BOSTON TRANSPORTATION DEPARTMENT

Benefit-Cost Evaluation of the BTD Traffic Signal Retiming Program

FY 2013-2016

TETRA TECH

City of Boston Contract #35698

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EXECUTIVE SUMMARY

Consistent with the 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 2016, the BTD has implemented traffic signal retiming improvements at 705 intersections city-wide, which represents approximately 83 percent of the city's 845 traffic signals.

This report summarizes the improvements implemented by the BTD at 295[1] intersections that were completed as part of the FY2013 – FY2016 signal retiming program. The signal retiming improvements were undertaken with the assistance of the consulting firm Tetra Tech, Inc., under Contract #35698. The improvements were made through the efforts of 11 separate work orders at intersections located throughout the city. Approximately 32 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 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 FY2013 and FY2016 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. Although not immediately quantifiable, pedestrian safety has also been enhanced as part of these signal retiming programs. Pedestrian crossing times were recalculated using current walking speed standards. In most areas, these changes were offset by other improvements in efficiency. In the Back Bay area, there was a minor increase in vehicular delay. Concurrent pedestrian crossings were also implemented wherever feasible.

Overall, the signal retiming improvements implemented at the 295[1] intersections between FY2013 and FY2016 are expected to:

Reduce driver delays by	Reduce travel times up to	Reduce vehicular emissions by	Reduce fuel consumption is by	Reduce vehicle crashes by
15%	**14%**	**8%**	**7%**	**8%**

[1] Although 295 total locations were analyzed for this contract, the results for three (3) locations from the FY2016-2 (Roslindale & Roxbury) work order have been omitted from all tables and calculations in this benefit-cost analysis since these locations are not currently on BTD's Central Traffic Signal Control Software System per discussions with the BTD.

Table E-1 FY2013 - FY2016 Signal Retiming Program Benefits

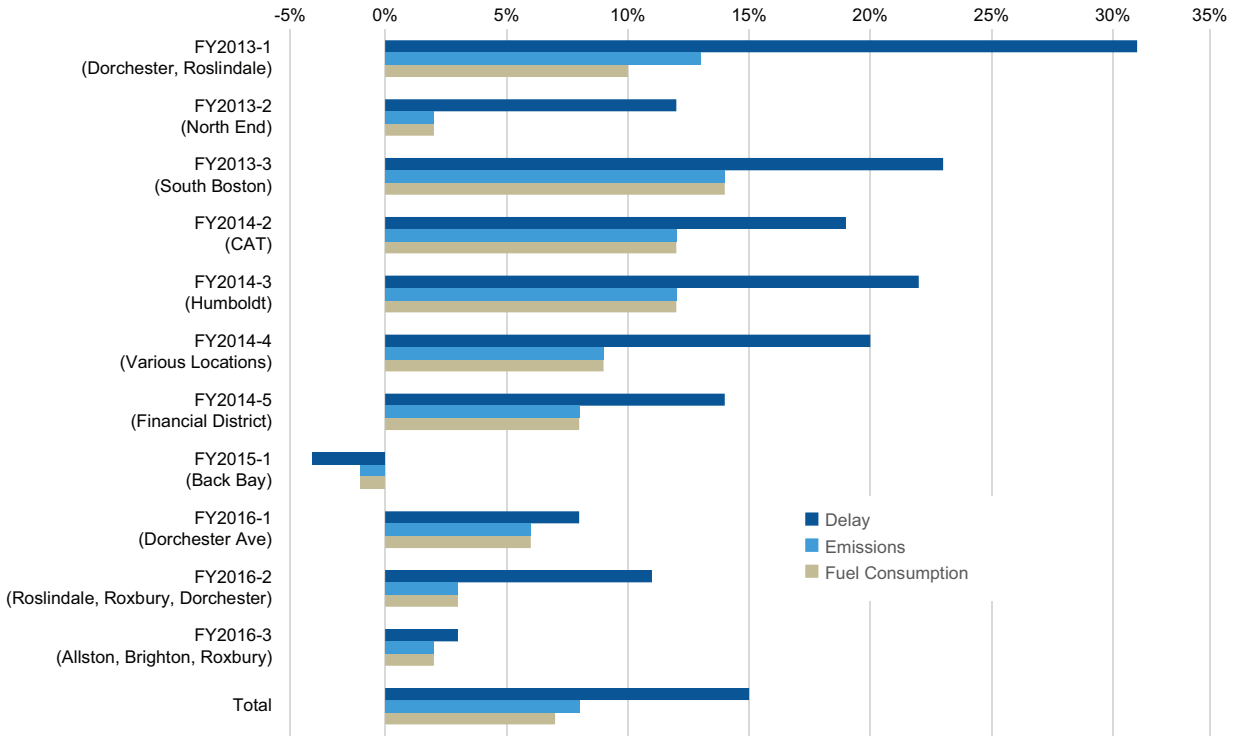
Work Order	Delay (Hours)	Emissions (kg)	Fuel Consumption (gal)
FY2013-1 (Dorchester, Roslindale)	-520 (31%)	-38.02 (13%)	-290 (10%)
FY2013-2 (North End)	-34 (12%)	-1.03 (2%)	-11 (2%)
FY2013-3 (South Boston)	-140 (23%)	-11.17 (14%)	-112 (14%)
FY2014-2 (CAT)	-618 (19%)	-51.79 (12%)	-520 (12%)
FY2014-3 (Humboldt)	-42 (22%)	-3.83 (12%)	-39 (12%)
FY2014-4 (Various Locations)	-48 (20%)	-4.15 (9%)	-42 (9%)
FY2014-5 (Financial District)	-92 (14%)	-7.34 (8%)	-74 (8%)
FY2015-1 (Back Bay)	+37 (-3%)	+1.29 (-1%)	+14 (-1%)
FY2016-1 (Dorchester Ave)	-44 (8%)	-6.35 (6%)	-64 (6%)
FY2016-2 (Roslindale, Roxbury, Dorchester)	-74 (11%)	-3.43 (3%)	-35 (3%)
FY2016-3 (Allston, Brighton, Roxbury)	-31 (3%)	-3.39 (2%)	-34 (2%)
Total	**1,606 (15%)**	**129.21 (8%)**	**-1,207 (7%)**

Notes: Expected daily reductions represent the total of 3 peak hours evaluated (AM, PM & Midday)
Emissions 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. Figure 1 presents graphical representation of Table E-1.

The annualized benefits of the recommended signal retiming improvements are estimated to be approximately **$13,935,000**, while the annualized costs of implementing the signal retiming improvements are estimated to be **$318,000**. This yields a benefit-cost ratio of approximately **44 to 1**, meaning that the

Figure 1: Graphical Representation of Table E-1



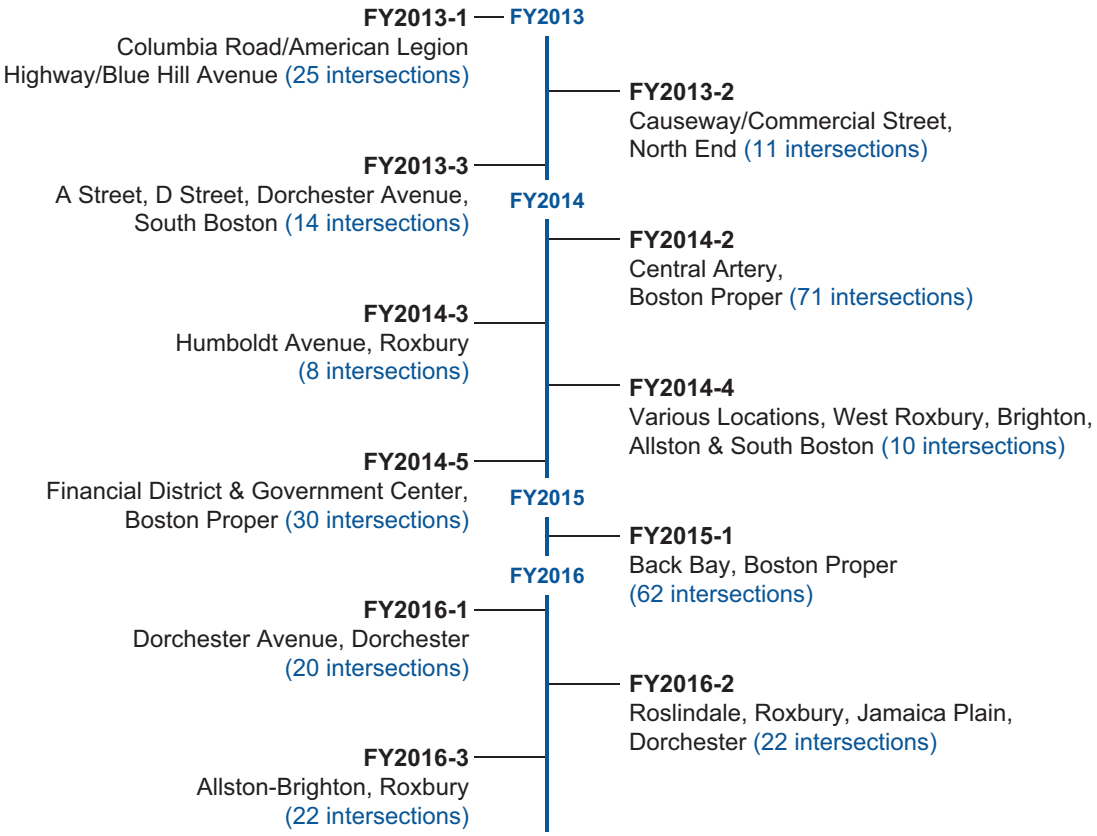
value of the benefits is 44 times greater than the costs to implement the improvements. Given this high rate-of-return, the costs to implement the signal retiming improvements are clearly a worthwhile investment of capital funds by the city, with the benefits accruing for both the roadway users and the citizens of the City of Boston. The benefit-cost analysis is summarized below.

