	per foot	$6
Existing Controller reprogramming	Each	$1,500
Remove & Stack signal post	Each	$200
Remove & Stack signal heads	Each	$200
Right turn Arrow Pav Marking	15.8 Sq Ft	$79
Left turn Arrow Pav Marking	15.8 Sq Ft	$79
Through Arrow Pav Marking	15.8 Sq Ft	$79
Through-Right Pav Marking	28.1 Sq Ft	$141
ONLY Pav Marking	29.6 sq ft	$148
6"Reflectorized White Line (Thermoplastic)	1 ft	$1
6"Reflectorized Yellow Line (Thermoplastic)	1 ft	$1
R3-2 No Left/Right Turn sign	36'X36' = 9 sq ft	$99
R3-8 lane use Regulatory sign	30'X30' = 6.25 sq ft	$69
R3-5 Mandatory lane use Regulatory sign	30"x36" = 7.5 sq ft	$83
R3-7 Right Lane Must turn Right sign	36"x36" = 9 sq ft	$99
R10-12 Left Turn yield on Green ball sign	30"x36" = 7.5 sq ft	$83
R5-1 DO NOT ENTER sign	30"x30" = 6.25 sq ft	$69
R6-1 ONE-WAY sign	36"x12" = 3 sq ft	$33
R3-2 NO LEFT TURN sign	24"x24" = 4 sq ft	$44
R1-1 STOP sign	30"x30" = 6.25 sq ft	$69

Note - signs were assumed to be $300 each for the sign plate, post, installation etc.

4 DW Controller	Each	$9,920
Rack Mounted Loop Amplifiers	Each	$94
Remove & Stack Cabinet Assembly	Each	$2,000
Install 4 DW Controller	Each	$3,500
Special Duty Police	Hour	$37
8 DW Controller	Each	$11,200
Install 8 DW Controller	Each	$5,500
8 DW Controller with closed loop master	Each	$14,700
4 DW Controller - Total		$15,904
8 DW Controller - Total		$19,668
8 DW Controller with Master - Total		$23,168

Appendix F

Benefit-Cost Analysis – Work Order #6

DATA

Data from Network MOE Summary Tables Submitted in Recommendations Technical memorandum

	AM Peak Hour		Midday Peak Hour		PM Peak Hour		Difference	% Difference
	Existing	Improved	Existing	Improved	Existing	Improved		
Total Delay (Hr.)	184	150	124	116	261	167	**136**	23.9%
Stops/Vehicle	0.69	0.61	0.69	0.58	0.73	0.68		
Average Speed (mph)	8	9	10	10	7	9		
Fuel Consumed (gal)	257	228	206	195	332	262	**110**	13.8%
Fuel Economy (mpg)	7.8	8.8	9.3	9.8	7.0	8.9		
CO Emissions (Kg)	17.99	15.93	14.38	13.61	23.21	18.33	**7.71**	13.9%
NOx Emissions (Kg)	3.5	3.1	2.8	2.65	4.52	3.57	**1.5**	13.9%
VOC Emissions (Kg)	4.17	3.69	3.33	3.15	5.38	4.25	**1.79**	13.9%

Truck Percentages

Location	AM	MD	PM	Average
Blue Hill Avenue at Washington Street	9.3%	5.1%	7.6%	7.3%
Blue Hill Avenue at Warren Street	8.2%	5.5%	4.4%	6.0%
Blue Hill Avenue at Intervale Street	8.6%	6.2%	4.4%	6.4%
Blue Hill Avenue at Quincy Street	6.5%	4.4%	2.6%	4.5%
Blue Hill Avenue at Alaska Street/ W. Cottage Street	5.6%	4.5%	4.4%	4.8%
Blue Hill Avenue at Moreland Street	6.5%	6.1%	5.2%	5.9%
Blue Hill Avenue at Dudley Street / Magazine Street	8.4%	7.4%	6.1%	7.3%
Average				**6.0%**

DATA (Continued)

Crash Data

	Location (BTD Intersection Numbers)								
Severity	**190**	**189**	**1437**	**394**	**1486**	**1729**	**306**	**Total**	**Per Year**
Property Damage	4	2	3	7	0	3	1	20	**7**
Personal Injury	6	4	2	4	2	3	7	28	**9**
Fatality	0	0	0	0	0	0	0	0	**0**
Other	4	2	1	8	0	1	2	18	**6**
Total	14	8	6	19	2	7	10	66	**22**

Benefits Performance Measures values

Category	Performance Measures	Unit of measure	Value per unit in 2009 dollars	Value per unit in 2012 dollars
Delay	Intersection Delay	Person Hours (Cars)	$16.09	$17.22
	Intersection Delay	Person Hours (Trucks)	$106.24	$113.68
Crashes	Property Damage Only (PDO) Crash	Number of Crashes	$3,165	$3,387
	Minor Injury Crash	Number of Crashes	$18,771	$20,085
	Moderate Injury Crash	Number of Crashes	$392,755	$420,248
	Severe Injury Crash	Number of Crashes	$3,003,746	$3,214,008
	Fatality Crash	Number of Crashes	$4,207,985	$4,502,544
Emissions	Carbon Monoxide (CO)	Metric ton	$138	$148
	Nitrous Oxide (Nox)	Metric ton	$7,490	$8,014
	Volatile Organic Compounds (VOC)	Metric ton	$5,682	$6,080
Energy	Fuel	Gallon	$2.64	$3.65

Consumer Price Index increased from 2009 to 2012 by 7.0%.

Hence all values are increased by 7.0% to calculate equivalent 2012 values.

BENEFIT CALCULATIONS

Calculation of Delay Reduction Per Year

Assuming
Truck Percentage: 6.0%
Vehicle Occupancy 1.25
Delay decreased by: 136 Vehicle hours per weekday

	Veh. Hours Per Day	Passenger Hours Per Day		Hours Per Year	Cost per Hour	Benefit / Year
Vehicle and Passenger Car Delay (94%)	128 hrs.	159	x 260 days/year =	**41,340**	$17.22	$711,722
Truck Delay (6%)	8 hrs.		x 260 days/year =	**2,138**	$113.68	$243,091

Calculation of Crash Reduction Per Year

Assume 8 % crash reduction factor for signal retiming

	Total Accidents	Reduction	Annual Reduction	Cost per Crash	Benefit / Year
Property Damage Accidents	7	0.08	**1.00**	$3,387	$3,387
Personal Injury Accidents	9	0.08	**1.00**	$20,085	$20,085
Fatality Accidents	0	0.08	**-**	$4,502,544	$0

Calculation of Emissions Reductions from Kilograms to Metric Tons to Annual Metric Tons

	KG per day	Metric Tons per day		Annual Reduction	Cost per Ton	Benefit / Year
CO Reduction	7.71	0.00771	x 260 days/year =	**2.0046**	$148	$296
Nox Reduction	1.5	0.0015	x 260 days/year =	**0.3900**	$8,014	$3,126
VOC Reduction	1.79	0.00179	x 260 days/year =	**0.4654**	$6,080	$2,830

Calculation of Fuel Reduction Per Year

	Gal. per day		Annual Reduction	Cost per Gal.	Benefit / Year
Fuel reduction in gallons =	110	x 260 days/year =	**28,600**	$3.65	$104,390

Benefits Summary

Category	Performance Measure	Unit	Value per Unit in 2012 $	Benefits in Appropriate Units	Benefits Value
Delay	Intersection Delay	Person Hours (Cars)	$17.22	41340	$711,722
		person Hours (Trucks)	$113.68	2138	$243,091
Crashes	Property Damage Only (PDO) Crash	Number of Crashes	$3,387	1	$3,387
	Minor Injury Crash	Number of Crashes	$20,085	1	$20,085
	Moderate Injury Crash	Number of Crashes	$420,248	0	$0
	Severe Injury Crash	Number of Crashes	$3,214,008	0	$0
	Fatality Crash	Number of Crashes	$4,502,544	0.00	$0
Emissions	Carbon Monoxide (CO)	Metric ton	$148	2.0046	$296
	Nitrous Oxide (Nox)	Metric ton	$8,014	0.3900	$3,126
	Volatile Organic Compounds (VOC)	Metric ton	$6,080	0.4654	$2,830
Energy	Fuel	Gallon	$3.65	28600	$104,390
TOTAL					**$1,088,925**

COST CALCULATIONS

Intersection Improvements Cost Calculations

Intersection	Needed Items	Cost Estimate	
Washington Street at Blue Hill Avenue	New pedestrian signal, stack old post		$5,180
	Maintenance N/A		$0
	About 100' of 6" white thermoplastic, other markings and signs		$1,435
	Maintenance, N/A		$0
Warren Street at Blue Hill Avenue	Relocate pedestrian signal		$2,760
	Long-term, N/A		$0
	Enforcement, N/A		$0
Intervale Street at Blue Hill Avenue	Add New pedestrian signal heads		$2,100
	Policy, N/A		$0
	Maintenance, N/A		$0
	New Pedestrian signal		$2,100
	New Pedestrian signal		$2,100
Quincy Street at Blue Hill Avenue		0	$0
	Relocate pedestrian signal		$2,760
	New sign		$83
W Cottage Street/ Alaska Street at Blue Hill Avenue	Maintenance, N/A		$0
	Relocate and restripe Zebra crosswalk (about 220' 6" thermo)		$220
	Maintenance, N/A		$0
Moreland Street at Blue Hill Avenue		0	$0
	Maintenance, N/A		$0
	Policy, N/A		$0
Dudley Street/ Magazine Street at Blue Hill Avenue			
	Maintenance, N/A		$0
	About 700' of 12" white thermoplastic		$1,400
Signal Equipment Cost that can be annualized over 15 years			**$17,000**
Signing and Pavement Marking Cost that can be annualized over 5 years			**$3,055**
Costs that cannot be annualized			**$0**

NOTE - Improvements considered above are based on Table 1 of Recommendations Technical memorandum

BTD Contractor Costs For implementing Signal timing and phasing improvements

7 intersections with clearance time changes (0.5 hour per intersection at $125 per hour)	$438
Travel time for Contractor (4 hours at $125 per hour)	$500
Total BTD Contractor costs =	**$938**

COST CALCULATIONS (Continued)

Engineering Costs, Signs and Pavement Marking Costs		
Engineering Fee for Work Order 6		$28,450
Signs and Pavement marking Costs		$3,055
BTD Contractor costs		$938
Sum of above costs		$32,443
Assume BTD retimes signals every 5 years		
Assume signs and pavement markings are replaced every 5 years		
Annualized Cost Per Year =P{ [i*(1+i)^n] / [(1+i)^n - 1] }		
P = Present Worth		$32,443
Assume i=7.0 (CPI)		
N = 5		
Numerator = 0.07*(1+0.07)^5 =		$0
Denominator = (1+0.07)^5 -1 =		$0
A = P *(Numerator/Denominator)		$7,912
Total Annual Engineering/Signs/Markings Cost =		**$7,910**

Signal Equipment Costs		
Signal equipment costs		$17,000
Assume signal equipment has a life time of fifteen years		
Annualized Cost Per Year =P{ [i*(1+i)^n] / [(1+i)^n - 1] }		
P= Present worth		$17,000
Assume i=7.0 (CPI)	N= 15	
Numerator = 0.07*(1+0.07)^15 =		$0
Denominator = (1+0.07)^15 -1 =		$2
A = P *(Numerator/Denominator)		$1,867
Total Annual Signal Equipment Costs =		**$1,867**

Annual Cost Summary	
Type	
Engineering/Signs/Pavement markings	$7,910
Signal Equipment	$1,867
Other Non-Annualized Costs	$0
Total	**$9,777**

BENEFIT COST RATIO CALCULATIONS

Benefit	$1,088,925	
Cost	$9,777	
Ratio	**111**	**to 1**

Improvement Costs		
Intersection	Needed Items	Cost Estimate
Washington Street at Blue Hill Avenue	New pedestrian signal, stack old post	$5,180
	Maintenance N/A	
	About 100' of 6" white thermoplastic, other markings and signs	$1,435
	Maintenance, N/A	
Warren Street at Blue Hill Avenue	Relocate pedestrian signal	$2,760
	N/A	
	Long-term, N/A	
	Enforcement, N/A	
Intervale Street at Blue Hill Avenue		
	Add New pedestrian signal heads	$2,100
	Policy, N/A	
	Maintenance, N/A	
	New Pedestrian signal	$2,100
	New Pedestrian signal	$2,100
Quincy Street at Blue Hill Avenue	Relocate pedestrian signal	$2,760
	New sign	$83
W Cottage Street/ Alaska Street at Blue Hill Avenue	Maintenance, N/A	
	Relocate and restripe Zebra crosswalk (about 220' 6" thermo)	$220
	Maintenance, N/A	
Moreland Street at Blue Hill Avenue	Maintenance, N/A	
	Policy, N/A	
Dudley Street/ Magazine Street at Blue Hill Avenue	Maintenance, N/A	
	About 700' of 12" white thermoplastic	$1,400

Signal Equipment Cost that can be annualized over 15 years	**$17,000**
Signing and Pavement Marking Cost that can be annualized over 5 years	**$3,055**
Costs that cannot be annualized	**$0**

Recommended Improvements

- Replace broken pedestrian signal heads on the median on westbound Washington Street approach. Consider relocating the pedestrian signal post to the larger median.
- Replace missing visors on signal heads for eastbound Cheney Street approach and northbound Blue Hill Avenue approach.
- Westbound Washington Street approach was observed to be regularly used as a two-lane approach. Appropriate signs and pavement markings should be provided.
- Pedestrian signals across Washington Street approach are malfunctioning. Please repair as necessary.

- At the northwest corner of the intersection, the pushbutton is located far away (more than 5 feet) from the ADA ramp. Consider providing a pedestal that is closer to the ADA ramp.
- The northbound Blue Hill Avenue approach to the intersection consists of an exclusive left-turn lane, a through lane and a shared through/right-turn lane. Just north of the intersection only one receiving lane is provided and the curb lane is used for on-street parking. Vehicles on the through/right-turn lane that continue north often were observed to be trapped behind the parked vehicles.
- Consider replacing the through/right-turn lane on the northbound approach with a right-turn only lane.
- Enforce “No Parking” zone just north of the northbound approach. Provide additional lane change distance by extending the length of the “No Parking” zone.

- Pedestrian Signal is not provided on the northeast corner of the intersection for the crosswalk across Intervale Street. Add a pedestrian signal head.
- Consider using concurrent pedestrian phase as BTD warrants for an exclusive pedestrian phase are not met at this location.
- The signal phase for Intervale Street approach was observed to be called without any vehicles on that approach. Check for broken loops or incorrect controller settings.
- The LED hand symbol on the pedestrian signal located on the southwest corner was not being displayed completely. Replace the LED panel.
- The LED panel on the pedestrian signal located on the southeast corner does not work (Blacked out). Replace the LED panel.

- The pedestrian pushbuttons are located more than 5' away from the ADA ramp at the northeast and southwest corners of the intersection. Relocate to be closer to the ADA ramp if possible.
- Replace the damaged “NO TURN ON RED” sign located on the southeast corner of the intersection.

- Replace missing visor on the southwest corner signal head (visor on green ball).
- The ADA ramp on the northwest corner of the intersection has an adjacent catch basin. Restripe crosswalk markings to better align with the ADA ramp.
- Pedestrian button in the northeast corner of the intersection was not working. Repair as necessary.

- Replace missing visors on signal heads located on northwest and southeast corners of the intersection.
- Consider using concurrent pedestrian phase as BTD warrants for an exclusive pedestrian phase are not met at this location.

- During field observations few Citizens complained that the pedestrian signals were not working at this intersection. Walk and Don’t walk symbols were displayed simultaneously. Flashing don’t walk phase was not displayed on some of the signal heads.
- Designated lane markings are not provided on the Blue Hill Avenue and Dudley street approaches. Drivers were observed to use the available road space per their needs. At times, Dudley Street southbound approach was observed to be used as three lanes. Provide lane markings and signs.

Standard Item Costs

Item	Unit	cost
Signal head - 3 section one-way LED	Each	$1,000
3 section one-way programmable signal heads	Each	$2,000
Pedestrian signal head	Each	$1,500
8 Feet signal post & Foundation	Each	$2,500
Push Button and sign Assembly	Each	$500
Pull box 12"X12" SD 2.031	Each	$750
Wiring & testing signal cable	per foot	$5
Wiring & testing pedestrian cable	per foot	$6
Existing Controller reprogramming	Each	$1,500
Remove & Stack signal post	Each	$200
Remove & Stack signal heads	Each	$200
Right turn Arrow Pav Marking	15.8 Sq Ft	$79
Left turn Arrow Pav Marking	15.8 Sq Ft	$79
Through Arrow Pav Marking	15.8 Sq Ft	$79
Through-Right Pav Marking	28.1 Sq Ft	$141
ONLY Pav Marking	29.6 sq ft	$148
6"Reflectorized White Line (Thermoplastic)	1 ft	$1
6"Reflectorized Yellow Line (Thermoplastic)	1 ft	$1
R3-2 No Left/Right Turn sign	36'X36' = 9 sq ft	$99
R3-8 lane use Regulatory sign	30'X30' = 6.25 sq ft	$69
R3-5 Mandatory lane use Regulatory sign	30"x36" = 7.5 sq ft	$83
R3-7 Right Lane Must turn Right sign	36"x36" = 9 sq ft	$99
R10-12 Left Turn yield on Green ball sign	30"x36" = 7.5 sq ft	$83
R5-1 DO NOT ENTER sign	30"x30" = 6.25 sq ft	$69
R6-1 ONE-WAY sign	36"x12" = 3 sq ft	$33
R3-2 NO LEFT TURN sign	24"x24" = 4 sq ft	$44
R1-1 STOP sign	30"x30" = 6.25 sq ft	$69

Note - signs were assumed to be $300 each for the sign plate, post, installation etc. $300

Rack Mounted Loop Amplifiers	Each	$94
Remove & Stack Cabinet Assembly	Each	$2,000
Install 4 DW Controller	Each	$3,500
Special Duty Police	Hour	$37
8 DW Controller	Each	$11,200
Install 8 DW Controller	Each	$5,500
8 DW Controller with closed loop master	Each	$14,700
4 DW Controller - Total		$5,984
8 DW Controller - Total		$19,668
8 DW Controller with Master - Total		$23,168

Appendix G

Benefit Cost Analysis – Work Order #7

DATA

Data from Network MOE Summary Tables Submitted in Recommendations Technical memorandum

	AM Peak Hour		Midday Peak Hour		PM Peak Hour		Difference	% Difference
	Existing	Improved	Existing	Improved	Existing	Improved		
Total Delay (Hr.)	164	138	81	85	164	162	**24**	5.9%
Stops/Vehicle	0.58	0.45	0.50	0.42	0.57	0.43		
Average Speed (mph)	13	14	17	17	14	15		
Fuel Consumed (gal)	343	312	236	235	383	366	**49**	5.1%
Fuel Economy (mpg)	10.1	11.6	12.2	12.9	10.8	11.8		
CO Emissions (Kg)	23.97	21.83	16.51	16.4	26.74	25.61	**3.38**	5.0%
NOx Emissions (Kg)	4.66	4.25	3.21	3.19	5.2	4.98	**0.65**	5.0%
VOC Emissions (Kg)	5.56	5.06	3.83	3.8	6.2	5.94	**0.79**	5.1%

Truck Percentages

Location	AM	MD	PM	Average
Spring Street at Gould Street/V.A. Hopsital Driveway	6.3%	5.1%	2.6%	4.7%
Centre Street at Spring Street/Temple Street	5.3%	5.9%	2.2%	4.5%
Centre Street at Lorette Street/St. Theresa Avenue	4.8%	4.9%	2.0%	3.9%
Centre Street at LaGrange Street	4.7%	4.8%	2.2%	3.9%
Centre Street Mt. Vernon Street	8.3%	4.0%	3.0%	5.1%
Centre Street at Bellevue Street/Bird Place	6.6%	4.1%	2.8%	4.5%
Centre Street at Park Street	7.0%	4.9%	3.2%	5.0%
Centre Street at Corey Street	6.5%	4.2%	2.5%	4.4%
Centre Street at Willow Street	6.2%	4.2%	2.7%	4.4%
Centre Street at Belgrade Avenue	5.9%	4.8%	2.5%	4.4%
Washington Street at West Boundary Road	6.2%	4.4%	3.3%	4.6%
Washington Street at Rockingham Road	6.6%	4.4%	4.0%	5.0%
Washington Street at Grove Street	7.0%	6.6%	2.3%	5.3%
Washington Street at Rockland Street	6.6%	6.0%	2.6%	5.1%
Average				**4.6%**

DATA (Continued)

Crash Data

	Location (BTD Intersection Numbers)															
Severity	**714**	**275**	**620**	**261**	**1779**	**1086**	**1687**	**272**	**1493**	**260**	**1051**	**1003**	**256**	**2335**	**Total**	**Per Year**
Property Damage	1	4	2	7	2	0	1	3	2	5	1	0	3	0	31	**10**
Personal Injury	0	2	0	8	1	0	0	3	2	0	1	0	3	0	20	**7**
Fatality	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	**0**
Other	1	2	1	2	1	1	0	2	1	0	2	1	3	2	19	**6**
Total	2	8	3	17	4	1	1	8	5	5	5	1	9	2	71	**24**

Benefits Performance Measures values

Category	Performance Measures	Unit of measure	Value per unit in 2009 dollars	Value per unit in 2012 dollars
Delay	Intersection Delay	Person Hours (Cars)	$16.09	$17.22
	Intersection Delay	Person Hours (Trucks)	$106.24	$113.68
Crashes	Property Damage Only (PDO) Crash	Number of Crashes	$3,165	$3,387
	Minor Injury Crash	Number of Crashes	$18,771	$20,085
	Moderate Injury Crash	Number of Crashes	$392,755	$420,248
	Severe Injury Crash	Number of Crashes	$3,003,746	$3,214,008
	Fatality Crash	Number of Crashes	$4,207,985	$4,502,544
Emissions	Carbon Monoxide (CO)	Metric ton	$138	$148
	Nitrous Oxide (Nox)	Metric ton	$7,490	$8,014
	Volatile Organic Compounds (VOC)	Metric ton	$5,682	$6,080
Energy	Fuel	Gallon	$2.64	$3.65

Consumer Price Index increased from 2009 to 2012 by 7.0%.

Hence all values are increased by 7.0% to calculate equivalent 2012 values.

BENEFIT CALCULATIONS

Calculation of Delay Reduction Per Year

Assuming

Truck Percentage: 4.6%

Vehicle Occupancy 1.25

Delay decreased by: 24 Vehicle hours per weekday

	Veh. Hours Per Day	Passenger Hours Per Day		Hours Per Year	Cost per Hour	Benefit / Year
Vehicle and Passenger Car Delay (95%)	23 hrs.	28	x 260 days/year =	**7,280**	$17.22	$125,335
Truck Delay (5%)	1 hrs.		x 260 days/year =	**289**	$113.68	$32,799

Calculation of Crash Reduction Per Year

Assume 8 % crash reduction factor for signal retiming

	Total Accidents	Reduction	Annual Reduction	Cost per Crash	Benefit / Year
Property Damage Accidents	10	0.08	**0.83**	$3,387	$2,800
Personal Injury Accidents	7	0.08	**0.53**	$20,085	$10,712
Fatality Accidents*	0	0.08	**-**	$4,502,544	$0

* NOTE- Since signal retiming is not likely to influence occurance of fatalities, fatal crashes were not included in benefit calcualtions. This presents a conservative scenario

Calculation of Emissions Reductions from Kilograms to Metric Tons to Annual Metric Tons

	KG per day	Metric Tons per day		Annual Reduction	Cost per Ton	Benefit / Year
CO Reduction	3.38	0.00338	x 260 days/year =	**0.8788**	$148	$130
Nox Reduction	0.65	0.00065	x 260 days/year =	**0.1690**	$8,014	$1,354
VOC Reduction	0.79	0.00079	x 260 days/year =	**0.2054**	$6,080	$1,249

Calculation of Fuel Reduction Per Year

	Gal. per day		Annual Reduction	Cost per Gal.	Benefit / Year
Fuel reduction in gallons =	49	x 260 days/year =	**12,740**	$3.65	$46,501

Benefits Summary

Category	Performance Measure	Unit	Value per Unit in 2012 $	Benefits in Appropriate Units	Benefits Value
Delay	Intersection Delay	Person Hours (Cars)	$17.22	7280	$125,335
		person Hours (Trucks)	$113.68	289	$32,799
Crashes	Property Damage Only (PDO) Crash	Number of Crashes	$3,387	1	$3,387
	Minor Injury Crash	Number of Crashes	$20,085	1	$20,085
	Moderate Injury Crash	Number of Crashes	$420,248	0	$0
	Severe Injury Crash	Number of Crashes	$3,214,008	0	$0
	Fatality Crash	Number of Crashes	$4,502,544	0.00	$0
Emissions	Carbon Monoxide (CO)	Metric ton	$148	0.8788	$130
	Nitrous Oxide (Nox)	Metric ton	$8,014	0.1690	$1,354
	Volatile Organic Compounds (VOC)	Metric ton	$6,080	0.2054	$1,249
Energy	Fuel	Gallon	$3.65	12740	$46,501
TOTAL					**$230,839**

COST CALCULATIONS

Intersection Improvements Cost Calculations

Intersection	Needed Items	Cost Estimate
Spring Street at Gould Street/V.A. Hopsital Driveway	Remove 8" heads and replace with 12" heads	$1,800
	Restripe Zebra Crosswalk (about 550' 6" thermo)	$550
	Maintenance, N/A	$0
Centre Street at Spring Street/Temple Street	Maintenance, N/A	$0
	Restripe Zebra Crosswalk (about 1000' 6" thermo) Stop Bars and LT Markings	$1,427
Centre Street at Lorette Street/St. Theresa Avenue	Maintenance, N/A	$0
	Restripe Zebra Crosswalk (about 750' 6" thermo)	$750
Centre Street at Lagrange Street	Maintenance, N/A	$0
	Restripe Zebra Crosswalk (about 1200' 6" thermo)	$2,022
Centre Street at Mount Vernon Street	Maintenance, N/A	$0
	Maintenance, N/A	$0
	Restripe Crosswalks (Textured and Zebra) along with Stop Bars and "SCHOOL" marking	$800
	2 Ped signal, 2 post, 2 button, 4 pull box, say 200' wire	$0
Centre Street at Bellevue Street/Bird Street	Maintenance, N/A	$0
	Maintenance, N/A	$0
	Maintenance, N/A	$0
	2 Ped signal, 2 post, 2 button, 4 pull box, say 200' wire	$0
Centre Street at Park Street	Maintenance, N/A	$0
	Maintenance, N/A	$0
	Restripe (Textured and Zebra) and Stop Bars	$575
Centre Street at Corey Street	Restripe (Textured and Zebra) and Stop Bars	$575
Centre Street at Willow Street	N/A	$0
	Restripe Crosswalks (Textured and Zebra) along with Stop Bars and lane use markings	$1,683
Centre Street at Manthorne Road/Belgrade Avenue	Maintenance, N/A	$0
	Restripe Crosswalks (Textured and Zebra) along with Stop Bars and lane use markings	$677
Washington Street at West Boundary Road	Replace (2) 3 Section Heads with 5 Section (Doghouse) Style Signals	$4,400
	Maintenance, N/A	$0
	Maintenance, N/A	$0
	Restripe Crosswalks (Zebra) along with Stop Bars and lane use markings	$1,229
Washington Street at Rockingham Road	2 Ped signal, 2 post, 2 button, 4 pull box, say 200' wire	$0
	Maintenance, N/A	$0
	Restripe Crosswalks (Zebra) along with Stop Bars and lane use markings	$852
Washington Street at Grove Street	Maintenance, N/A	$0
	Restripe Crosswalks (Zebra) along with Stop Bars and lane use markings	$2,083
Washington Street at Rockland Street	2 Ped signal, 2 post, 2 button, 4 pull box, say 200' wire	$0
	Replace (1) 3 Section Heads with 5 Section (Doghouse) Style Signal	$2,200
	Maintenance, N/A	$0
	Restripe Crosswalks (Zebra) along with Stop Bars and lane use markings	$727
		$0
Signal Equipment Cost that can be annualized over 15 years		**$8,400**
Signing and Pavement Marking Cost that can be annualized over 5 years		**$13,950**
Costs that cannot be annualized		**$0**