Signal Improvement Benefits	Cost to Implement Improvements	Benefit to Cost Ratio
$13,936,120	**$318,335**	**44:1**

The following report describes in detail the analyses, methodologies, and calculations used to quantify the benefit-cost ratio for the BTD's FY2013 – FY2016 signal retiming program.

1.0 INTRODUCTION

The Boston Transportation Department (BTD) retained Tetra Tech to evaluate potential signal timing improvements under the FY2013 – FY2016 Signal Retiming Program (Contract #35698). This work was completed between August 2012 and June 2016 and was comprised of 11 work orders that included 295[1] intersections throughout the City of Boston (shown on Figures A through K in the appendices). The work orders evaluated under this contract are as follows:



As part of the evaluation performed for each of these work orders, the following deliverables were prepared by Tetra Tech 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. Twelve-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 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. 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 eleven work orders are summarized below. The benefit-cost analyses for each work order are provided in Appendices A through L.

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 2015 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 2014 dollars. For the purposes of this report, the 2014 values were increased to reflect 2015 dollars. The adjustments made to the 2014 values were based on Consumer Price Index (CPI), which indicates an inflationary escalation factor of 0.12 percent between 2014 and 2015. Therefore, the 2014 constants from the 2015 Urban Mobility Report were increased by 0.12 percent.

Urban Mobility Report Constants

Vehicle Occupancy	Average Cost of Time (2015)	Commercial Vehicle Operating Cost (2015)
1.25 persons/vehicle	**$17.69** person-hour	**$94.15** 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 2015 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 2015 Urban Mobility Report (converted to corresponding 2015 dollar values) is $17.69 per person (in passenger cars) and $94.15 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 FY2013 - FY2016 signal retiming program as a whole. All work orders had passenger car and truck delay reductions with annualized benefits except in the Back Bay area, which had a minor increase in vehicular delay.

Table 1 FY2013-FY2016 Signal Retiming Program: Annual Delay Reductions and Annual Benefits

Work Order	Passenger Car Delay (hours)	Truck Delay (hours)	Annual Benefits (2015 Dollars)
FY2013-1 (Dorchester, Roslindale)	159,640	7,540	$3,534,136
FY2013-2 (North End)	10,140	780	$252,828
FY2013-3 (South Boston)	42,380	2,600	$994,551
FY2014-2 (CAT)	186,680	11,440	$4,379,703
FY2014-3 (Humboldt)	12,870	610	$285,134
FY2014-4 (Various Locations)	14,846	586	$317,792
FY2014-5 (Financial District)	27,716	1,727	$652,909
FY2015-1 (Back Bay)	-11,466	-432	-$243,480
FY2016-1 (Dorchester Ave)	13,286	805	$310,820
FY2016-2 (Roslindale, Roxbury, Dorchester)	22,438	1,274	$516,896
FY2016-3 (Allston, Brighton, Roxbury)	9,386	545	$217,365
Total	**487,916**	**27,475**	**$11,218,654**

Notes: Annual benefit calculations based on 2014 delay values given in 2015 Urban Mobility Report and adjusted by consumer price index to create 2015 value. 2015 values are as follows: $17.69 per hour for passenger cars and $94.15 per hour for trucks.

As shown in Table 1, in total, the FY2013 – FY2016 retiming program is expected to reduce person delay (passenger cars) by nearly 488,000 hours per year, and truck delays by over 27,000 hours per year. This equates to an annual benefit of approximately **$11.2 million.**

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 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 two and ten travel time runs were conducted during each peak period with the number of runs varying based on corridor length and congestion. The results of the travel time analyses for each work order, and a total for the FY2013 - FY2016 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 L.

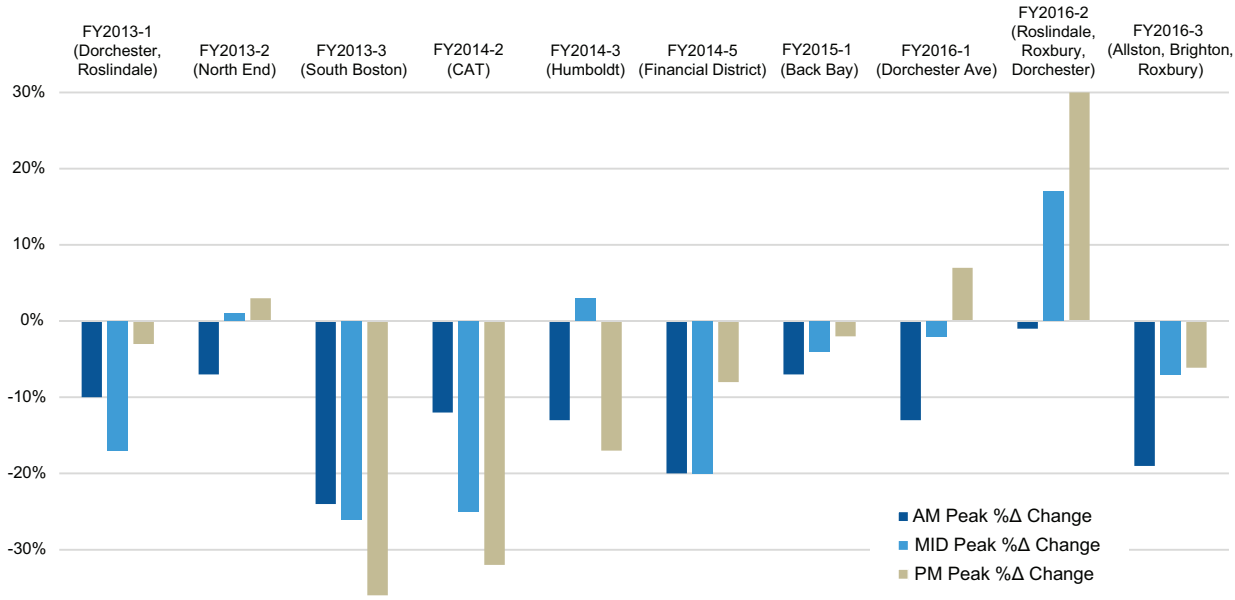
As noted in Table 2, the signal retiming improvements resulted in travel time reductions measured in the field which averaged approximately 11 percent during the AM peak, 12 percent during the Midday peak, and 14 percent during the afternoon peak hour. Figure 2 presents graphical representation of travel time reductions when compared with the existing conditions.

Table 2 FY2013 - FY2016 Signal Retiming Program: Travel Time Comparisons

	AM Peak Hour				Midday Peak Hour				PM Peak Hour			
Work Order	**Before[1]**	**After[2]**	**Δ**	**%Δ[3]**	**Before[1]**	**After[2]**	**Δ**	**%Δ[3]**	**Before[1]**	**After[2]**	**Δ**	**%Δ[3]**
FY2013-1 (Dorchester, Roslindale)	35:30	31:58	-3:32	-10%	32:38	26:56	-5:42	-17%	39:39	38:17	-1:22	-3%
FY2013-2 (North End)	12:48	11:55	-0:53	-7%	11:12	11:22	+0:10	1%	11:24	11:44	+0:22	3%
FY2013-3 (South Boston)	7:15	5:31	-1:44	-24%	6:07	4:30	-1:37	-26%	7:20	4:42	-2:38	-36%
FY2014-2 (CAT)	37:08	32:36	-4:32	-12%	39:56	29:47	-10:09	-25%	57:23	38:59	-18:24	-32%
FY2014-3 (Humboldt)	7:13	6:15	-0:58	-13%	5:52	6:04	+0:12	3%	7:17	6:04	-1:13	-17%
FY2014-5 (Financial District)	16:21	13:07	-3:14	-20%	19:12	15:25	-3:47	-20%	18:58	17:27	-1:31	-8%
FY2015-1 (Back Bay)	43:03	40:01	-3:02	-7%	43:43	41:50	-1:53	-4%	50:30	49:29	-1:01	-2%
FY2016-1 (Dorchester Ave)	55:24	48:27	-6:57	-13%	48:53	48:01	-0:52	-2%	60:19	64:37	+4:18	7%
FY2016-2 (Roslindale, Roxbury, Dorchester)	30:43	30:32	-0:11	-1%	25:16	29:34	+4:18	+17%	37:38	49:03	+11:25	30%
FY2016-3 (Allston, Brighton, Roxbury)	25:11	20:22	-4:49	-19%	22:14	20:45	-1:29	-7%	27:06	25:31	-1:35	-6%
Total	**4:30:36**	**4:00:44**	**-29:52**	**-11%**	**4:15:03**	**3:54:14**	**-30:09**	**-12%**	**5:17:34**	**5:05:53**	**-43:47**	**-14%**

Before[1] = Pre-implementation, Existing Signal Timing conditions travel time runs, After[2] = Post-implementation, Optimized Signal Timing conditions travel time runs, Δ = Change in travel time from existing to optimized conditions, %Δ[3] = Percentage Change from existing to optimized conditions

Figure 2: Graphical Representation of Table 2



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. The 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 2015 report, prepared by the National Highway Traffic Safety Administration. The costs per crash contained in this reference source were increased to 2015 dollars in accordance with the rate of inflation tracked by the CPI.