NOTE - Improvements considered above are based on Table 1 of Recommendations Technical memorandum

BTD Contractor Costs For implementing Signal timing and phasing improvements	
14 intersections with clearance time changes (0.5 hour per intersection at $125 per hour)	$875
Travel time for Contractor (4 hours at $125 per hour)	$500
Signal head changes at intersectons of Washington St with Rockland St & W Boundary St	$5,000
Total BTD Contractor costs =	**$6,375**

COST CALCULATIONS (Continued)

Engineering Costs, Signs and Pavement Marking Costs		
Engineering Fee for Work Order 7		$51,500
Signs and Pavement marking Costs		$13,950
BTD Contractor costs		$6,375
Sum of above costs		$71,825
Assume BTD retimes signals every 5 years		
Assume signs and pavement markings are replaced every 5 years		
Annualized Cost Per Year =P{ [i*(1+i)^n] / [(1+i)^n - 1] }		
P = Present Worth		$71,825
Assume i=7.0 (CPI)		
N = 5		
Numerator = 0.07*(1+0.07)^5 =		$0
Denominator = (1+0.07)^5 -1 =		$0
A = P *(Numerator/Denominator)		$17,517
Total Annual Engineering/Signs/Markings Cost =		**$17,520**

Signal Equipment Costs		
Signal equipment costs		$8,400
Assume signal equipment has a life time of fifteen years		
Annualized Cost Per Year =P{ [i*(1+i)^n] / [(1+i)^n - 1] }		
P= Present worth		$8,400
Assume i=7.0 (CPI)	N= 15	
Numerator = 0.07*(1+0.07)^15 =		$0
Denominator = (1+0.07)^15 -1 =		$2
A = P *(Numerator/Denominator)		$922
Total Annual Signal Equipment Costs =		**$922**

Annual Cost Summary	
Type	
Engineering/Signs/Pavement markings	$17,520
Signal Equipment	$922
Other Non-Annualized Costs	$0
Total	**$18,442**

BENEFIT COST RATIO CALCULATIONS

Benefit	$230,839	
Cost	$18,442	
Ratio	**13**	**to 1**

Improvement Costs		
Intersection	Needed Items	Cost Estimate
Spring Street at Gould Street/V.A. Hopsital Driveway	Remove 8" heads and replace with 12" heads	$1,800
	Restripe Zebra Crosswalks (about 550' of 6" white thermo)	$550
	Maintenance, N/A	
Centre Street at Spring Street/Temple Street	Maintenance, N/A	
	Restripe Zebra Crosswalks (about 1000' of 6" white thermo) plus Stop Bars (about 100' of 12" white thermo) and LT Markings	$1,427
Centre Street at Lorette Street/St. Theresa Avenue	Maintenance, N/A	
	Restripe Zebra Crosswalks (about 750' of 6" white thermo)	$750
Centre Street at Lagrange Street	Maintenance, N/A	
	Restripe Zebra Crosswalks (about 1000' of 6" white thermo) plus Stop Bars (about 100' of 12" white thermo) and lane use markings	$2,022
Centre Street at Mount Vernon Street	Maintenance, N/A	
	Maintenance, N/A	
	Restripe Crosswalks (about 300' of white thermo Textured and Zebra) plus Stop Bars (about 75' of 12" white thermo) and "SCHOOL"* marking	$800
	N/A	
Centre Street at Bellevue Street/Bird Street	Maintenance, N/A	
	Maintenance, N/A	
	Maintenance, N/A	
	N/A	
Centre Street at Park Street	Maintenance, N/A	
	Maintenance, N/A	
	Restripe Crosswalks (425' of 6" white thermo Textured and Zebra) plus Stop Bars (about 75' of 12" white thermo)	$575
Centre Street at Corey Street	Restripe Crosswalks (425' of 6" white thermo Textured and Zebra) plus Stop Bars (about 75' of 12" white thermo)	$575
Centre Street at Willow Street	N/A	
	Restripe Crosswalks (575' of 6" white thermo Textured and Zebra) plus Stop Bars (about 100' of 12" white thermo) and lane use markings	$1,683
Centre Street at Manthorne Road/Belgrade Avenue	Maintenance, N/A	
	Restripe Crosswalks (250' of 6" white thermo Textured and Zebra) plus Stop Bars (about 100' of 12" white thermo) and lane use markings	$677
Washington Street at West Boundary Road	Replace (2) 3 Section Heads with 5 Section (Doghouse) Style Signals	$4,400
	Maintenance, N/A	
	Maintenance, N/A	
	Restripe Crosswalks (525' of 6" white thermo Zebra) plus Stop Bars (about 125' of 12" white thermo) and lane use markings	$1,229
Washington Street at Rockingham Road	N/A	
	Maintenance, N/A	
	Restripe Crosswalks (425' of 6" white thermo Zebra) plus Stop Bars (about 100' of 12" white thermo) and lane use markings	$852
Washington Street at Grove Street	Maintenance, N/A	
	Restripe Crosswalks (Zebra) along with Stop Bars and lane use markings	$2,083
Washington Street at Rockland Street	N/A	
	Replace (1) 3 Section Heads with 5 Section (Doghouse) Style Signal	$2,200
	Maintenance, N/A	
	Restripe Crosswalks (450' of 6" white thermo Zebra) plus Stop Bars (about 55' of 12" white thermo) and lane use markings	$727

Signal Equipment Cost that can be annualized over 15 years	**$8,400**
Signing and Pavement Marking Cost that can be annualized over 5 years	**$13,950**
Costs that cannot be annualized	**$0**

***Note - Price estimate for "SCHOOL" pavement paint calculated on a per letter basis, based on "ONLY" pavement paint price structure**

Recommended Improvements

- Signal heads on VA Hospital approach and post mounted signal on northwest corner of the intersection for Spring Street NB are 8 inches. Consider replacing with 12 inch signal heads.
- Restripe crosswalk pavement markings to improve visibility.
- Visor missing from green indication on signal head 2A (Spring Street southwest approach). Consider replacing to improve visibility.
- The pedestrian signal across the Spring Street northeast approach on the east side of the road appeared to be malfunctioning (WALK and DON'T WALK indications come up simultaneously). Repair to eliminate pedestrian confusion and impro
- Crosswalks and some pavement marking are faded. Consider restriping to improve visibility.
- Backplate bent on Centre Street southwest leftmost signal on mast arm. Consider repairing.
- Crosswalks are faded. Consider restriping to improve visibility.
- Some LEDs not working on green indications on Centre Street northeast bound and LaGrange Street westbound signal heads. Consider repairing.
- Crosswalks and pavement markings are faded. Consider restriping to improve visibility.
- Loops on Mount Vernon Street may be broken. Consider repairing (or installing, if not built as shown on plans) to prevent this phase from being called when no vehicles are present.

- Wheelchair ramp at northwest corner of the intersection is in poor condition. Consider repairing to improve accessibility.
- Pavement markings and crosswalks are faded. Consider restriping to improve visibility.
- No pedestrian push buttons or signal heads across Mount Vernon Street. Consider providing pedestrian phasing with pedestrian signal heads across side street.
- Loops on Bird Place and Bellevue Street may be broken. Consider repairing (or installing, if not built as shown on plans) to prevent this phase from being called when no vehicles are present.
- Countdown does not work on pedestrian signal at northeast corner of intersection (crossing Centre Street). Consider repairing.
- Foliage blocking Bellevue Street bracket-mounted westbound signal at southwest corner of intersection. Consider trimming back foliage to improve visibility.
- No pedestrian push buttons or signal heads across Bird Place. Consider providing pedestrian phasing with pedestrian signal heads across side street.
- Countdown on Park Street eastbound pedestrian signal at northwest corner of the intersection is malfunctioning (countdown is stuck on 8). Consider repairing to reduce pedestrian confusion and safety.
- DON'T WALK indication is malfunctioning on pedestrian signal across Park Street at northeast corner of intersection. Consider repairing to reduce pedestrian confusion and safety.
- Crosswalks and pavement markings beginning to fade. Consider restriping to improve visibility.
- Pavement markings and crosswalks faded. Consider restriping to improve visibility.
- Parking on Willow Street southbound extends over loop, so if vehicles are parked too close to the intersection the phase is called every cycle. Consider restricting parking at least one car length back from loops to prevent phase from being ca
- Crosswalks and some pavement markings faded. Consider restriping to improve visibility.
- Flashing and solid DON'T WALK indications do not work on pedestrian signal across Manthorne Road at northwest corner of intersection (countdown still works). Consider repairing to reduce pedestrian confusion and safety.
- Crosswalks and pavement markings beginning to fade. Consider restriping to improve visibility.
- Replace 3-section left turn signal heads on Washington Street SWB and NEB with 5-section doghouse signal heads.
- Loops on West Boundary Road and driveway may be broken. Consider repairing (or installing, if not built as shown on plans) to prevent this phase from being called when no vehicles are present.
- Broken signal post base in center of Washington Street southwest bound median. Consider removing or repairing (if there is supposed to be a pedestrian push button in that location).
- Crosswalks and pavement markings faded. Consider restriping to improve visibility.
- No pedestrian push buttons or signal heads across Rockingham Road. Consider providing pedestrian phasing with pedestrian signal heads across side street.
- Loops on Rockingham Road may be broken. Consider repairing (or installing, if not built as shown on plans) to prevent this phase from being called when no vehicles are present.
- Crosswalks and pavement markings starting to fade, especially on Washington Street southwest approach. Consider restriping to improve visibility.

- Loops on Washington Street southwest left turn pocket and Grove Street may be broken. Consider repairing (or installing, if not built as shown on plans) to prevent this phase from being called when no vehicles are present.
- Crosswalks and pavement markings faded. Consider restriping to improve visibility.
- No pedestrian push buttons or signal heads across Rockland Street. Consider providing pedestrian phasing with pedestrian signal heads across side street.
- Replace 3-section left turn signal heads on Washington Street SWB with 5-section doghouse signal heads
- Loops on Rockland Street may be broken. Consider repairing (or installing, if not built as shown on plans) to prevent this phase from being called when no vehicles are present.
- Crosswalks and pavement markings faded. Consider restriping to improve visibility.

Standard Item Costs

Item	Unit	cost
Signal head - 3 section one-way LED	Each	$1,000
3 section one-way programmable signal heads	Each	$2,000
Pedestrian signal head	Each	$1,500
8 Feet signal post & Foundation	Each	$2,500
Push Button and sign Assembly	Each	$500
Pullbox 12"X12" SD 2.031	Each	$750
Wiring & testing signal cable	per foot	$5
Wiring & testing pedestrian cable	per foot	$6
Existing Controller reprogramming	Each	$1,500
Remove & Stack signal post	Each	$200
Remove & Stack signal heads	Each	$200
Right turn Arrow Pav Marking	15.8 Sq Ft	$79
Left turn Arrow Pav Marking	15.8 Sq Ft	$79
Through Arrow Pav Marking	15.8 Sq Ft	$79
Through-Right Pav Marking	28.1 Sq Ft	$141
ONLY Pav Marking	29.6 sq ft	$148
6"Reflectorized White Line (Thermoplastic)	1 ft	$1
6"Reflectorized Yellow Line (Thermoplastic)	1 ft	$1
R3-2 No Left/Right Turn sign	36'X36' = 9 sq ft	$99
R3-8 lane use Regulatory sign	30'X30' = 6.25 sq ft	$69
R3-5 Mandatory lane use Regulatory sign	30"x36" = 7.5 sq ft	$83
R3-7 Right Lane Must turn Right sign	36"x36" = 9 sq ft	$99
R10-12 Left Turn yield on Green ball sign	30"x36" = 7.5 sq ft	$83
R5-1 DO NOT ENTER sign	30"x30" = 6.25 sq ft	$69
R6-1 ONE-WAY sign	36"x12" = 3 sq ft	$33
R3-2 NO LEFT TURN sign	24"x24" = 4 sq ft	$44
R1-1 STOP sign	30"x30" = 6.25 sq ft	$69

Note - signs were assumed to be $300 each for the sign plate, post, installation etc.

Rack Mounted Loop Amplifiers	Each	$94
Remove & Stack Cabinet Assembly	Each	$2,000
Install 4 DW Controller	Each	$3,500
Special Duty Police	Hour	$37
8 DW Controller	Each	$11,200
Install 8 DW Controller	Each	$5,500
8 DW Controller with closed loop master	Each	$14,700
4 DW Controller - Total		$5,984
8 DW Controller - Total		$19,668
8 DW Controller with Master - Total		$23,168

Appendix H

Benefit Cost Analysis – Work Order #8

DATA

Data from Network MOE Summary Tables Submitted in Recommendations Technical memorandum

	AM Peak Hour		Midday Peak Hour		PM Peak Hour		Difference	% Difference
	Existing	Improved	Existing	Improved	Existing	Improved		
Total Delay (Hr.)	175	155	55	50	168	133	**60**	15.1%
Stops/Vehicle	0.58	0.47	0.43	0.49	0.58	0.53		
Average Speed (mph)	7	7	13	12	7	9		
Fuel Consumed (gal)	240	220	117	112	244	213	**56**	9.3%
Fuel Economy (mpg)	6.2	7.1	10.1	10.0	6.7	7.7		
CO Emissions (Kg)	16.75	15.39	8.19	7.86	17.06	14.87	**3.88**	9.2%
NOx Emissions (Kg)	3.26	2.99	1.59	1.53	3.32	2.89	**0.76**	9.3%
VOC Emissions (Kg)	3.88	3.57	1.9	1.82	3.95	3.45	**0.89**	9.1%

Truck Percentages

Location	AM	MD	PM	Average
Washington Street at New Washington Street/South Street/	6.3%	5.6%	4.3%	5.4%
Washington Street at South Street/Forest Hill MBTA Bus Exit	6.5%	6.6%	5.4%	6.2%
Washington Street at Forest Hill MBTA Bus Entrance	9.4%	8.2%	8.4%	8.7%
Washington Street at Ukraine Way	10.0%	7.1%	7.8%	8.3%
Washington Street at New Washington Street/Morton Stree	8.5%	8.9%	4.3%	7.2%
Hyde Park Avenue at MBTA Bus Entrance	11.2%	9.3%	6.0%	8.8%
Hyde Park Avenue at MBTA Bus Exit /Tower Street	11.2%	8.9%	5.5%	8.5%
Hyde Park Avenue at Ukraine Way	6.9%	6.0%	3.2%	5.4%
Average				**7.3%**

DATA (Continued)

Crash Data

	Location (BTD Intersection Numbers)									
Severity	**2163**	**253**	**1712**	**2272**	**2164**	**2303**	**1759**	**2162**	**Total**	**Per Year**
Property Damage	4	3	0	4	3	0	1	1	16	**5**
Personal Injury	2	4	0	2	7	0	1	1	17	**6**
Fatality	0	0	0	0	0	0	0	0	0	**0**
Other	1	2	0	2	3	0	1	2	11	**4**
Total	7	9	0	8	13	0	3	4	44	**15**

Benefits Performance Measures values

Category	Performance Measures	Unit of measure	Value per unit in 2009 dollars	Value per unit in 2012 dollars
Delay	Intersection Delay	Person Hours (Cars)	$16.09	$17.22
	Intersection Delay	Person Hours (Trucks)	$106.24	$113.68
Crashes	Property Damage Only (PDO) Crash	Number of Crashes	$3,165	$3,387
	Minor Injury Crash	Number of Crashes	$18,771	$20,085
	Moderate Injury Crash	Number of Crashes	$392,755	$420,248
	Severe Injury Crash	Number of Crashes	$3,003,746	$3,214,008
	Fatality Crash	Number of Crashes	$4,207,985	$4,502,544
Emissions	Carbon Monoxide (CO)	Metric ton	$138	$148
	Nitrous Oxide (Nox)	Metric ton	$7,490	$8,014
	Volatile Organic Compounds (VOC)	Metric ton	$5,682	$6,080
Energy	Fuel	Gallon	$2.64	$3.65

Consumer Price Index increased from 2009 to 2012 by 7.0%.

Hence all values are increased by 7.0% to calculate equivalent 2012 values.

BENEFIT CALCULATIONS

Calculation of Delay Reduction Per Year

Assuming

Truck Percentage: 7.3%

Vehicle Occupancy 1.25

Delay decreased by: 60 Vehicle hours per weekday

	Veh. Hours Per Day	Passenger Hours Per Day		Hours Per Year	Cost per Hour	Benefit / Year
Vehicle and Passenger Car Delay (93%)	56 hrs.	69	x 260 days/year =	**17,940**	$17.22	$308,860
Truck Delay (7%)	4 hrs.		x 260 days/year =	**1,141**	$113.68	$129,677

Calculation of Crash Reduction Per Year

Assume 8 % crash reduction factor for signal retiming

	Total Accidents	Reduction	Annual Reduction	Cost per Crash	Benefit / Year
Property Damage Accidents	5	0.08	**1.00**	$3,387	$3,387
Personal Injury Accidents	6	0.08	**1.00**	$20,085	$20,085
Fatality Accidents	0	0.08	**-**	$4,502,544	$0

Calculation of Emissions Reductions from Kilograms to Metric Tons to Annual Metric Tons

	KG per day	Metric Tons per day		Annual Reduction	Cost per Ton	Benefit / Year
CO Reduction	3.88	0.00388	x 260 days/year =	**1.0088**	$148	$149
Nox Reduction	0.76	0.00076	x 260 days/year =	**0.1976**	$8,014	$1,584
VOC Reduction	0.89	0.00089	x 260 days/year =	**0.2314**	$6,080	$1,407

Calculation of Fuel Reduction Per Year

	Gal. per day		Annual Reduction	Cost per Gal.	Benefit / Year
Fuel reduction in gallons =	56	x 260 days/year =	**14,560**	$3.65	$53,144

Benefits Summary

Category	Performance Measure	Unit	Value per Unit in 2012 $	Benefits in Appropriate Units	Benefits Value
Delay	Intersection Delay	Person Hours (Cars)	$17.22	17940	$308,860
		person Hours (Trucks)	$113.68	1141	$129,677
Crashes	Property Damage Only (PDO) Crash	Number of Crashes	$3,387	1	$3,387
	Minor Injury Crash	Number of Crashes	$20,085	1	$20,085
	Moderate Injury Crash	Number of Crashes	$420,248	0	$0
	Severe Injury Crash	Number of Crashes	$3,214,008	0	$0
	Fatality Crash	Number of Crashes	$4,502,544	0.00	$0
Emissions	Carbon Monoxide (CO)	Metric ton	$148	1.0088	$149
	Nitrous Oxide (Nox)	Metric ton	$8,014	0.1976	$1,584
	Volatile Organic Compounds (VOC)	Metric ton	$6,080	0.2314	$1,407
Energy	Fuel	Gallon	$3.65	14560	$53,144
TOTAL					**$518,292**

COST CALCULATIONS

Intersection Improvements Cost Calculations

Intersection	Needed Items	Cost Estimate
Washington Street at New Washington Street/Hyde Park Avenue	Restripe Zebra Crosswalks (about 750' of 6" white thermo) plus Stop Bars (about 80' of 12" v	$1,000
	Maintenance, N/A	$0
	Maintenance, N/A	$0
	Repaint lane use pavement markings	$987
	Replace missing "Route 203" portion of trailblazer sign set-up	$300
	Maintenance, N/A	$0
Washington Street at New Washington Street/South Street	Maintenance, N/A	$0
	Maintenance, N/A	$0
	Maintenance, N/A	$0
	Restripe (20 total) bicycle lane pavement marking symbols along Washington Street	$1,400
	Restripe Zebra Crosswalks (about 1075' of 6" white thermo) plus Stop Bars (about 100' of 12	$1,275
	Add pavement markings (1 LT Only, 3 Shared TH/RT, 2 Shared LT/TH) and signs (R3-5L,(3) R3	$2,730
	2 Ped signal, 2 post, 2 button, 4 pull box, say 200' wire	$14,400
	N/A	$0
New Washington Street at Pedestrian Crossing	Maintenance, N/A	$0
Washington Street at South Street/MBTA Bus Exit	Restripe Zebra Crosswalks (about 350' of 6" white thermo) plus Stop Bars (about 25' of 12" v	$400
	Maintenance, N/A	$0
	Replace Sign (Panel Only)	$300
	Replace Sign (Panel Only) BTD Sign Code R-12	$300
Washington Street at MBTA Bus Entrance	Maintenance, N/A	$0
	Maintenance, N/A	$0
Washington Street at Ukraine Way	Add lane use markings (TH arrow and TH/RT arrow	$220
	Restripe Zebra Crosswalks (about 500' of 6" white thermo) plus Stop Bars (about 75' of 12" v	$650
	Maintenance, N/A	$0
	Maintenance, N/A	$0
	Maintenance, N/A	$0
	Replace pedestrian signal head	$1,500
	Replace broken signal heads or LED boards	$1,000
Hyde Park Avenue at Ukraine Way	Maintenance, N/A	$0
	Restripe Crosswalks and add in crosswalk striping (about 750' of 6" white thermo) plus Stop	$950
	Add signal heads for overlap right turn phase	$5,000
Hyde Park Avenue at MBTA Bus Exit/Tower Street	Maintenance, N/A	$0
	Maintenance, N/A	$0
	Restripe Zebra Crosswalk (about 500' of 6" white thermo) plus Stop Bars (about 100' of 12" v	$700
	Install new sign	$300
	Maintenance, N/A	$0
Hyde Park Avenue at MBTA Bus Entrance/Parking Lot Exit	Install new sign	$300
	Maintenance, N/A	$0
	Restripe Crosswalks and add in crosswalk striping (about 425' of 6" white thermo) plus Stop	$575
	Maintenance, N/A	$0
		$0
Signal Equipment Cost that can be annualized over 15 years		**$21,900**
Signing and Pavement Marking Cost that can be annualized over 5 years		**$12,386**
Costs that cannot be annualized		**$0**

NOTE - Improvements considered above are based on Table 1 of Recommendations Technical memorandum

BTD Contractor Costs For implementing Signal timing and phasing improvements	
8 intersections with clearance time changes (0.5 hour per intersection at $125 per hour)	$500
Travel time for Contractor (4 hours at $125 per hour)	$500
BTD Contractor cost for signal phasing changes at Ukraine/Hyde Park Ave (add overlap phase)	$2,500
BTD Contractor cost for pedestrian signal phasing changes atSouth/New Washington/Washington	$2,500
Total BTD Contractor costs =	**$6,000**

COST CALCULATIONS (Continued)

Engineering Costs, Signs and Pavement Marking Costs		
Engineering Fee for Work Order 8		$29,000
Signs and Pavement marking Costs		$12,386
BTD Contractor costs		$6,000
Sum of above costs		$47,386
Assume BTD retimes signals every 5 years		
Assume signs and pavement markings are replaced every 5 years		
Annualized Cost Per Year =P{ [i*(1+i)^n] / [(1+i)^n - 1] }		
P = Present Worth		$47,386
Assume i=7.0 (CPI)		
N = 5		
Numerator = 0.07*(1+0.07)^5 =		$0
Denominator = (1+0.07)^5 -1 =		$0
A = P *(Numerator/Denominator)		$11,557
Total Annual Engineering/Signs/Markings Cost =		**$11,560**

Signal Equipment Costs		
Signal equipment costs		$21,900
Assume signal equipment has a life time of fifteen years		
Annualized Cost Per Year =P{ [i*(1+i)^n] / [(1+i)^n - 1] }		
P= Present worth		$21,900
Assume i=7.0 (CPI)	N= 15	
Numerator = 0.07*(1+0.07)^15 =		$0
Denominator = (1+0.07)^15 -1 =		$2
A = P *(Numerator/Denominator)		$2,405
Total Annual Signal Equipment Costs =		**$2,405**

Annual Cost Summary	
Type	
Engineering/Signs/Pavement markings	$11,560
Signal Equipment	$2,405
Other Non-Annualized Costs	$0
Total	**$13,965**

BENEFIT COST RATIO CALCULATIONS

Benefit	$518,292	
Cost	$13,965	
Ratio		**37 to 1**

Improvement Costs		
Intersection	Needed Items	Cost Estimate
Washington Street at New Washington Street/Hyde Park Avenue	Restripe Zebra Crosswalks (about 750' of 6" white thermo) plus Stop Bars (about 125' of 12" white thermo)	$1,000
	Maintenance, N/A	
	Maintenance, N/A	
	Repaint lane use pavement markings	$987
	Replace missing "Route 203" portion of trailblazer sign set-up	$300
	Maintenance, N/A	
Washington Street at New Washington Street/South Street	Maintenance, N/A	
	Maintenance, N/A	
	Maintenance, N/A	
	Restripe (20 total) bicycle lane pavement marking symbols along Washington Street	$1,400
	Restripe Zebra Crosswalks (about 1075' of 6" white thermo) plus Stop Bars (about 100' of 12" white thermo)	$1,275
	Add pavement markings (1 LT Only, 3 Shared TH/RT, 2 Shared LT/TH) and signs (R3-5L,(3) R3-6R, (2) R3-6L)	$2,730
	2 Ped signal, 2 post, 2 button, 4 pull box, say 200' wire	$14,400
	N/A	
New Washington Street at Pedestrian Crossing	Maintenance, N/A	
Washington Street at South Street/MBTA Bus Exit	Restripe Zebra Crosswalks (about 350' of 6" white thermo) plus Stop Bars (about 25' of 12" white thermo)	$400
	Maintenance, N/A	
	Replace Sign (Panel Only)	$300
	Replace Sign (Panel Only) BTD Sign Code R-12	$300
Washington Street at MBTA Bus Entrance	Maintenance, N/A	
	Maintenance, N/A	
Washington Street at Ukraine Way	Add lane use markings (TH arrow and TH/RT arrow	$220
	Restripe Zebra Crosswalks (about 500' of 6" white thermo) plus Stop Bars (about 75' of 12" white thermo)	$650
	Maintenance, N/A	
	Maintenance, N/A	
	Maintenance, N/A	
	Replace pedestrian signal head	$1,500
	Replace broken signal heads or LED boards	$1,000
Hyde Park Avenue at Ukraine Way	Maintenance, N/A	
	Restripe Crosswalks and add in crosswalk striping (about 750' of 6" white thermo) plus Stop Bars (about 100' of 12" white thermo)	$950
	Add signal heads for overlap right turn phase	$5,000
Hyde Park Avenue at MBTA Bus Exit/Tower Street	Maintenance, N/A	
	Maintenance, N/A	
	Restripe Zebra Crosswalk (about 500' of 6" white thermo) plus Stop Bars (about 100' of 12" white thermo)	$700
	Install new sign	$300
	Maintenance, N/A	
Hyde Park Avenue at MBTA Bus Entrance/Parking Lot Exit	Install new sign	$300
	Maintenance, N/A	
	Restripe Crosswalks and add in crosswalk striping (about 425' of 6" white thermo) plus Stop Bars (about 75' of 12" white thermo)	$575
	Maintenance, N/A	
Signal Equipment Cost that can be annualized over 15 years		**$21,900**
Signing and Pavement Marking Cost that can be annualized over 5 years		**$12,386**
Costs that cannot be annualized		**$0**