Economic Costs by Crash Severity (2015 Dollars)

Property Damage Crashes	Injury Crashes	Fatal Crashes
$6,605 per crash	**$47,765** per crash	**$9,941,700** per 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 FY2013 - FY2016 Signal Retiming Program: Safety Benefits

Work Order	Property Damage Only		Personal Injury		Fatality		Annual Benefits
	Existing Crashes	Reduction (-8%)	Existing Crashes	Reduction (-8%)	Existing Crashes	Reduction (-8%)	(2015 Dollars)
FY2013-1 (Dorchester, Roslindale)	30	3	42	4	0	0	$210,874
FY2013-2 (North End)	7	1	6	1	0.33	0.03	$319,482
FY2013-3 (South Boston)	6	1	3	1	0	0	$54,370
FY2014-2 (CAT)	74	6	42	4	0.33	0.03	$495,799
FY2014-3 (Humboldt)	2	0.12	2	0.16	0	0	$8,435
FY2014-4 (Various Locations)	6	1	3	1	0	0	$54,370
FY2014-5 (Financial District)	9	0.69	8	0.67	0	0	$36,423
FY2015-1 (Back Bay)	11	0.85	13	1.04	0.33	0.03	$320,423
FY2016-1 (Dorchester Ave)	6	0.51	16	1.31	0	0	$65,759
FY2016-2 (Roslindale, Roxbury, Dorchester)	3	0.27	4	0.35	0	0	$18,320
FY2016-3 (Allston, Brighton, Roxbury)	6	0.48	11	0.91	0.33	0.03	$311,589
Total	**159**	**14.92**	**152**	**15.43**	**1.33**	**0.11**	**$1,895,844**

Notes: Crashes = Average number of crashes per year at all of the intersections evaluated in the work order based on 3 years of data

Annual Benefits = Expected reduction in Property Damage Only crashes x $6,605 per crash + expected reduction in Personal Injury crashes x $47,765 per crash + expected reduction in fatal crashes x $9,941,700 per crash. Annual benefits for each Work Order rounded to the nearest dollar.

As noted in Table 3, the FY2013 – FY2016 signal retiming program is expected to reduce the total number of crashes at the 295 studied intersections by approximately 30 crashes per year (15 property damage only crashes plus 15 personal injury crashes). The economic benefits to society associated with the crash reductions is estimated to be approximate $1,900,000 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 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 FY2013 – FY2016 signal retiming program, the cost of gasoline has varied significantly (between $2.40 and $3.60 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 $2.40 was used to calculate the annual economic benefits of the improvements. $2.40 represents the average cost of fuel per gallon in 2015 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 FY2013 - FY2016 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 (2015 $)
FY2013-1 (Dorchester, Roslindale)	2908	2618	-290 (10%)	-75,400	$180,960
FY2013-2 (North End)	539	528	-11 (2%)	-4,160	$6,864
FY2013-3 (South Boston)	798	686	-112 (14%)	-29,120	$69,888
FY2014-2 (CAT)	4468	3948	-520 (12%)	-135,200	$324,480
FY2014-3 (Humboldt)	327	288	-39 (12%)	-10,140	$24,336
FY2014-4 (Various Locations)	443	401	-42 (9%)	-10,920	$26,208
FY2014-5 (Financial District)	898	824	-74 (8%)	-19,240	$46,176
FY2015-1 (Back Bay)	2273	2287	+14 (-1%)	+3,640	-$8,736
FY2016-1 (Dorchester Ave)	1002	938	-64 (6%)	-16,640	$39,936
FY2016-2 (Roslindale, Roxbury, Dorchester)	1124	1089	-35 (3%)	-9,160	$21,840
FY2016-3 (Allston, Brighton, Roxbury)	1571	1537	-34 (2%)	-8,840	$21,216
Total	**16,351**	**15,144**	**-1,207 (7%)**	**-313,820**	**$753,168**

Notes: Annual change in fuel consumption = daily change in fuel consumption x 260 work days
Annual benefits = annual change in fuel consumption x $2.40 (average price per gallon of fuel in 2015)
Annual benefits for each Work Order rounded to the nearest dollar

As noted in Table 4, the FY2013 – FY2016 signal retiming program is expected to reduce fuel consumption by more than 1,200 gallons per day, or nearly 314,000 gallons per year. This represents an approximate seven (7) percent reduction in fuel consumption as compared to the pre-improvement conditions and translates to an annual economic benefit of approximately $750,000.

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 2015 dollars based upon Consumer Price Index data.

Economic Costs by Vehicle Emissions (2015 Dollars)

Carbon Monoxide (CO)	Nitrous Oxide (NOx)	Volatile Organic Compunds (VOC)
$138 per metric ton	**$7,482** per metric ton	**$5,676** per 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 FY2013 – FY2016 program.

As noted in Table 8, the signal retiming improvements implemented under the FY2013 – FY2016 program are expected to realize approximately **$68,000** in air quality economic benefits on an annual basis. Additionally, an overall reduction of approximately **34 metric tons** of emissions per year is anticipated to occur as a result of the implementation of the signal retiming improvements (23.56 metric tons of CO + 4.58 metric tons of NOx + 5.46 metric tons of VOC). Figure 3 below presents overall benefits or reductions in emissions (kg/day) when compared with the Existing Conditions.

Figure 3: CO, NOx & VOC Benefits of Signal Retiming Improvements

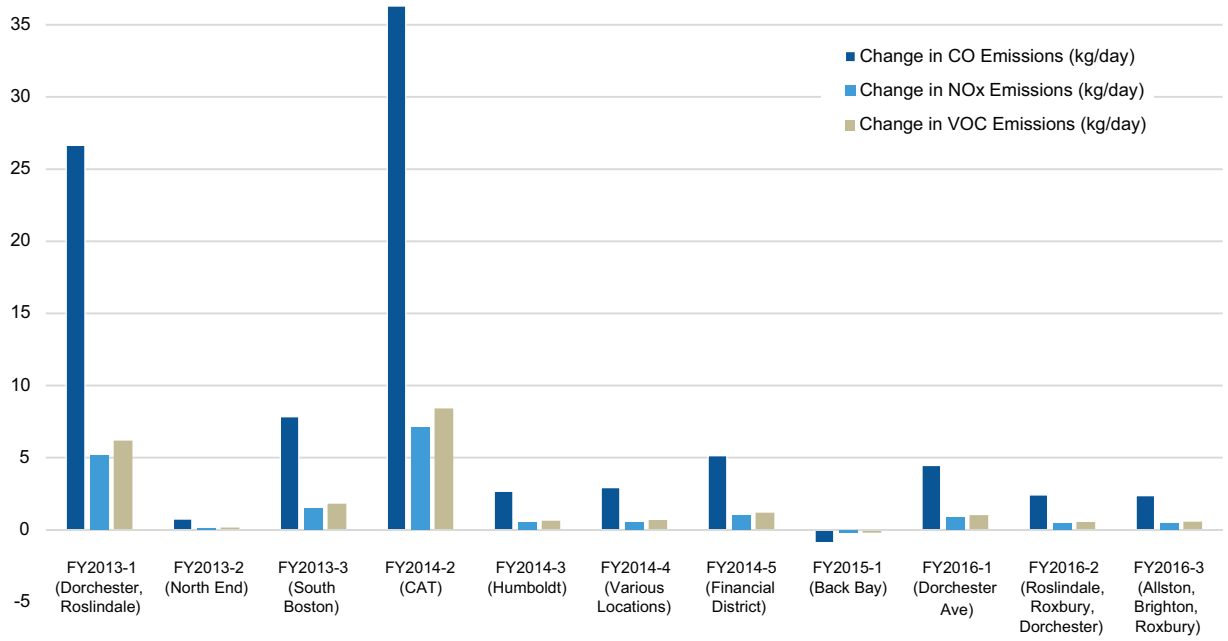


Table 5 FY2013 - FY2016 Signal Retiming Program: Carbon Monoxide (CO) Reductions

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 Benefit (2015 $)
FY2013-1 (Dorchester, Roslindale)	209.64	182.99	26.65	-13%	-6.9290	$953
FY2013-2 (North End)	37.67	36.93	0.74	-2%	-0.1924	$26
FY2013-3 (South Boston)	55.81	47.97	7.84	-14%	-2.0384	$280
FY2014-2 (CAT)	312.32	276.02	36.3	-12%	-9.4380	$1,299
FY2014-3 (Humboldt)	22.81	20.13	2.68	-12%	-0.6968	$96
FY2014-4 (Various Locations)	30.93	28.01	2.92	-9%	-0.7592	$104
FY2014-5 (Financial District)	62.75	57.61	5.14	-8%	-1.3364	$184
FY2015-1 (Back Bay)	158.91	159.8	-0.89	+1%	+0.2314	-$32
FY2016-1 (Dorchester Ave)	70.05	65.59	4.46	-6%	-1.1596	$160
FY2016-2 (Roslindale, Roxbury, Dorchester)	78.55	76.14	2.41	-3%	-0.6266	$86
FY2016-3 (Allston, Brighton, Roxbury)	109.82	107.45	2.37	-2%	-0.6162	$85
Total	**1,149.26**	**1,058.64**	**90.62**	**-8%**	**-23.5612**	**$3,241**

Notes: Annual change in vehicular emissions = daily change in emission x 260 workdays x kilogram to metric ton conversion factor
Annual Benefits = annual change in emission levels x economic cost per metric ton of CO ($137.60/metric ton)
Annual Benefits for each Work Order rounded to the nearest dollar.

Table 6 FY2013 - FY2016 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 Benefit (2015 $)
FY2013-1 (Dorchester, Roslindale)	40.79	35.6	5.19	-13%	-1.3494	$10,096
FY2013-2 (North End)	7.33	7.19	0.14	-2%	-0.0364	$272
FY2013-3 (South Boston)	10.86	9.34	1.52	-14%	-0.3952	$2,957
FY2014-2 (CAT)	60.77	53.7	7.07	-12%	-1.8382	$13,753
FY2014-3 (Humboldt)	4.44	3.92	0.52	-12%	-0.1352	$1,012
FY2014-4 (Various Locations)	6.01	5.46	0.55	-9%	-0.1430	$1,070
FY2014-5 (Financial District)	12.21	11.2	1.01	-8%	-0.2626	$1,965
FY2015-1 (Back Bay)	30.92	31.12	-0.2	+1%	+0.0520	-$389
FY2016-1 (Dorchester Ave)	13.63	12.76	0.87	-6%	-0.2262	$1,692
FY2016-2 (Roslindale, Roxbury, Dorchester)	15.28	14.81	0.47	-3%	-0.1222	$914
FY2016-3 (Allston, Brighton, Roxbury)	21.37	20.91	0.46	-2%	-0.1196	$895
Total	**223.61**	**206.01**	**17.60**	**-8%**	**-4.5760**	**$34,237**

Notes: Annual change in vehicular emissions = daily change in emission x 260 workdays x kilogram to metric ton conversion factor
Annual Benefits = annual change in emission levels x economic cost per metric ton of CO ($137.60/metric ton)
Annual Benefits for each Work Order rounded to the nearest dollar.

Table 7 FY2013 - FY2016 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 Benefit (2015 $)
FY2013-1 (Dorchester, Roslindale)	48.59	42.41	6.18	-13%	-1.6068	$9,120
FY2013-2 (North End)	8.72	8.57	0.15	-2%	-0.0390	$221
FY2013-3 (South Boston)	12.93	11.12	1.81	-14%	-0.4706	$2,671
FY2014-2 (CAT)	72.39	63.97	8.42	-12%	-2.1892	$12,426
FY2014-3 (Humboldt)	5.29	4.66	0.63	-12%	-0.1638	$930
FY2014-4 (Various Locations)	7.17	6.49	0.68	-9%	-0.1768	$1,004
FY2014-5 (Financial District)	14.54	13.35	1.19	-8%	-0.3094	$1,756
FY2015-1 (Back Bay)	36.83	37.03	-0.2	+1%	+0.0520	-$295
FY2016-1 (Dorchester Ave)	16.23	15.21	1.02	-6%	-0.2652	$1,505
FY2016-2 (Roslindale, Roxbury, Dorchester)	18.20	17.65	0.55	-3%	-0.1430	$812
FY2016-3 (Allston, Brighton, Roxbury)	25.46	24.90	0.56	-2%	-0.1456	$826
Total	**266.35**	**245.36**	**20.99**	**-8%**	**-5.4574**	**$30,976**

Notes: Annual change in vehicular emissions = daily change in emission x 260 workdays x kilogram to metric ton conversion factor
Annual Benefits = annual change in emission levels x economic cost per metric ton of CO ($137.60/metric ton)
Annual Benefits for each Work Order rounded to the nearest dollar.

Table 8 FY2013 - FY2016 Signal Retiming Program: Air Quality Benefits Summary

Work Order	Carbon Monoxide (CO)	Nitrous Oxide (NOx)	Volatile Organic Compounds (VOC)	Total Annual Benefits (2015 $)
FY2013-1 (Dorchester, Roslindale)	$953	$10,096	$9,120	$20,169
FY2013-2 (North End)	$26	$272	$221	$519
FY2013-3 (South Boston)	$280	$2,957	$2,671	$5,908
FY2014-2 (CAT)	$1,299	$13,753	$12,426	$27,478
FY2014-3 (Humboldt)	$96	$1,012	$930	$2,038
FY2014-4 (Various Locations)	$104	$1,070	$1,004	$2,178
FY2014-5 (Financial District)	$184	$1,965	$1,756	$3,905
FY2015-1 (Back Bay)	-$32	-$389	-$295	-$716
FY2016-1 (Dorchester Ave)	$160	$1,692	$1,505	$3,357
FY2016-2 (Roslindale, Roxbury, Dorchester)	$86	$914	$812	$1,812
FY2016-3 (Allston, Brighton, Roxbury)	$85	$895	$826	$1,806
Total	**$3,241**	**$34,237**	**$30,976**	**$68,454**

Notes: Total Annual Benefits = annual benefits of CO + NOx + VOC reductions.
Annual Benefits 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 2015 dollars. As shown in Table 9, the FY2013 -FY2016 signal retiming improvements are estimated to yield annual benefits worth **more than $13,900,000.**

Table 9 FY2013 - FY2016 Signal Retiming Program: Total Benefits

Work Order	Delay (Vehicular)	Safety (Crashes)	Energy (Fuel Consumption)	Air Quality (Emissions)	Total Annualized Benefits (2015 $)
FY2013-1 (Dorchester, Roslindale)	$3,534,136	$210,874	$180,960	$20,169	$3,946,139
FY2013-2 (North End)	$252,828	$319,482	$6,864	$519	$579,693
FY2013-3 (South Boston)	$994,551	$54,370	$69,888	$5,908	$1,124,717
FY2014-2 (CAT)	$4,379,703	$495,799	$324,480	$27,478	$5,227,460
FY2014-3 (Humboldt)	$285,134	$8,435	$24,336	$2,038	$319,943
FY2014-4 (Various Locations)	$317,792	$54,370	$26,208	$2,178	$400,548
FY2014-5 (Financial District)	$652,909	$36,423	$46,176	$3,905	$739,413
FY2015-1 (Back Bay)	-$243,480	$320,423	-$8,736	-$716	$67,491
FY2016-1 (Dorchester Ave)	$310,820	$65,759	$39,936	$3,357	$419,872
FY2016-2 (Roslindale, Roxbury, Dorchester)	$516,896	$18,320	$21,840	$1,812	$558,868
FY2016-3 (Allston, Brighton, Roxbury)	$217,365	$311,589	$21,216	$1,806	$551,976
Total	**$11,218,654**	**$1,895,844**	**$753,168**	**$68,454**	**$13,936,120**

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 FY2013 – FY2016 Signal Retiming Program.