Recommended Improvements

- Restripe Crosswalks; most are faded to various extents.
- Adjust support for pedestal mounted signal facing Hyde Park Avenue northbound traffic. Signal has a noticeable forward lean.
- With the exception of the mast arm mounted signals facing Hyde Park Avenue/Washington Street, paint on other signal heads have faded and/or chipping. Repaint signal heads.
- Restripe pavement markings designating lane use on Washington Street, New Washington Street and Arborway off Ramp approaches.
- Replace Route number portion of “trailblazer” type sign facing Hyde Park Avenue northbound traffic. Currently it reads “ to west” and has a diagonal left arrow, but the route number portion is missing (route 203, Arborway)
- Pavement is badly rutted at this location.
- Some pavement rutting also occurs at this location.
- Replace missing visors on signal heads for New Washington Street westbound approach, Washington Street southbound approach and Washington Street northbound approach.
- Pedestal mount carrying left most signals facing Arborway eastbound off ramp traffic and New Washington Street westbound are leaning/ unstable. Replace signals and provide stable support.
- Restripe Bicycle markings and symbols on Washington Street in both directions as they are faded

- Restripe crosswalks, especially those crossing Washington Street/South Street as these are the most faded
- Add lane use pavement markings and advanced signs.
- No pedestrian signals for crosswalks across westbound Washington Street and southbound South Street. Install signals or remove crosswalk markings.
- Designate right lane on northbound Washington Street approach as right turn only and stripe accordingly or remove overlapping protected right turn. This is currently being used as a shared through/right lane. Right turning drivers often were observed t
- Repaint vehicular signal heads
- Restripe crosswalks and MBTA Bus Exit stop bar. Both are faded.
- Install visor over green indication facing MBTA Bus Exit.
- Replace “State law: do not block intersection” sign. It is in very poor condition
- Replace “Yield to pedestrians on turns” sign. Also in poor condition
- Sidewalk crossing the MBTA bus entrance on the eastern side of Washington Street is in poor condition and is not traversable for handicap individuals.
- Sidewalk on west side of Washington Street is in poor condition and narrow, with many light posts mounted within the sidewalk, making it nearly impassable for handicapped persons
- Add lane-use pavement markings on Washington Street northbound approach.
- Restripe faded crosswalks
- Pavement is in average to poor condition overall, with some rutting on both Washington Street and Ukraine Way
- Add visors to left most signal facing Ukraine Way westbound traffic
- Pedestrian push button mounted on mast arm in northeast corner of intersection does not work
- Pedestrian head facing southbound across Ukraine Way from the northeast hand indication is out. No indication of any type is shown when the phase is not in use (on same mast arm as faulty pushbutton)
- Part of the LED on signal head for Washington Street southbound left-turn arrow (5 section head) is not working.
- Some rutting is also present at this location
- Restripe faded crosswalks and stop bars
- Consider adding overlap protected right turn phasing to run along with Hyde Park Avenue northbound leading left turns
- Install visors over right most green indication on Tower Street westbound and MBTA Bus Exit eastbound approaches

- Repaint signals. Paint is very faded
- Repaint crosswalks and stop bars, as they are very worn
- Install additional “Do Not Enter: $50 Fine excluded way MBTA buses only” sign to complete the pair facing the Tower Street westbound approach
- Sidewalks are in average to poor condition especially on the MBTA bus exit and may be hard for handicapped persons to navigate
- Install additional “Do Not Enter: $50 Fine excluded way MBTA buses only”” type sign to pair with existing sign
- Repaint both signals facing parking lot exit approach. Both are extremely faded
- Repaint crosswalks and stop bars. Both are very faded
- “State Law: Do not block intersection” sign is mounted very high on mast arm support. Adjust sign mounting height.

Standard Item Costs

Item	Unit	cost
Signal head - 3 section one-way LED	Each	$1,000
3 section one-way programmable signal heads	Each	$2,000
Pedestrian signal head	Each	$1,500
8 Feet signal post & Foundation	Each	$2,500
Push Button and sign Assembly	Each	$500
Pullbox 12"X12" SD 2.031	Each	$750
Wiring & testing signal cable	per foot	$5
Wiring & testing pedestrian cable	per foot	$6
Existing Controller reprogramming	Each	$1,500
Remove & Stack signal post	Each	$200
Remove & Stack signal heads	Each	$200
Right turn Arrow Pav Marking	15.8 Sq Ft	$79
Left turn Arrow Pav Marking	15.8 Sq Ft	$79
Through Arrow Pav Marking	15.8 Sq Ft	$79
Left-Through Pav Marking	28.1 Sq Ft	$141
Through-Right Pav Marking	28.1 Sq Ft	$141
ONLY Pav Marking	29.6 sq ft	$148
Bicycle Lane Pav Marking	Each	$70
6"Reflectorized White Line (Thermoplastic)	1 ft	$1
6"Reflectorized Yellow Line (Thermoplastic)	1 ft	$1
R3-2 No Left/Right Turn sign	36'X36' = 9 sq ft	$99
R3-8 lane use Regulatory sign	30'X30' = 6.25 sq ft	$69
R3-5 Mandatory lane use Regulatory sign	30"x36" = 7.5 sq ft	$83
R3-6 Mandatory lane use Regulatory sign	30"x36" = 7.5 sq ft	$83
R3-7 Right Lane Must turn Right sign	36"x36" = 9 sq ft	$99
R10-12 Left Turn yield on Green ball sign	30"x36" = 7.5 sq ft	$83
R5-1 DO NOT ENTER sign	30"x30" = 6.25 sq ft	$69
R6-1 ONE-WAY sign	36"x12" = 3 sq ft	$33
R3-2 NO LEFT TURN sign	24"x24" = 4 sq ft	$44
R1-1 STOP sign	30"x30" = 6.25 sq ft	$69
M1-5 "203" Route Sign	30"x24"= 5 sq ft	$100

Note - signs were assumed to be $300 each for the sign plate, post, installation etc. $300

Rack Mounted Loop Amplifiers	Each	$94
Remove & Stack Cabinet Assembly	Each	$2,000
Install 4 DW Controller	Each	$3,500
Special Duty Police	Hour	$37
8 DW Controller	Each	$11,200
Install 8 DW Controller	Each	$5,500
8 DW Controller with closed loop master	Each	$14,700
4 DW Controller - Total		$5,984
8 DW Controller - Total		$19,668
8 DW Controller with Master - Total		$23,168

Appendix I

Benefit Cost Analysis – Work Order #9

DATA

Data from Network MOE Summary Tables Submitted in Recommendations Technical memorandum

	AM Peak Hour		Midday Peak Hour		PM Peak Hour		Difference	%
	Existing	Improved	Existing	Improved	Existing	Improved		Difference
Total Delay (Hr.)	181	102	82	67	144	85	**153**	37.6%
Stops/Vehicle	0.39	0.49	0.39	0.43	0.38	0.42		
Average Speed (mph)	10	14	12	13	11	15		
Fuel Consumed (gal)	290	222	157	119	255	198	**163**	23.2%
Fuel Economy (mpg)	9.7	11.4	11.0	11.5	10.5	12.3		
CO Emissions (Kg)	20	15.53	10.99	9.64	17.8	13.85	**9.77**	20.0%
NOx Emissions (Kg)	3.95	3.02	2.14	1.87	3.46	2.69	**1.97**	20.6%
VOC Emissions (Kg)	4.7	3.6	2.55	2.23	4.13	3.21	**2.34**	20.6%

Truck Percentages

Location	AM	MD	PM	Average
Commonwealth Avenue at Summit Avenue	3.5%	4.7%	3.0%	3.7%
Commonwealth Avenue at Washington Street	5.3%	5.1%	2.4%	4.3%
Commonwealth Avenue at Colborne Road	3.9%	4.9%	2.9%	3.9%
Commonwealth Avenue at Wallingford Road/Kinross Road	4.6%	5.3%	3.2%	4.4%
Commonwealth Avenue at Chiswick Road	4.7%	6.2%	3.8%	4.9%
Commonwealth Avenue at Chestnut Hill Avenue	4.8%	5.1%	3.8%	4.6%
Commonwealth Avenue at South Street	4.3%	6.5%	2.8%	4.5%
Commonwealth Avenue (N.Roadway) at Greycliff Road	2.9%	4.1%	2.7%	3.2%
Commonwealth Avenue (S.Roadway) at Greycliff Road	4.9%	6.0%	3.6%	4.8%
Commonwealth Avenue at Lake Street/St. Thomas More Road	4.0%	4.5%	2.5%	3.7%
Average				**4.2%**

DATA (Continued)

Crash Data

	Location (BTD Intersection Numbers)						
Severity	**470**	**180**	**1206**	**1191**	**453**	**182**	**1208**
Property Damage	2	10	3	4	3	7	1
Personal Injury	2	6	0	1	3	4	0
Fatality	0	0	0	1	0	0	0
Other	2	2	2	0	1	3	1
Total	6	18	5	6	7	14	2

	Location (BTD Intersection Numbers)			
Severity	**1788/1789**	**879**	**Total**	**Per Year**
Property Damage	1	2	33	**11**
Personal Injury	1	0	17	**6**
Fatality	0	0	1	**0**
Other	2	0	13	**4**
Total	4	2	64	**21**

Benefits Performance Measures values

Category	Performance Measures	Unit of measure	Value per unit in 2009 dollars	Value per unit in 2012 dollars
Delay	Intersection Delay	Person Hours (Cars)	$16.09	$17.22
	Intersection Delay	Person Hours (Trucks)	$106.24	$113.68
Crashes	Property Damage Only (PDO) Crash	Number of Crashes	$3,165	$3,387
	Minor Injury Crash	Number of Crashes	$18,771	$20,085
	Moderate Injury Crash	Number of Crashes	$392,755	$420,248
	Severe Injury Crash	Number of Crashes	$3,003,746	$3,214,008
	Fatality Crash	Number of Crashes	$4,207,985	$4,502,544
Emissions	Carbon Monoxide (CO)	Metric ton	$138	$148
	Nitrous Oxide (Nox)	Metric ton	$7,490	$8,014
	Volatile Organic Compounds (VOC)	Metric ton	$5,682	$6,080
Energy	Fuel	Gallon	$2.64	$3.65

Consumer Price Index increased from 2009 to 2012 by 7.0%.

Hence all values are increase by 7.0% to calculate equivalent 2012 values.

BENEFIT CALCULATIONS

Calculation of Delay Reduction Per Year

Assuming

Truck Percentage:	4.2%						
Vehicle Occupancy	1.25						
Delay decreased by:	153 Vehicle hours per weekday						
	Veh. Hours Per Day	Passenger Hours Per Day			Hours Per Year	Cost per Hour	Benefit / Year
Vehicle and Passenger Car Delay (96%)	147 hrs.	183	x	260 days/year =	**47,580**	$17.22	$819,152
Truck Delay (4%)	6 hrs.		x	260 days/year =	**1,671**	$113.68	$189,927

Calculation of Crash Reduction Per Year

Assume 8 % crash reduction factor for signal retiming

	Total Accidents	Reduction	Annual Reduction	Cost per Crash	Benefit / Year
Property Damage Accidents	11	0.08	**0.88**	$3,387	$2,980
Personal Injury Accidents	6	0.08	**0.45**	$20,085	$9,105
Fatality Accidents*	0	0.08	-	$4,502,544	$0

* NOTE- Since signal retiming is not likely to influence occurance of fatalities, fatal crashes were not included in benefit calcualtions. This presents a conservative scenario

Calculation of Emissions Reductions from Kilograms to Metric Tons to Annual Metric Tons

	KG per day	Metric Tons per day			Annual Reduction	Cost per Ton	Benefit / Year
CO Reduction	9.77	0.00977	x	260 days/year =	**2.5402**	$148	$375
Nox Reduction	1.97	0.00197	x	260 days/year =	**0.5122**	$8,014	$4,105
VOC Reduction	2.34	0.00234	x	260 days/year =	**0.6084**	$6,080	$3,699

Calculation of Fuel Reduction Per Year

	Gal. per day			Annual Reduction	Cost per Gal.	Benefit / Year
Fuel reduction in gallons =	163	x	260 days/year =	**42,380**	$3.65	$154,687

Benefits Summary

Category	Performance Measure	Unit	Value per Unit in 2012 $	Benefits in Appropriate Units	Benefits Value
Delay	Intersection Delay	Person Hours (Cars)	$17.22	47580	$819,152
		person Hours (Trucks)	$113.68	1671	$189,927
Crashes	Property Damage Only (PDO) Crash	Number of Crashes	$3,387	1	$3,387
	Minor Injury Crash	Number of Crashes	$20,085	1	$20,085
	Moderate Injury Crash	Number of Crashes	$420,248	0	$0
	Severe Injury Crash	Number of Crashes	$3,214,008	0	$0
	Fatality Crash	Number of Crashes	$4,502,544	0.00	$0
Emissions	Carbon Monoxide (CO)	Metric ton	$148	2.5402	$375
	Nitrous Oxide (Nox)	Metric ton	$8,014	0.5122	$4,105
	Volatile Organic Compounds (VOC)	Metric ton	$6,080	0.6084	$3,699
Energy	Fuel	Gallon	$3.65	42380	$154,687
TOTAL					**$1,195,416**