Table 10 FY2013 - FY2016 Signal Retiming Program: Benefits Summary

Work Order	Areas/Corridors	# of Intersections	Annualized Benefits
FY2013-1	Columbia Rd/Blue Hill Ave/American Legion Hwy	25	$3,946,139
FY2013-2	Causeway St/Commercial St	11	$579,693
FY2013-3	Dorchester Ave/A St	14	$1,124,717
FY2014-2	Atlantic Ave/Surface Artery/Seaport Blvd/Congress St/Summer St/D St	71	$5,227,460
FY2014-3	Humboldt Ave/Martin Luther King Blvd	8	$319,943
FY2014-4	Various Locations	10	$400,548
FY2014-5	Purchase St/North St/Devonshire St	30	$739,413
FY2015-1	Arlington St/Beacon St/Commonwealth Ave/Boylston St/Huntington Ave/St James St/Columbus Ave/Berkeley St/Clarendon St/Dartmouth St/Exeter St	62	$67,491
FY2016-1	Dorchester Ave	20	$419,872
FY2016-2	Washington St (Roslindale and Roxbury)	19	$558,868
FY2016-3	Cambridge St/N. Beacon St/Brighton Ave/Malcolm X Blvd/Warren St	22	$551,976
Total		**292***	**$13,936,120**

Notes: * Although 295 total locations were analyzed for this contract, the results for three (3) locations from the FY2016-2 (Roslindale & Roxbury) work order have been omitted from all tables and calculations in this benefit-cost analysis per discussions with the BTD.

3.2 Costs Calculations

There are costs to the city associated with the implementation of the recommended signal retiming improvements that were undertaken during the FY2013 – FY2016 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'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 varied year to year, but for consistency throughout this Benefit-Cost Evaluation a CPI of three (3) percent was used for cost calculations. 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 K. 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 FY2013 – FY2016 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 K.

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 K, 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 FY2013 – FY2016 signal retiming program is estimated to be approximately **$318,000 (2015 dollars).**

Table 11 FY2013 - FY2016 Signal Retiming Program: Costs Calculated

Work Order	Areas/Corridors	# of Intersections	Annualized Cost (2015 $)
FY2013-1	Columbia Rd/Blue Hill Ave/American Legion Hwy	25	$36,210
FY2013-2	Causeway St/Commercial St	11	$14,800
FY2013-3	Dorchester Ave/A St	14	$21,495
FY2014-2	Atlantic Ave/Surface Artery/Seaport Blvd/Congress St/Summer St/D St	71	$72,495
FY2014-3	Humboldt Ave/Martin Luther King Blvd	8	$9,355
FY2014-4	Various Locations	10	$12,850
FY2014-5	Purchase St/North St/Devonshire St	30	$30,210
FY2015-1	Arlington St/Beacon St/Commonwealth Ave/Boylston St/Huntington Ave/St James St/Columbus Ave/Berkeley St/Clarendon St/Dartmouth St/Exeter St	62	$58,660
FY2016-1	Dorchester Ave	20	$19,680
FY2016-2	Washington St (Roslindale and Roxbury)	19	$19,510
FY2016-3	Cambridge St/N. Beacon St/Brighton Ave/Malcolm X Blvd/Warren St	22	$23,070
Total		**292***	**$318,335**

Notes: * Although 295 total locations were analyzed for this contract, the results for three (3) locations from the FY2016-2 (Roslindale & Roxbury) work order have been omitted from all tables and calculations in this benefit-cost analysis per discussions with the BTD.

4.0 BENEFIT-COST RATIOS

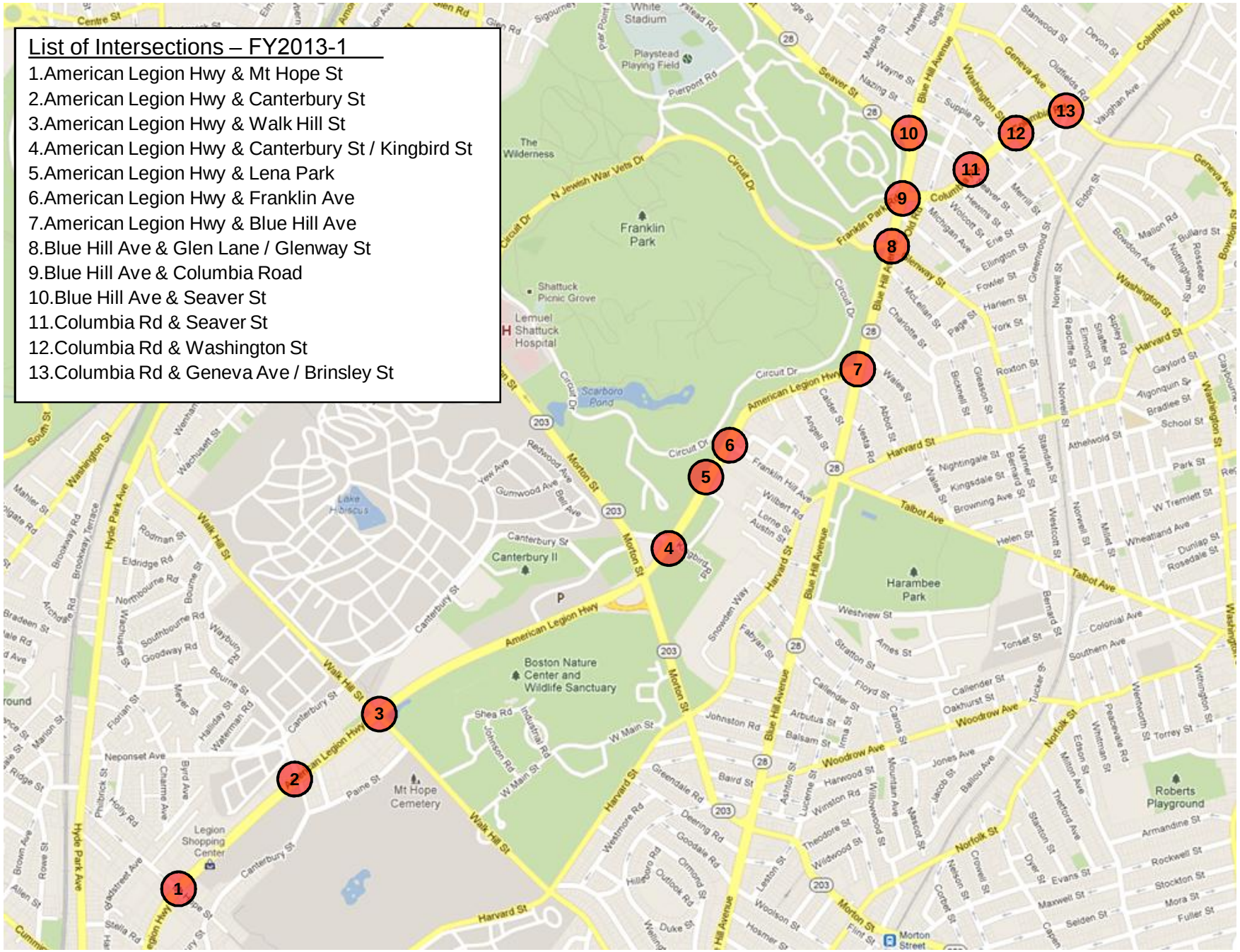
The total benefits and costs associated with the signal retiming improvements implemented through the 11 work orders completed as part of the FY2013 – FY2016 signal retiming program (Contract #35698) are summarized below. The value of the benefits realized by the improvements was calculated to be approximately 44 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 FY2013 – FY2016 signal retiming program is beneficial to both the City of Boston and the users of the city's roadway system.

FY 2013-FY 2016 - Signal Retiming Program: Summary of Benefit-Cost Analysis

Signal Improvement Benefits	Cost to Implement Improvements	Benefit-Cost Ratio
$13,936,120	**$318,335**	**44:1**

APPENDIX A

FY2013-1 (DORCHESTER, ROSLINDALE)



TETRA TECH

Figure A-1

TETRA TECH

Figure A-2

DATA

Data from Network MOE Summary Tables Submitted in Recommendations Technical memorandum								Totals for Final B-C report			
	AM Peak Hour		Midday Peak Hour		PM Peak Hour		Difference				
	Existing	Improved	Existing	Improved	Existing	Improved		Existing	Improved	Δ	Δ%
Total Delay (Hr.)	568	404	382	288	734	472	**-520**	**1684**	**1164**	**-520**	**-31%**
Stops/Vehicle	0.57	0.52	0.56	0.53	0.57	0.53	**-0.12**				
Average Speed (mph)	11	14	12	15	10	14	**10**				
Fuel Consumed (gal)	1036	913	762	702	1110	1003	**-290**	**2908**	**2618**	**290**	**10%**
Fuel Economy (mpg)	10.2	11.8	10.8	12.1	9.4	11.4	**4.9**				
CO Emissions (Kg)	72.39	63.81	53.28	49.05	83.97	70.13	**-26.65**	**209.64**	**182.99**	**26.65**	**13%**
NOx Emissions (Kg)	14.08	12.42	10.37	9.54	16.34	13.64	**-5.19**	**40.79**	**35.60**	**5.19**	**13%**
VOC Emissions (Kg)	16.78	14.79	12.35	11.37	19.46	16.25	**-6.18**	**48.59**	**42.41**	**6.18**	**13%**

Truck Percentages				
Location	**AM**	**MD**	**PM**	**Average**
American Legion Hwy at Mt Hope	4.5%	4.0%	3.1%	3.9%
American Legion Hwy at Canterbury St	5.1%	4.2%	2.0%	3.8%
American Legion Hwy at Walk Hill St	3.9%	4.7%	2.2%	3.6%
American Legion Hwy at Canterbury St / Kingbird St	4.1%	5.2%	2.6%	4.0%
American Legion Hwy at Lena Park	4.3%	5.2%	2.5%	4.0%
American Legion Hwy at Franklin Ave	4.6%	5.7%	2.7%	4.3%
American Legion Hwy at Blue Hill Ave	6.1%	6.0%	3.0%	5.0%
Blue Hill Ave at Glen Lane / Glenway St	6.2%	6.0%	3.8%	5.3%
Blue Hill Ave at Columbia Road	6.1%	6.1%	3.9%	5.4%
Blue Hill Ave at Seaver St	6.5%	5.3%	4.1%	5.3%
Columbia Rd at Seaver St	6.3%	6.9%	2.7%	5.3%
Columbia Rd at Washington St	7.0%	6.0%	3.5%	5.5%
Columbia Rd at Geneva Ave / Brinsley St	8.2%	6.2%	3.2%	5.9%
Columbia Rd at Devon St	7.3%	6.2%	3.2%	5.6%
Columbia Rd at Wyola Place	7.1%	6.1%	3.5%	5.6%
Columbia Rd at Ceylon St / Richfield St	7.0%	6.4%	3.4%	5.6%
Columbia Rd at Quincy St	7.1%	6.5%	6.1%	6.6%
Columbia Rd at Bellevue / Glendale St	7.9%	6.7%	3.1%	5.9%
Columbia Rd at Bird St	9.0%	6.3%	3.9%	6.4%
Columbia Rd at Arion/Davern / Hancock St	8.6%	6.3%	5.0%	6.6%
Columbia Rd at Dudley / Stoughton St	8.1%	6.3%	4.8%	6.4%
Columbia Rd at Annabel / Holden St	6.9%	6.4%	4.7%	6.0%
Columbia Rd at Massachusetts Ave / Boston St	6.8%	6.3%	3.6%	5.6%
Columbia Rd at Pond St	7.8%	7.9%	4.5%	6.7%
Columbia Rd at Dorchester Ave	8.7%	9.3%	5.5%	7.8%
Average				**5.4%**

Crash Data														
Location (BTD Intersection Numbers)														
Severity	**1194**	**1195**	**369**	**999**	**3020**	**1301**	**216**	**215**	**218**	**2103**	**229**	**144**	**541**	**1164**
Property Damage	0	1	2	0	0	1	6	1	4	4	2	3	6	2
Personal Injury	5	11	8	0	0	2	4	3	10	6	2	6	6	2
Fatality	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other	0	0	3	0	0	2	3	4	9	5	2	3	9	2
Total	5	12	14	0	0	5	13	8	23	15	6	12	21	6

Crash Data Continued													
Location (BTD Intersection Numbers)													
Severity	**3121**	**995**	**371**	**4081**	**536**	**226**	**223**	**542**	**220**	**448**	**221**	**Total**	**per Year**
Property Damage	0	1	8	1	1	7	6	0	8	5	22	91	**30**
Personal Injury	4	4	8	4	3	9	5	3	4	4	14	127	**42**
Fatality	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Other	0	6	3	5	1	2	7	5	3	0	2	76	25
Total	4	11	19	10	5	18	18	8	15	9	38	295	98

Benefits Performance Measures values						
Category	**Performance Measures**	**Unit of measure**	**Value per unit in 2009 dollars**	**Value per unit in 2012 dollars**	**Value per unit in 2015 dollars**
Delay	Intersection Delay	Person Hours (Cars)	$16.09	$17.22	$17.69
	Intersection Delay	person Hours (Trucks)	$106.24	$113.68	$94.15
Crashes	Property Damage Only (PDO) Crash	Number of Crashes	$3,165	$3,387	$6,605
	Minor Injury Crash	Number of Crashes	$18,771	$20,085	$47,765
	Moderate Injury Crash	Number of Crashes	$392,755	$420,248	$434,393
	Severe Injury Crash	Number of Crashes	$3,003,746	$3,214,008	$6,065,040
	Fatality Crash	Number of Crashes	$4,207,985	$4,502,544	$9,941,700
Emissions	Carbon Monoxide (CO)	Metric ton	$138	$148	$138
	Nitrous Oxide (Nox)	Metric ton	$7,490	$8,014	$7,482
	Volatile Organic Compounds (VOC)	Metric ton	$5,682	$6,080	$5,676
Energy	Fuel	Gallon	$2.64	$3.60	$2.40

1. 2014 Delay value per unit taken from 2015 Urban Mobility Report
2. 2010 Crash unit value taken from May 2015 (revised) "The Economic and Societal Impact of Motor Vehicle Crashes" Report
3. 2000 Emission value per unit taken from HERS-ST Highway Economic Requirements System – State Version: Technical Report . No 2015 updates were found on FHWA website. Still referring to 2000 $ values
   - Consumer Price Index increased from 2000 to 2015 by 37.6%, from 2010 to 2015 by 8.7%, and from 2014 to 2015 by 0.12%. All values (except fuel price) were adjusted accordingly to calculate equivalent 2015 values.
   - National average Fuel price in 2015 ($2.40) according to AAA

BENEFIT CALCULATIONS

Calculation of Delay Reduction Per Year

Assuming
Truck Percentage: 5.4%
Vehicle Occupancy 1.25
Delay decreased by: 520 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%)	492 hrs.	614	x	260 days/year =	**159,640**	$17.69	$2,824,223.81
Truck Delay (3.4%)	29 hrs.		x	260 days/year =	**7,540**	$94.15	$709,912.47
							$3,534,136.28

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	30	0.08		**3.00**	$6,605	$19,813.84
Personal Injury Accidents	42	0.08		**4.00**	$47,765	$191,059.82
Fatality Accidents	0.00	0.08		-	$9,941,700	$0.00

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	26.65	0.02665	x	260 days/year =	**6.9290**	$138	$953.43
Nox Reduction	5.19	0.00519	x	260 days/year =	**1.3494**	$7,482	$10,096.21
VOC Reduction	6.18	0.00618	x	260 days/year =	**1.6068**	$5,676	$9,120.20

Calculation of Fuel Reduction Per Year

	Gal. per day		Annual Reduction		Cost per Gal.	Benefit per Year
Phase II fuel reduction in gallons =	290	x	260 days/year =	**75,400**	$2.40	$180,960.00

Benefits Summary

Category	Performance Measure	Unit	Value per Unit in 2015 Dollars	Benefits in Appropriate Units	Benefits Value
Delay	Intersection Delay	Person Hours (Cars)	$17.69	159640	$2,824,223.81
		Person Hours (Trucks)	$94.15	7540	$709,912.47
Crashes	Property Damage Only (PDO) Crash	Number of Crashes	$6,605	3	$19,814
	Minor Injury Crash	Number of Crashes	$47,765	4	$191,060
	Moderate Injury Crash	Number of Crashes	$434,393	0	$0
	Severe Injury Crash	Number of Crashes	$6,065,040	0	$0
	Fatality Crash	Number of Crashes	$9,941,700	0	$0
Emissions	Carbon Monoxide (CO)	Metric ton	$138	6.9290	$953
	Nitrous Oxide (Nox)	Metric ton	$7,482	1.3494	$10,096
	Volatile Organic Compounds (VOC)	Metric ton	$5,676	1.6068	$9,120
Energy	Fuel	Gallon	$2.40	75400	$180,960.00
TOTAL					**$3,946,140**