COST CALCULATIONS

Intersection Improvements Cost Calculations

Intersection	Needed Items	Cost Estimate
Commonwealth Avenue at Summit Avenue	Restripe Zebra Crosswalks (about 125' of 6" white thermo) plus Stop Bars (about 75' of 12" w	$275
	Maintenance, N/A	$0
	New 3 section signal head and 8' pedestal mount	$3,500
Commonwealth Avenue at Washington Street	Replace R3-2 Sign and Yield to Trains Sign (Panels only, support to remain)	$198
	Replace Yield to Trains Sign (Panel only, support to remain)	$99
	Restripe Zebra Crosswalks (about 1325' of 6" white thermo) plus Stop Bars (about 150' of 12"	$1,625
	Replace Pedestrian signal head	$1,500
	Replace Pedestrian signal head	$1,500
Commonwealth Avenue at Colborne Road	Maintenance, N/A	$0
	Replace Signs (2 Panels, 1 post)	$400
	Maintenance, N/A	$0
	N/A	$0
Commonwealth Avenue at Wallingford Road/Kinross Road	Stripe Zebra Crosswalks (about 200' of 6" white thermo)	$200
	Replace Sign (Panel only, support to remain)	$100
Commonwealth Avenue at Chiswick Road	Maintenance, N/A	$0
	Stripe Zebra Crosswalks (about 175' of 6" white thermo)	$175
	Install pedestrian signal head	$4,200
Commonwealth Avenue at Chestnut Hill Avenue	Repaint left turn pavement markings on Commonwealth Avenue in both directions	$454
	Repaint Railroad Crossing pavement markings	$347
	Install new R3-8a style signs on Comonwealth Avenue in both directions	$600
	Maintenance, N/A	$0
	Maintenance, N/A	$0
	Pavement markings on Commonwealth Avenue eastbound approach	$985
Commonwealth Avenue at South Street	Replace signs (Panels only)	$200
Commonwealth Avenue (N.Roadway) at Greycliff Road	Maintenance, N/A	$0
	Maintenance, N/A	$0
Commonwealth Avenue (S.Roadway) at Greycliff Road	Maintenance, N/A	$0
	Maintenance, N/A	$0
	Install lane-use signs	$600
Commonwealth Avenue at Lake Street/St. Thomas More Road	Repaint pavement markings on Commonwealth Avenue in both directions	$612
	Maintenance, N/A	$0
	Replace signs (Panels only)	$200
		$0
Signal Equipment Cost that can be annualized over 15 years		**$10,700**
Signing and Pavement Marking Cost that can be annualized over 5 years		**$7,070**
Costs that cannot be annualized		**$0**

NOTE - Improvements considered above are based on Table 1 of Recommendations Technical memorandum

BTD Contractor Costs For implementing Signal timing and phasing improvements

10 intersections with clearance time changes (0.5 hour per intersection at $125 per hour)	$625
Travel time for Contractor (4 hours at $125 per hour)	$500
Signal phasing changes at Comm Ave/Chestnut Hill Ave Intersection	$2,500
Total BTD Contractor costs =	**$3,625**

COST CALCULATIONS (Continued)

Engineering Costs, Signs and Pavement Marking Costs		
Engineering Fee for Work Order 9		$36,400
Signs and Pavement marking Costs		$7,070
BTD Contractor costs		$3,625
Sum of above costs		$47,095
Assume BTD retimes signals every 5 years		
Assume signs and pavement markings are replaced every 5 years		
Annualized Cost Per Year =P{ [i*(1+i)^n] / [(1+i)^n - 1] }		
P = Present Worth		$47,095
Assume i=7.0 (CPI)		
N = 5		
Numerator = 0.07*(1+0.07)^5 =		$0.098
Denominator = (1+0.07)^5 -1 =		$0.403
A = P *(Numerator/Denominator)		$11,486
Total Annual Engineering/Signs/Markings Cost =		**$11,490**

Signal Equipment Costs		
Signal equipment costs		$10,700
Assume signal equipment has a life time of fifteen years		
Annualized Cost Per Year =P{ [i*(1+i)^n] / [(1+i)^n - 1] }		
P= Present worth		$10,700
Assume i=7.0 (CPI)	N= 15	
Numerator = 0.07*(1+0.07)^15 =		$0.193
Denominator = (1+0.07)^15 -1 =		$1.76
A = P *(Numerator/Denominator)		$1,175
Total Annual Signal Equipment Costs =		**$1,175**

Annual Cost Summary	
Type	
Engineering/Signs/Pavement markings	$11,490
Signal Equipment	$1,175
Other Non-Annualized Costs	$0
Total	**$12,665**

BENEFIT-COST RATIO CALCULATIONS

Benefit	$1,195,416	
Cost	$12,665	
Ratio	**94**	**to 1**

Improvement Costs		
Intersection	Needed Items	Cost Estimate
Commonwealth Avenue at Summit Avenue	Restripe Zebra Crosswalks (about 125' of 6" white thermo) plus Stop Bars (about 75' of 12" white thermo)	$275
	Maintenance, N/A	
	New 3 section signal head and 8' pedestal mount	$3,500
	Maintenance, N/A	
	Maintenance, N/A	
	Maintenance, N/A	
Commonwealth Avenue at Washington Street	Replace R3-2 Sign and Yield to Trains Sign (Panels only, support to remain)	$198
	Replace Yield to Trains Sign (Panel only, support to remain)	$99
	Maintenance, N/A	
	Maintenance, N/A	
	Maintenance, N/A	
	Restripe Zebra Crosswalks (about 1325' of 6" white thermo) plus Stop Bars (about 150' of 12" white thermo)	$1,625
	Replace Pedestrian signal head	$1,500
	N/A	
	N/A	
	Replace Pedestrian signal head	$1,500
Commonwealth Avenue at Colborne Road	Maintenance, N/A	
	Replace Signs (2 Panels, 1 post)	$400
	Maintenance, N/A	
	N/A	
Commonwealth Avenue at Wallingford Road/Kinross Road	Stripe Zebra Crosswalks (about 200' of 6" white thermo)	$200
	Replace Sign (Panel only, support to remain)	$100
	Maintenance, N/A	
	Maintenance, N/A	
	Maintenance, N/A	
	Maintenance, N/A	
	Maintenance, N/A	
Commonwealth Avenue at Chiswick Road	Maintenance, N/A	
	Stripe Zebra Crosswalks (about 175' of 6" white thermo)	$175
	Maintenance, N/A	
	Maintenance, N/A	
	Maintenance, N/A	
	Install pedestrian signal head	$4,200
Commonwealth Avenue at Chestnut Hill Avenue	Repaint left turn pavement markings on Commonwealth Avenue in both directions	$454
	Repaint Railroad Crossing pavement markings	$347
	Install new R3-8a style signs on Comonwealth Avenue in both directions	$600
	Maintenance, N/A	
	Maintenance, N/A	
	Pavement markings on Commonwealth Avenue eastbound approach. Add lane-use signs	$985
Commonwealth Avenue at South Street	Replace signs (Panels only)	$200
	Maintenance, N/A	
	Maintenance, N/A	
	Maintenance, N/A	
	Maintenance, N/A	
Commonwealth Avenue (N.Roadway) at Greycliff Road	Maintenance, N/A	
	Maintenance, N/A	
Commonwealth Avenue (S.Roadway) at Greycliff Road	Maintenance, N/A	
	Maintenance, N/A	
	Install lane-use signs	$600
Commonwealth Avenue at Lake Street/St. Thomas More Road	Repaint pavement markings on Commonwealth Avenue in both directions	$612
	Maintenance, N/A	
	Replace signs (Panels only)	$200

Signal Equipment Cost that can be annualized over 15 years	**$10,700**
Signing and Pavement Marking Cost that can be annualized over 5 years	**$7,070**
Costs that cannot be annualized	**$0**

Recommended Improvements

- Restripe faded crosswalks across northbound Commonwealth Avenue
- Repaint visors on signal facing Summit Avenue located on the median on Commonwealth Avenue. Visors are faded/peeling and old paint is showing through.
- Consider adding a second far-side signal for Summit Avenue.
- Replace visors on signal post at southeast corner of intersection.
- Add curb cuts for handicap ramps for crosswalk across Commonwealth Avenue.
- Fix wires hanging out of the signal head in the median on the east side of the intersection
- Replace faded no left turn sign and yield sign (trains) on Commonwealth Avenue northbound approach
- Replace faded yield sign (trains) on Commonwealth Avenue southbound approach
- Replace missing visor on red indication on signal head facing trains on Commonwealth Avenue southbound.
- Pedestal mounted signals located in center medians on north side of intersection are leaning and appear to be unstable. Repair alignment of signal heads.

- Black paint is fading and yellow paint is showing through on right most pedestal mounted signal facing Service Road southbound traffic. Repaint signal heads
- Crosswalks are faded on all approaches. Restripe crosswalks.
- Replace LED indication on pedestrian head in median on east side to cross Eastbound Commonwealth Avenue.
- Relocate handicap access on southwest corner of the intersection to align with crosswalk.
- Move stop bar and crosswalk closer to the intersection on Washington Street Northbound approach
- Pedestrian heads across Commonwealth Avenue Westbound west of intersection never displays. Replace signal heads
- Provide curb cuts and ADA ramps for handicap access on all medians and sidewalks across Commonwealth Avenue east of the intersection.
- Replace faded Stop signs on Service Road westbound approach. Mount at proper height per MUTCD specificaitons.

- Signal facing Commonwealth Avenue eastbound lacks visor on yellow indication. Replace visor.
- Medians should be reconstructed to accommodate ADA ramps.
- Provide crosswalk markings across Kinross Road to connect opposing handicap ramps
- Replace faded Yield (trains) sign facing Commonwealth Avenue westbound traffic
- Left most pedestal mounted signal is yellow instead of black (all other signals are black). Repaint signal head
- Repaint or replace rusted pedestal supports for pedestrian indications.
- Repair pedestrian pushbutton to cross Commonwealth Avenue Westbound approach
- Replace visor for green indication facing Wallingford Road
- Provide handicap accessibility through median across Commonwealth Avenue
- Provide ADA access across medians/train tracks on Commonwealth Avenue.
- Align ramp/crosswalk markings with one-another across Chiswick Road south of the intersection.
- Repaint signals facing Commonwealth Avenue westbound as they are faded (one is showing yellow).
- Repaint left most signal head facing Chiswick Road northbound approach
- Right most signal facing Commonwealth Avenue eastbound is missing visors for the red and green indications. Replace visors
- Provide pedestrian signal head on north side of Commonwealth Avenue (no signal head exists, only push button)
- Repaint left turn lane pavement markings on Commonwealth Avenue approaches
- Repaint railroad crossing pavement markings on Commonwealth Avenue eastbound approach
- Install advanced warning sign to drivers showing upcoming lane designations on both Commonwealth Avenue approaches
- All signal heads would benefit from replacement or repainting. Paint is faded and peeling.
- Repair pedestrian indications (walk is not displayed on most pedestrian heads)
- On Commonwealth Avenue Eastbound approach the wide rightmost lane is used as a through lane and a right-turn lane, consider adding pavement markings and signs to indicate this lane use
- Replace extremely faded Yield signs (trains). Could add customized light-rail yield signs that will not confuse common drivers.
- Relocate crosswalks across eastbound or westbound Commonwealth Avenue to reduce total crossing distance.
- Navigating across Commonwealth Avenue via crosswalks seems difficult for handicapped individuals. Add handicap ramps to center median and sidewalks across Commonwealth Avenue. Relocate poles located on pedestrian paths.
- Install visors on pedestrian indicators. These can be hard to see in bright conditions, especially those facing pedestrians walking northbound toward South Street
- South Street approach phase was observed to get called without any vehicles on the approach. Revise controller settings or repair broken loops.
- Repair pedestrian push buttons across Commonwealth Avenue eastbound as they are not working.
- Add handicap accessibility to center median
- Repair pedestrian pushbutton within center median for crossing Commonwealth Avenue Westbound
- Repaint signal heads facing Commonwealth Avenue traffic in the eastbound direction
- Add visors to pedestrian indications
- Check support to signal connection for left most indication facing eastbound traffic, looks unstable
- Advanced diagrammatic lane use sign may reduce driver confusion. Install advance warning signs showing lane use
- Repaint pavement markings on both Commonwealth Avenue approaches
- Repaint signal heads. Many are badly faded or peeling.
- Replace faded Yield sign (trains).