COST CALCULATIONS

Intersection Improvements Cost Calculations

Intersection	Needed Items	Cost Estimate
American Legion Highway/ Mount Hope St	· Repaint crosswalks and stop bars, except Mt Hope St WB approach (about 920 feet 12" white thermo)	$1,840.00
	· Trim trees on Mt Hope St EB approach	Maintenance, N/A
	· Reconstruct all ADA sidewalk ramps	Maintenance, N/A
	· Add R10-15 (TURNING TRAFFIC MUST YIELD TO PEDESTRIANS) sign	$82.50
American Legion Highway/ Canterbury St	· Restripe crosswalks and stop bars on all approaches	$1,420.00
	· Relocate ADA ramp	Maintenance, N/A
	· No action necessary	Maintenance, N/A
American Legion Highway/ Walk Hill St	· Restripe crosswalks and stop bars on all approaches	$2,420.00
American Legion Highway/ Canterbury St/ Kingbird St	· Restripe crosswalks and stop bars on both American Legion Hwy approaches	$1,400.00
	· No action necessary	Maintenance, N/A
American Legion Highway/ Lena Park	· Restripe crosswalks and stop bars	$600.00
	· Fix pedestrian push buttons. This is a pedestrian only crossing, but none of the buttons at this location would actuate the signal	Maintenance, N/A
American Legion Highway/ Franklin Avenue	· Restripe crosswalks and stop bars	$1,100.00
	· Fix broken detector loops, as Intersection is running pretimed with no pedestrian phase	Maintenance, N/A
	· Relocate ADA ramp	Maintenance, N/A
American Legion Highway/ Blue Hill Avenue	· Repair pedestrian signal displays	Maintenance, N/A
	· Repaint signal heads and supports	Maintenance, N/A
Blue Hill Avenue/ Glen Lane / Glenway St	· Replace “Tow Zone, No Stopping Any Time” sign and one “Do Not Enter” (code R5-1) as both are faded.	Maintenance, N/A
	· Repaint back of left pedestal mounted signal facing Blue Hill Ave SB traffic	Maintenance, N/A
	· Repaint bicycle lane markings on Glen Ln approach	$210.00
	· Repaint crosswalks, stop bars and lane use markings on Blue Hill Ave approaches	$1,707.00
	· Secure keep right sign (R4-7) mounted in the center median of Blue Hill Ave SB	Maintenance, N/A
Blue Hill Avenue/ Columbia Road	· Replace faded parking related signs (various types, all in need of replacement)	Maintenance, N/A
	· Repaint faded and peeling signal heads	Maintenance, N/A
	· No action necessary	Maintenance, N/A
Blue Hill Avenue/ Seaver St	· Repaint crosswalk and stop bar across Seaver St EB approach	$660.00
	· Repaint faded and peeling vehicular and pedestrian signal heads	Maintenance, N/A
	· Install visors over red and green indications on right most signal facing Blue Hill Ave NB traffic	Maintenance, N/A
	· Install visor over red indication on left most signal facing Seaver St EB approach	Maintenance, N/A
Columbia Road/ Seaver St	· Repaint crosswalks and stop bars on both Columbia Rd approaches and the Seaver St NB approach	$1,760.00
	· Replace faded “No Parking” signs	Maintenance, N/A
	· Repaint faded yellow signal heads to match the newer equipment which is black	Maintenance, N/A
	· Add visor to red indication on right most signal facing Columbia Rd EB traffic	Maintenance, N/A
	· Repaint LT only markings to be U-turn only markings on the Columbia Rd EB approach to avoid LT's into Seaver St (One-Way)	$227.00
	· Add sign(s) for Columbia Rd EB vehicles (possibly a "No Left Turn" sign to make it clear that a LT is not possible at this location)	$44.00
Columbia Road/ Washington St	· Replace faded “No Parking During St Cleaning & No Parking During Snow Emergency” sign	Maintenance, N/A
	· Replace “2 Hour Parking Limit Mon-Fri 8AM-6PM” sign as it has been defaced	Maintenance, N/A
	· Trim trees near signals on NE and SW corners of the int as these interfere with visibility of signals, especially winter	Maintenance, N/A
	· Repaint yellow signal heads to match the newer equipment, which is black	Maintenance, N/A
	· Repaint peeling pedestrian signal heads	Maintenance, N/A
	· Add pedestrian pushbutton to center median for pedestrians crossing east most Columbia Rd approach	$500
	· No action necessary (does not impact signal operations)	Maintenance, N/A
Columbia Road/ Geneva Avenue/ Brinsley St	· Replace faded no parking signs	Maintenance, N/A
	· Replace damaged “No Turn on Red” sign (R10-11)	Maintenance, N/A
	· Repaint faded, peeling and mismatched signal heads. All should be black in color	Maintenance, N/A
	· No action necessary (does not impact signal operations)	Maintenance, N/A
Columbia Road/ Devon St	· Restripe crosswalks, and stop bars on all approaches	$1,680
	· Repaint “SCHOOL” text on pavement facing Columbia Rd EB vehicles	$220.00
	· No action necessary (stop bar was incorporated into restriping calculation above)	
	· Add pedestrian signal heads across both Devon St approaches	$6,000.00
Columbia Road/ Wyola Place	· Replace faded “No Parking During Snow Emergency” sign	Maintenance, N/A
	· Replace dead L.E.D. bulbs within green indications on Columbia Rd in both directions	Maintenance, N/A
	· Restripe crosswalks, stop bars, and lane use markings on all approaches	$1,620
	· No action necessary (School should incur restriping cost to better delineate entrance from exit)	
	· Remove stop sign from school exit EB approach (no action required as this was said to be done already)	
	· Realign right most signal head facing Columbia Rd WB traffic, as it is askew	Maintenance, N/A
	· Repaint faded and peeling signal heads	Maintenance, N/A
	· Add pedestrian pushbutton to center median on east most Columbia Rd approach, to accommodate slow peds. School nearby	$500
Columbia Road/ Ceylon St/ Columbia Terrace/ Richfield St	· Restripe crosswalks, stop bars, and lane use markings on all approaches	$2,754
	· Repaint signal heads, many are faded and peeling	Maintenance, N/A
	· Secure keep right sign (R4-7) facing Richfield St WB traffic, as an anchor bolt has come loose and the sign is currently upside down	Maintenance, N/A
Columbia Road/ Quincy St	· Repaint faded, mismatched and peeling vehicular and pedestrian signal heads	Maintenance, N/A
	· Add visors to the few signal heads that do not have them	Maintenance, N/A
	· Relocate ADA ramp	Maintenance, N/A
	· Add pedestrian pushbutton to center median for pedestrians crossing west most Columbia Rd approach	$500
	· No action necessary (does not impact signal operations)	Maintenance, N/A
Columbia Road/ Bellevue St/ Glendale St	· Replace faded no parking sign	Maintenance, N/A
	· Restripe all crosswalks and stop bars	$3,240.00
	· Reset and secure left most mast arm mounted signal head facing Columbia Rd NB traffic as it is mounted askew	Maintenance, N/A
Columbia Road/ Bird St	· Restripe crosswalks and stop bars	$3,180.00
	· Repaint faded signal heads	Maintenance, N/A
	· Add visors to the few signal heads that do not have them	Maintenance, N/A
	· Repaint faded signal heads	Maintenance, N/A
	· Add visors to the few signal heads that do not have them	Maintenance, N/A
	· Reset no parking during street cleaning sign which is falling down on Bird St in the EB direction	Maintenance, N/A
	· No action necessary (does not impact signal operations)	Maintenance, N/A
Columbia Rd & Arion/Davern / Hancock St	· Secure existing “Drive Slow” and “No Parking” signs well. These are currently mounted askew	Maintenance, N/A
	· Repaint bicycle lane markings on Columbia Rd EB approach	$130.00
Columbia Rd & Dudley / Stoughton St	· Straighten out “Yield to Pedestrians on Turns” sign facing Columbia Rd SB traffic, as it is bent badly	Maintenance, N/A
	· Restripe double yellow center line where road patching has occurred on Dudley St EB approach	$20.00
	· Repaint bicycle lane markings on both Columbia Rd approaches	$260.00
	· Add diagonal striping to crosswalk across Columbia Rd SB approach to be consistent with all other crosswalks	$360.00
	· Restripe all crosswalks and stop bars (inlcuding Ramsey St)	$2,520.00
	· Repaint yellow signal heads to match other signals and add visor to green indication on signal facing Dudley St	Maintenance, N/A
Columbia Rd & Annabel / Holden St	· Add visor to yellow indication on signal facing Columbia Rd NB traffic	Maintenance, N/A
	· Relocate ADA ramps	Maintenance, N/A
Columbia Rd & Massachusetts Ave / Boston St	· Restripe textured crosswalks and stop bars on all approaches	$3,280.00
	· Restripe lane use marking and bicycle lane markings on Columbia Rd NB approach	$160.00
Columbia Rd & Pond St	· Replace faded “No Parking during snow emergency” and “No parking during St cleaning” signs on Pond St approach	Maintenance, N/A
	· Repaint faded signal heads facing Columbia Rd in the EB and WB directions	Maintenance, N/A
	· Add visor to yellow indication facing Columbia Rd EB traffic	Maintenance, N/A
Columbia Road/Dorchester Avenue	· Replace faded “No Stopping” sign	Maintenance, N/A
	· Remove no left turn from 4-6 PM sign from Columbia Rd WB approach since it is now protected only phasing	$50.00
Signal Equipment Cost that can be annualized over 15 years		**$7,500**
Signing and Pavement Marking Cost that can be annualized over 5 years		**$32,945**
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

Total BTD Contractor costs (Including signal phasing and timing changes and travel time) = $20,000.00

COST CALCULATIONS (Continued)

Engineering Costs, Signs and Pavement Marking Costs	
Engineering Fee for Work Order 1	$100,000.00
BTD Engineering Costs (200 hours at $50/hour)	$10,000.00
Signs and Pavement marking Costs	$32,945
BTD Contractor costs	$20,000
Sum of above costs	$162,944.50
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	$162,945
Assume i=3.0 (CPI)	
N = 5	
Numerator = 0.03*(1+0.03)^5 =	$0.03
Denominator = (1+0.03)^5 -1 =	$0.16
A = P *(Numerator/Denominator)	$35,579.68
Total Annual Engineering/Signs/Markings Cost =	**$35,579.68**