Standard Item Costs

Item	Unit	cost
Signal head - 3 section one-way LED	Each	$1,000
3 section one-way programmable signal heads	Each	$2,000
Pedestrian signal head	Each	$1,500
8 Feet signal post & Foundation	Each	$2,500
Push Button and sign Assembly	Each	$500
Pullbox 12"X12" SD 2.031	Each	$750
Wiring & testing signal cable	per foot	$5
Wiring & testing pedestrian cable	per foot	$6
Existing Controller reprogramming	Each	$1,500
Remove & Stack signal post	Each	$200
Remove & Stack signal heads	Each	$200
Right turn Arrow Pav Marking	15.8 Sq Ft	$79
Left turn Arrow Pav Marking	15.8 Sq Ft	$79
Through Arrow Pav Marking	15.8 Sq Ft	$79
Left-Through Pav Marking	28.1 Sq Ft	$141
Through-Right Pav Marking	28.1 Sq Ft	$141
Railroad Crossing Pavement Marking	69.4 Sq Ft	$347
ONLY Pav Marking	29.6 Sq Ft	$148
Bicycle Lane Pav Marking	Each	$70
6"Reflectorized White Line (Thermoplastic)	1 ft	$1
6"Reflectorized Yellow Line (Thermoplastic)	1 ft	$1
R3-2 No Left/Right Turn sign	36"X36" = 9 sq ft	$99
R3-8 lane use Regulatory sign	30"X30" = 6.25 sq ft	$69
R3-8 lane use Regulatory sign	48"x30" = 10 sq ft	$110
R3-5 Mandatory lane use Regulatory sign	30"x36" = 7.5 sq ft	$83
R3-6 Mandatory lane use Regulatory sign	30"x36" = 7.5 sq ft	$83
R3-7 Right Lane Must turn Right sign	36"x36" = 9 sq ft	$99
R10-12 Left Turn yield on Green ball sign	30"x36" = 7.5 sq ft	$83
R5-1 DO NOT ENTER sign	30"x30" = 6.25 sq ft	$69
R6-1 ONE-WAY sign	36"x12" = 3 sq ft	$33
R3-2 NO LEFT TURN sign	24"x24" = 4 sq ft	$44
R1-1 STOP sign	30"x30" = 6.25 sq ft	$69
M1-5 "203" Route Sign	30"x24"= 5 sq ft	$100

Notes - signs were assumed to be $300 each for the sign plate, post, installation etc. $300
with the exception of sign M1-5 which is assumed to be $100 total for the sign plate and installation since the post currently exists

"Yield to Trains" sign estimated to be the same cost as R3-2

Rack Mounted Loop Amplifiers	Each	$94
Remove & Stack Cabinet Assembly	Each	$2,000
Install 4 DW Controller	Each	$3,500
Special Duty Police	Hour	$37
8 DW Controller	Each	$11,200
Install 8 DW Controller	Each	$5,500
8 DW Controller with closed loop master	Each	$14,700
4 DW Controller - Total		$5,984
8 DW Controller - Total		$19,668
8 DW Controller with Master - Total		$23,168

Appendix J

Benefit Cost Analysis – Work Order #10

DATA

Data from Network MOE Summary Tables Submitted in Recommendations Technical memorandum

	AM Peak Hour		Midday Peak Hour		PM Peak Hour		Difference	%
	Existing	Improved	Existing	Improved	Existing	Improved		Difference
Total Delay (Hr.)	157	135	129	120	186	155	**62**	13.1%
Stops/Vehicle	0.66	0.63	0.68	0.65	0.65	0.65		
Average Speed (mph)	8	9	8	9	7	8		
Fuel Consumed (gal)	242	223	213	204	265	242	**51**	7.1%
Fuel Economy (mpg)	6.8	7.4	7.1	7.4	6.2	6.8		
CO Emissions (Kg)	16.93	15.6	14.87	14.24	18.5	16.91	**3.55**	7.1%
NOx Emissions (Kg)	3.29	3.04	2.89	2.77	3.6	3.29	**0.68**	7.0%
VOC Emissions (Kg)	3.92	3.62	3.45	3.3	4.29	3.92	**0.82**	7.0%

Truck Percentages

Location	AM	MD	PM	Average
Massachusetts Avenue at Melnea Cass Boulevard/Mass Ave. Connector	7.8%	8.9%	7.0%	7.9%
Massachusetts Avenue at Albany Street	8.2%	7.8%	5.3%	7.1%
Albany Street at City Hospital Signal	9.4%	7.5%	7.8%	8.2%
Albany Street at East Concord Street	7.4%	6.6%	6.9%	7.0%
Albany Street at East Newton Street	10.1%	7.8%	4.5%	7.5%
Albany Street at Northampton Street	6.8%	7.9%	5.0%	6.6%
Melnea Cass Boulevard at Hampden Street	7.1%	9.1%	3.3%	6.5%
Average				**7.2%**

DATA (Continued)

Crash Data

	Location (BTD Intersection Numbers)								
Severity	**1093**	**100**	**2341**	**813**	**382**	**204**	**2092**	**Total**	**Per Year**
Property Damage	26	13	1	1	0	2	5	48	**16**
Personal Injury	25	8	0	0	1	2	6	42	**14**
Fatality	0	0	0	0	0	0	0	0	**0**
Other	19	8	0	0	0	0	7	34	**11**
Total	70	29	1	1	1	4	18	124	**41**

Benefits Performance Measures values

Category	Performance Measures	Unit of measure	Value per unit in 2009 dollars	Value per unit in 2012 dollars
Delay	Intersection Delay	Person Hours (Cars)	$16.09	$17.22
	Intersection Delay	Person Hours (Trucks)	$106.24	$113.68
Crashes	Property Damage Only (PDO) Crash	Number of Crashes	$3,165	$3,387
	Minor Injury Crash	Number of Crashes	$18,771	$20,085
	Moderate Injury Crash	Number of Crashes	$392,755	$420,248
	Severe Injury Crash	Number of Crashes	$3,003,746	$3,214,008
	Fatality Crash	Number of Crashes	$4,207,985	$4,502,544
Emissions	Carbon Monoxide (CO)	Metric ton	$138	$148
	Nitrous Oxide (Nox)	Metric ton	$7,490	$8,014
	Volatile Organic Compounds (VOC)	Metric ton	$5,682	$6,080
Energy	Fuel	Gallon	$2.64	$3.65

Consumer Price Index increased from 2009 to 2012 by 7.0%.
Hence all values are increased by 7.0% to calculate equivalent 2012 values.

TETRA TECH

BENEFIT CALCULATIONS

Calculation of Delay Reduction Per Year

Assuming
Truck Percentage: 7.2%
Vehicle Occupancy 1.25
Delay decreased by: 62 Vehicle hours per weekday

	Veh. Hours Per Day	Passenger Hours Per Day		Hours Per Year	Cost per Hour	Benefit / Year
Vehicle and Passenger Car Delay (93%)	58 hrs.	71	x 260 days/year =	**18,460**	$17.22	$317,813
Truck Delay (7%)	4 hrs.		x 260 days/year =	**1,168**	$113.68	$132,810

Calculation of Crash Reduction Per Year

Assume 8 % crash reduction factor for signal retiming

	Total Accidents	Reduction	Annual Reduction	Cost per Crash	Benefit / Year
Property Damage Accidents	16	0.08	**2.00**	$3,387	$6,773
Personal Injury Accidents	14	0.08	**2.00**	$20,085	$40,170
Fatality Accidents	0	0.08	-	$4,502,544	$0

Calculation of Emissions Reductions from Kilograms to Metric Tons to Annual Metric Tons

	KG per day	Metric Tons per day		Annual Reduction	Cost per Ton	Benefit / Year
CO Reduction	3.55	0.00355	x 260 days/year =	**0.9230**	$148	$136
Nox Reduction	0.68	0.00068	x 260 days/year =	**0.1768**	$8,014	$1,417
VOC Reduction	0.82	0.00082	x 260 days/year =	**0.2132**	$6,080	$1,296

Calculation of Fuel Reduction Per Year

	Gal. per day		Annual Reduction	Cost per Gal.	Benefit / Year
Fuel reduction in gallons =	51	x 260 days/year =	**13,260**	$3.65	$48,399

Benefits Summary

Category	Performance Measure	Unit	Value per Unit in 2012 $	Benefits in Appropriate Units	Benefits Value
Delay	Intersection Delay	Person Hours (Cars)	$17.22	18460	$317,813
		person Hours (Trucks)	$113.68	1168	$132,810
Crashes	Property Damage Only (PDO) Crash	Number of Crashes	$3,387	2	$6,773
	Minor Injury Crash	Number of Crashes	$20,085	2	$40,170
	Moderate Injury Crash	Number of Crashes	$420,248	0	$0
	Severe Injury Crash	Number of Crashes	$3,214,008	0	$0
	Fatality Crash	Number of Crashes	$4,502,544	0.00	$0
Emissions	Carbon Monoxide (CO)	Metric ton	$148	0.9230	$136
	Nitrous Oxide (Nox)	Metric ton	$8,014	0.1768	$1,417
	Volatile Organic Compounds (VOC)	Metric ton	$6,080	0.2132	$1,296
Energy	Fuel	Gallon	$3.65	13260	$48,399
TOTAL					**$548,815**

TETRA TECH

COST CALCULATIONS

Intersection Improvements Cost Calculations		
Intersection	Needed Items	Cost Estimate
Massachusetts Ave/Melnea Cass Blvd/MA. Ave Connector	Restripe Crosswalks (about 1125' of 6") + Stop Bars (about 150' of 12") & Pav't Markings	$3,261
	Maintenance, N/A	
	Install 3 signs	$900
Melnea Cass Boulevard/ Hampden Street	Add 4 new 3-section heads & remove 4 existing signal heads. Rewiring and reprograming controller .	$7,800
Massachusetts Ave/Albany St	Restripe Zebra Crosswalks (about 1275' of 6") + Stop Bars (about 150' of 12") & Pav't Markings	$5,039
	Maintenance, N/A	
	Maintenance, N/A	
	Install 3 signs	$900
	Maintenance, N/A	
Albnay St/City Hospital Crossing	Restripe Zebra Crosswalks (about 450' of 6") + Stop Bars (about 25' of 12")	$500
	Maintenance, N/A	
Albany St/East Concord St	Restripe Zebra Crosswalks (about 650' of 6") + Stop Bars (about 75' of 12") & Pav't Markings	$1,913
Albany St/East Newton St	Maintenance, N/A	
	Restripe Zebra Crosswalks (about 600' of 6") + Stop Bars (about 75' of 12")	$1,863
	*Included in price above ↑	
Albany St/Northampton St	Maintenance, N/A	
	Restripe Zebra Crosswalks (about 1025' of 6") + Stop Bars (about 100' of 12")	$1,225
	*Included in price above ↑	
	Repaint pavment markings	$807
	Install 2 signs	$600
	*Pedestrian signals exist, crosswalk markings Included in price above ↑	

Signal Equipment Cost that can be annualized over 15 years	**$7,800**
Signing and Pavement Marking Cost that can be annualized over 5 years	**$17,007**
Costs that cannot be annualized	**$0**

NOTE - Improvements considered above are based on Table 1 of Recommendations Technical memorandum

BTD Contractor Costs For implementing Signal timing and phasing improvements	
6 intersections with clearance time changes (0.5 hour per intersection at $125 per hour)	$375
Travel time for Contractor (4 hours at $125 per hour)	$500
BTD Contractor cost for signal phasing changes at Melnea Cass Blvd/Hampden St (change protected permissive lefts to protected lefts)	$2,500
Total BTD Contractor costs =	**$3,375**

COST CALCULATIONS (Continued)

Engineering Costs, Signs and Pavement Marking Costs		
Engineering Fee for Work Order 10		$27,000
Signs and Pavement marking Costs		$17,007
BTD Contractor costs		$3,375
Sum of above costs		$47,382
Assume BTD retimes signals every 5 years		
Assume signs and pavement markings are replaced every 5 years		
Annualized Cost Per Year =P{ [i*(1+i)^n] / [(1+i)^n - 1] }		
P = Present Worth		$47,382
Assume i=7.0 (CPI)		
N = 5		
Numerator = 0.07*(1+0.07)^5 =		$0
Denominator = (1+0.07)^5 -1 =		$0
A = P *(Numerator/Denominator)		$11,556
Total Annual Engineering/Signs/Markings Cost =		**$11,560**

Signal Equipment Costs		
Signal equipment costs		$7,800
Assume signal equipment has a life time of fifteen years		
Annualized Cost Per Year =P{ [i*(1+i)^n] / [(1+i)^n - 1] }		
P= Present worth		$7,800
Assume i=7.0 (CPI)	N= 15	
Numerator = 0.07*(1+0.07)^15 =		$0
Denominator = (1+0.07)^15 -1 =		$2
A = P *(Numerator/Denominator)		$856
Total Annual Signal Equipment Costs =		**$856**

Annual Cost Summary	
Type	
Engineering/Signs/Pavement markings	$11,560
Signal Equipment	$856
Other Non-Annualized Costs	$0
Total	**$12,416**

BENEFIT COST RATIO CALCULATIONS

Benefit	$548,815	
Cost	$12,416	
Ratio	**44 to 1**	

Improvement Costs

Intersection	Needed Items	Cost Estimate
Massachusetts Ave/Melnea Cass Bl	Restripe Zebra Crosswalks (about 1125' of 6" white thermo) plus Stop Bars (about 150' of 12" white the	$3,261
	Maintenance, N/A	
	Install 3 signs	$900
Melnea Cass Boulevard/ Hampden	Add four new 3-section heads (arrow heads for left turns). Remove and stack 4 existing signal heads	$7,800
Massachusetts Ave/Albany St	Restripe Zebra Crosswalks (about 1275' of 6" white thermo) plus Stop Bars (about 150' of 12" white the	$5,039
	Maintenance, N/A	
	Maintenance, N/A	
	Install 3 signs	$900
	Maintenance, N/A	
Albnay St/City Hospital Crossing	Restripe Zebra Crosswalks (about 450' of 6" white thermo) plus Stop Bars (about 25' of 12" white therr	$500
	Maintenance, N/A	
Albany St/East Concord St	Restripe Zebra Crosswalks (about 650' of 6" white thermo) plus Stop Bars (about 75' of 12" white therr	$1,913
Albany St/East Newton St	Maintenance, N/A	
	Restripe Zebra Crosswalks (about 600' of 6" white thermo) plus Stop Bars (about 75' of 12" white therr	$1,863
	*Included in price above ↑	
Albany St/Northampton St	Maintenance, N/A	
	Restripe Zebra Crosswalks (about 1025' of 6" white thermo) plus Stop Bars (about 100' of 12" white the	$1,225
	*Included in price above ↑	
	Repaint pavment markings	$807
	Install 2 signs	$600
	*Pedestrian signals exist, crosswalk markings Included in price above ↑	

Signal Equipment Cost that can be annualized over 15 years	**$7,800**
Signing and Pavement Marking Cost that can be annualized over 5 years	**$17,007**
Costs that cannot be annualized	**$0**

Recommended Improvements

- Restripe crosswalks, stop bars and lane use markings on Massachusetts Avenue and the Massachusetts Avenue Connector approaches.
- Rutting is present on Massachusetts Avenue and Massachusetts Avenue Connector approaches
- Install BTD “R-3” (MUTCD Code R 4 - 7) “Keep Right” signs on northbound and southbound Massachusetts Avenue approach medians and on the center median on th
- Convert protected-permissive left turn phasing on Melnea Cass Blvd approaches to Protected only left-turn phase.
- This will eliminate/minimize the conflicts with pedestrian phase that runs concurrent with the through movements.
- Restripe all crosswalks, stop bars, and lane use markings. All are extremely faded
- Signs at this location read “yield to pedestrians on turns, state law”. With state law on bottom. Consider swapping positions of these signs to read “state law, yield to
- Add visors to right most signal facing Albany Street eastbound approach
- Install BTD “R-3” (MUTCD Code R 4 - 7) “Keep Right” signs on Albany Street westbound approach median and on both Massachusetts Avenue approach center media
- Consider eliminating a few on-street parking spaces located just east of the intersection on Albany St (south side). Buses were observed to struggle to make the right

- Restripe faded crosswalks
- Add double yellow center line and solid white edge line to delineate any on street parking available in the area
- Restripe crosswalks, lane use designations, and stop bars
- Back plate is bent and damaged on left most signal facing northbound East Newton Street
- Restripe all crosswalks, stop bars, and lane use markings. All are faded except East Newton Street northbound approach.
- Add lane use markings to Albany Street westbound approach
- Rutting of pavement was observed at this intersection
- Restripe crosswalks and stop bars
- Add stop bar to eastbound Albany Street approach
- Add lane designations and lane use markings
- Install BTD “R-3” (MUTCD Code R 4 - 7) “Keep Right” signs on both Albany Street center medians
- Consider adding crosswalk and pedestrian signals across northbound Northampton St approach.

Standard Item Costs

Item	Unit	cost
Signal head - 3 section one-way LED	Each	$1,000
3 section one-way programmable signal heads	Each	$2,000
Pedestrian signal head	Each	$1,500
8 Feet signal post & Foundation	Each	$2,500
Push Button and sign Assembly	Each	$500
Pullbox 12"X12" SD 2.031	Each	$750
Wiring & testing signal cable	per foot	$5
Wiring & testing pedestrian cable	per foot	$6
Existing Controller reprogramming	Each	$1,500
Remove & Stack signal post	Each	$200
Remove & Stack signal heads	Each	$200
Right turn Arrow Pav Marking	15.8 Sq Ft	$79
Left turn Arrow Pav Marking	15.8 Sq Ft	$79
Through Arrow Pav Marking	15.8 Sq Ft	$79
Left-Through Pav Marking	28.1 Sq Ft	$141
Through-Right Pav Marking	28.1 Sq Ft	$141
Railroad Crossing Pavement Marking	69.4 Sq Ft	$347
ONLY Pav Marking	29.6 Sq Ft	$148
Bicycle Lane Pav Marking	Each	$70
6"Reflectorized White Line (Thermoplastic)	1 ft	$1
6"Reflectorized Yellow Line (Thermoplastic)	1 ft	$1
R3-2 No Left/Right Turn sign	36"X36" = 9 sq ft	$99
R3-8 lane use Regulatory sign	30"X30" = 6.25 sq ft	$69
R3-8 lane use Regulatory sign	48"x30" = 10 sq ft	$110
R3-5 Mandatory lane use Regulatory sign	30"x36" = 7.5 sq ft	$83
R3-6 Mandatory lane use Regulatory sign	30"x36" = 7.5 sq ft	$83
R3-7 Right Lane Must turn Right sign	36"x36" = 9 sq ft	$99
R10-12 Left Turn yield on Green ball sign	30"x36" = 7.5 sq ft	$83
R5-1 DO NOT ENTER sign	30"x30" = 6.25 sq ft	$69
R6-1 ONE-WAY sign	36"x12" = 3 sq ft	$33
R3-2 NO LEFT TURN sign	24"x24" = 4 sq ft	$44
R1-1 STOP sign	30"x30" = 6.25 sq ft	$69
M1-5 "203" Route Sign	30"x24"= 5 sq ft	$100

Notes - signs were assumed to be $300 each for the sign plate, post, installation etc. $300
with the exception of sign M1-5 which is assumed to be $100 total for the sign plate and installation since the post currently exists

"Yield to Trains" sign estimated to be the same cost as R3-2

Appendix K

Travel Time Summaries – Before and After Improvements

Work Order 1 - Travel Time Summary

Study Corridor	Average Travel Times (min:sec)								
	Morning			Midday			Afternoon		
	Pre-Timing Changes	Post-Timing Changes	Percent Change	Pre-Timing Changes	Post-Timing Changes	Percent Change	Pre-Timing Changes	Post-Timing Changes	Percent Change
Charles St northbound - from Boylston Street to Beacon Street	1:22	0:36	56%	1:51	0:38	66%	1:37	0:33	66%
Beacon St eastbound - from Charles Street to Park Street	2:27	1:43	30%	2:24	1:58	18%	2:52	1:57	32%
Beacon St westbound - from Park Street to Charles Street	1:31	1:05	29%	1:35	1:08	28%	1:31	1:32	-1%
Washington St northbound - from NEMC to Ave de Lafayette	1:36	0:52	46%	1:41	1:10	31%	1:36	1:33	3%
Total - All Corridors	6:56	4:16	38%	7:31	4:54	35%	7:36	5:35	27%

Work Order 2 - Travel Time Summary

Study Corridor	Average Travel Times (min:sec)								
	Morning			Midday			Afternoon		
	Pre-Timing Changes	Post-Timing Changes	Percent Change	Pre-Timing Changes	Post-Timing Changes	Percent Change	Pre-Timing Changes	Post-Timing Changes	Percent Change
Brighton Avenue eastbound from Allston Street to Commonwealth Avenue	3:16	2:52	12%	2:48	3:19	-18%	3:41	2:48	24%
Brighton Avenue westbound from Commonwealth Avenue to Allston Street	2:01	1:45	13%	2:32	1:55	24%	3:21	2:25	28%
Commonwealth Avenue eastbound from Warren Street/Kelton Street to Brighton Avenue	4:26	2:08	52%	3:05	2:10	30%	4:20	2:06	52%
Commonwealth Avenue westbound from Brighton Avenue to Warren Street /Kelton Street	3:35	2:34	28%	3:24	2:35	24%	3:03	2:33	16%
Total - All Corridors	13:18	9:19	30%	11:49	9:59	16%	14:25	9:52	32%

Work Order 3 - Travel Time Summary

Study Corridor	Average Travel Times (min:sec)								
	Morning			Midday			Afternoon		
	Pre-Timing Changes	Post-Timing Changes	Percent Change	Pre-Timing Changes	Post-Timing Changes	Percent Change	Pre-Timing Changes	Post-Timing Changes	Percent Change
Marginal Road – Westbound from Harrison Street to Arlington Street	1:45	1:58	-12%	2:34	3:07	-21%	2:57	2:26	18%
Herald Street – Eastbound from Arlington Street to Harrison Avenue	1:18	1:08	13%	1:24	1:29	-6%	1:51	1:30	19%
E. Berkeley Street - Westbound from Harrison Street to Tremont Street	2:05	1:32	26%	2:33	1:49	29%	1:58	1:38	17%
Tremont Street – Southbound from Beacon Street to Boylston Street	2:44	2:10	21%	3:10	2:35	18%	3:06	2:26	22%
Tremont Street – Southbound from Oak Street to E. Berkeley Street	2:39	2:21	11%	2:29	1:06	56%	2:20	1:28	37%
Tremont Street – Northbound from E. Berkeley Street to Oak Street	2:10	1:23	36%	2:31	1:23	45%	2:27	1:15	49%
Washington Street – Northbound from E. Berkeley to Oak Street	1:52	2:04	-11%	2:08	1:54	11%	2:16	2:41	-18%
Shawmut Street – Southbound from Oak Street to E. Berkeley Street	2:24	1:27	40%	3:26	1:41	51%	1:51	2:21	-27%
Harrison Avenue – Southbound from Oak Street to E. Berkeley Street	1:30	2:29	-66%	2:41	2:13	17%	1:50	1:32	16%
Total - All Corridors	18:27	16:32	10%	22:56	17:17	25%	20:36	17:17	16%

Work Order 4 - Travel Time Summary

Study Corridor	Average Travel Times (min:sec)								
	Morning			Midday			Afternoon		
	Pre-Timing Changes	Post-Timing Changes	Percent Change	Pre-Timing Changes	Post-Timing Changes	Percent Change	Pre-Timing Changes	Post-Timing Changes	Percent Change
Tremont Street Southbound from Access Drive (Ruggles) to Malcolm X Boulevard	4:40	2:05	55%	2:46	2:06	24%	5:30	3:24	38%
Columbus Avenue Southbound from Malcolm X Blvd/Tremont Street to Centre/Ritchie Street	2:45	2:03	25%	2:41	2:10	19%	2:24	1:58	18%
Columbus Avenue Southbound from Centre/Ritchie Street to Weld Street	1:58	1:51	6%	1:17	0:54	30%	2:48	2:26	13%
Columbus Avenue Northbound from Weld Street to Centre/Ritchie Street	3:50	3:04	20%	1:27	2:21	-62%	2:30	3:19	-33%
Columbus Avenue Northbound from Centre/Ritchie Street to Malcolm X Boulevard	4:19	2:58	31%	2:07	2:00	6%	2:33	2:39	-4%
Tremont Street Northbound from Malcolm X Boulevard to Access Drive (Ruggles)	2:08	1:42	20%	1:25	1:00	29%	1:49	1:14	32%
Total - All Corridors	19:40	13:43	30%	11:43	10:31	10%	17:34	15:00	15%

NOTE - Denotes travel time on Columbus Avenue between Centre/Richie Street and Bray Street due to police road blockage at Washington Street.

Work Order 6 - Travel Time Summary

Study Corridor	Average Travel Times (min:sec)								
	Morning			Midday			Afternoon		
	Pre-Timing Changes	Post-Timing Changes	Percent Change	Pre-Timing Changes	Post-Timing Changes	Percent Change	Pre-Timing Changes	Post-Timing Changes	Percent Change
Blue Hill Ave northbound - from Washington Street to Dudley Street	6:48	5:20	22%	5:59	6:21	-6%	7:57	7:51	1%
Blue Hill Ave southbound - from Dudley Street to Washington Street	6:08	5:28	11%	6:11	6:01	3%	10:12	9:06	11%
Total - All Corridors	12:56	10:48	16%	12:10	12:22	-2%	18:09	16:57	7%

Work Order 7 - Travel Time Summary

Study Corridor	Average Travel Times (min:sec)								
	Morning			Midday			Afternoon		
	Pre-Timing Changes	Post-Timing Changes	Percent Change	Pre-Timing Changes	Post-Timing Changes	Percent Change	Pre-Timing Changes	Post-Timing Changes	Percent Change
Centre Street southbound from Belgrade Street to Temple Street	3:59	3:23	15%	3:45	3:53	-4%	4:12	4:43	-12%
Centre Street northbound from Temple Street to Belgrade Street	4:16	3:26	20%	4:58	4:11	16%	5:01	4:13	16%
Total - All Corridors	8:15	6:49	17%	8:43	8:04	7%	9:13	8:56	3%

Work Order 8 - Travel Time Summary

Study Corridor	Average Travel Times (min:sec)								
	Morning			Midday			Afternoon		
	Pre-Timing Changes	Post-Timing Changes	Percent Change	Pre-Timing Changes	Post-Timing Changes	Percent Change	Pre-Timing Changes	Post-Timing Changes	Percent Change
Washington St northbound - from Ukraine Way to Arborway	2:24	5:46	-140%	1:42	1:19	23%	1:54	2:36	-37%
Washington St southbound - from Arborway to Ukraine Way	1:44	1:29	14%	1:43	1:18	24%	2:04	2:15	-9%
Hyde Park Ave northbound - from Ukraine Way to Arborway	4:32	1:39	64%	2:23	1:44	27%	2:40	1:25	47%
Hyde Park Ave southbound - from Arborway to Ukraine Way	2:27	2:03	16%	2:15	1:10	48%	8:01	3:09	61%
Total - All Corridors	11:07	10:57	1%	8:03	5:31	31%	14:39	9:25	36%

Work Order 9 - Travel Time Summary

Study Corridor	Average Travel Times (min:sec)								
	Morning			Midday			Afternoon		
	Pre-Timing Changes	Post-Timing Changes	Percent Change	Pre-Timing Changes	Post-Timing Changes	Percent Change	Pre-Timing Changes	Post-Timing Changes	Percent Change
Commonwealth Avenue EB from Lake St to Summit Ave	5:48	5:55	-2%	5:30	4:55	11%	4:44	5:14	-11%
Commonwealth Avenue WB from Summit to Lake St	5:51	5:18	9%	4:34	4:20	5%	5:23	5:23	0%
Total - All Corridors	11:39	11:13	4%	10:04	9:15	8%	10:07	10:37	-5%

Work Order 10 - Travel Time Summary

Study Corridor	Average Travel Times (min:sec)								
	Morning			Midday			Afternoon		
	Pre-Timing Changes	Post-Timing Changes	Percent Change	Pre-Timing Changes	Post-Timing Changes	Percent Change	Pre-Timing Changes	Post-Timing Changes	Percent Change
Mass Ave northbound - from Melnea Cass Blvd to Albany St	2:22	2:12	7%	2:46	2:41	3%	3:20	2:20	30%
Mass Ave southbound - from Albany St to Melnea Cass Blvd	1:45	2:00	-14%	3:02	2:18	24%	2:54	1:57	33%
Total - All Corridors	4:07	4:12	-2%	5:48	4:59	14%	6:14	4:17	31%