Signal Equipment Costs	
Signal equipment costs	$7,500
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	$7,500
Assume i=3.0 (CPI) N= 15	
Numerator = 0.03*(1+0.03)^15 =	$0.05
Denominator = (1+0.03)^15 -1 =	$0.56
A = P *(Numerator/Denominator)	$628
Total Annual Signal Equipment Costs =	**$628**

Annual Cost Summary	
Type	
Engineering/Signs/Pavement markings	$35,579.68
Signal Equipment	$628
Other Non-Annualized Costs	$0
Total	**$36,208**

COST BENEFIT RATIO CALCULATIONS

Benefit	$3,946,150	
Cost	$36,210	
Ratio		**109 to 1**

APPENDIX B

FY2013-2 (NORTH END)

TETRA TECH

Figure B

DATA

Data from Network MOE Summary Tables Submitted in Recommendations Technical memorandum								Totals for Final B-C report			
	AM Peak Hour		Midday Peak Hour		PM Peak Hour		Difference				
	Existing	Improved	Existing	Improved	Existing	Improved		Existing	Improved	Δ	Δ%
Total Delay (Hr.)	111	91	72	68	111	101	**34**	**294**	**260**	**-34**	**-12%**
Stops/Vehicle	0.53	0.63	0.54	0.54	0.52	0.53	**-0.11**				
Average Speed (mph)	10	12	12	12	11	12	**-3**				
Fuel Consumed (gal)	195	185	144	140	200	203	**11**	**539**	**528**	**11**	**2%**
Fuel Economy (mpg)	8.8	9.2	9.6	9.8	9	9.4	**-1**				
CO Emissions (Kg)	13.65	12.93	10.07	9.82	13.95	14.18	**0.74**	**37.67**	**36.93**	**0.74**	**2%**
NOx Emissions (Kg)	2.66	2.52	1.96	1.91	2.71	2.76	**0.14**	**7.33**	**7.19**	**0.14**	**2%**
VOC Emissions (Kg)	3.16	3	2.33	2.28	3.23	3.29	**0.15**	**8.72**	**8.57**	**0.15**	**2%**

Truck Percentages				
Location	**AM**	**MD**	**PM**	**Average**
Causeway at Lomasney	6.4%	6.3%	3.2%	5.3%
Causeway at Portland	9.6%	7.2%	3.5%	6.8%
Causeway at Haverhill	9.8%	8.3%	4.4%	7.5%
Causeway at N. Washington	8.2%	9.8%	4.5%	7.5%
Commercial at Charter	8.6%	5.8%	2.6%	5.7%
Commercial at Foster	7.6%	6.2%	2.4%	5.4%
Commercial at Hanover	10.4%	8.0%	2.8%	7.1%
Commercial at Battery	8.6%	9.0%	2.4%	6.7%
Commercial at Fleet	7.7%	9.0%	3.4%	6.7%
Atlantic at Commercial	9.8%	6.4%	3.4%	6.5%
Atlantic at Richmond	11.4%	7.7%	3.4%	7.5%
Average				**6.6%**

Crash Data													
Location (BTD Intersection Numbers)													
Severity	**109**	**303**	**506**	**29**	**537**	**328**	**424**	**32**	**33**	**1963**	**1964**	**Total**	**per Year**
Property Damage	5	0	0	7	1	0	2	2	4	0	0	21	**7**
Personal Injury	2	2	1	9	1	0	0	0	1	1	1	18	**6**
Fatality	0	0	0	1	0	0	0	0	0	0	0	1	**0.33**
Other	1	1	0	3	3	0	1	1	0	0	0	10	3
Total	8	3	1	20	5	0	3	3	5	1	1	50	17

Benefits Performance Measures values					
Category	**Performance Measures**	**Unit of measure**	**Value per unit in 2009 dollars**	**Value per unit in 2012 dollars**	**Value per unit in 2015 dollars**
Delay	Intersection Delay	Person Hours (Cars)	$16.09	$17.22	$17.69
	Intersection Delay	person Hours (Trucks)	$106.24	$113.68	$94.15
Crashes	Property Damage Only (PDO) Crash	Number of Crashes	$3,165	$3,387	$6,605
	Minor Injury Crash	Number of Crashes	$18,771	$20,085	$47,765
	Moderate Injury Crash	Number of Crashes	$392,755	$420,248	$434,393
	Severe Injury Crash	Number of Crashes	$3,003,746	$3,214,008	$6,065,040
	Fatality Crash	Number of Crashes	$4,207,985	$4,502,544	$9,941,700
Emissions	Carbon Monoxide (CO)	Metric ton	$138	$148	$138
	Nitrous Oxide (Nox)	Metric ton	$7,490	$8,014	$7,482
	Volatile Organic Compounds (VOC)	Metric ton	$5,682	$6,080	$5,676
Energy	Fuel	Gallon	$2.64	$3.60	$2.40

1. 2014 Delay value per unit taken from 2015 Urban Mobility Report
2. 2010 Crash unit value taken from May 2015 (revised) "The Economic and Societal Impact of Motor Vehicle Crashes" Report
3. 2000 Emission value per unit taken from HERS-ST Highway Economic Requirements System – State Version: Technical Report . No 2015 updates were found on FHWA website. Still referring to 2000 $ values
 - Consumer Price Index increased from 2000 to 2015 by 37.6%, from 2010 to 2015 by 8.7%, and from 2014 to 2015 by 0.12%. All values (except fuel price) were adjusted accordingly to calculate equivalent 2015 values.
 - National average Fuel price in 2015 ($2.40) according to AAA

BENEFIT CALCULATIONS

Calculation of Delay Reduction Per Year

Assuming
Truck Percentage: 6.6%
Vehicle Occupancy 1.25
Delay decreased by: 34 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%)	32 hrs.	39	x	260 days/year =	**10,140**	$17.69	$179,388.81
Truck Delay (3.4%)	3 hrs.		x	260 days/year =	**780**	$94.15	$73,439.22
							$252,828.03

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	7	0.08		**1.00**	$6,605	$6,604.61
Personal Injury Accidents	6	0.08		**1.00**	$47,765	$47,764.95
Fatality Accidents	0.33	0.08		**0.03**	$9,941,700	$265,112.00

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	0.74	0.00074	x	260 days/year =	**0.1924**	$138	$26.47
Nox Reduction	0.14	0.00014	x	260 days/year =	**0.0364**	$7,482	$272.34
VOC Reduction	0.15	0.00015	x	260 days/year =	**0.0390**	$5,676	$221.36

Calculation of Fuel Reduction Per Year

	Gal. per day		Annual Reduction		Cost per Gal.	Benefit per Year
Phase II fuel reduction in gallons =	11	x	260 days/year =	**2,860**	$2.40	$6,864.00

Benefits Summary

Category	Performance Measure	Unit	Value per unit in 2015 dollars	Benefits in Appropriate Units	Benefits Value
Delay	Intersection Delay	Person Hours (Cars)	$17.69	10140	$179,388.81
		Person Hours (Trucks)	$94.15	780	$73,439.22
Crashes	Property Damage Only (PDO) Crash	Number of Crashes	$6,605	1	$6,605
	Minor Injury Crash	Number of Crashes	$47,765	1	$47,765
	Moderate Injury Crash	Number of Crashes	$434,393	0	$0
	Severe Injury Crash	Number of Crashes	$6,065,040	0	$0
	Fatality Crash	Number of Crashes	$9,941,700	0.03	$265,112
Emissions	Carbon Monoxide (CO)	Metric ton	$138	0.1924	$26
	Nitrous Oxide (Nox)	Metric ton	$7,482	0.0364	$272
	Volatile Organic Compounds (VOC)	Metric ton	$5,676	0.0390	$221
Energy	Fuel	Gallon	$2.40	2860	$6,864.00
TOTAL					**$579,694**

COST CALCULATIONS

Intersection Improvements Cost Calculations

Intersection	Needed Items	Cost Estimate
Causeway Street at Lomasney Way	Remove & Reset R3-7R sign	Maintenance, N/A
	Replace damaged D6 sign (25 S.F.)	Maintenance, N/A
	Adjust loose R10-11b sign	Maintenance, N/A
	Repaint signal head assemblies	Maintenance, N/A
Causeway Street at Portland Street	Repaint signal head assemblies	Maintenance, N/A
	Add visor to green indication	Maintenance, N/A
	Replace damaged D6 sign (25 S.F.)	Maintenance, N/A
	Replace backplates on signal heads (2)	Maintenance, N/A
	Add backplate to signal head (1)	$120.00
Causeway Street at Haverhill Street	Repair pedestrian signal head	Maintenance, N/A
	Soften ADA ramp transition	Maintenance, N/A
	Repaint crosswalk and stop bar (about 110 feet 12" white thermo)	$220.00
Causeway Street at North Washington Street	Clean sign	Maintenance, N/A
	Replace signal head	$2,000.00
	Add arrow sign	$24.09
	Adjust "No Left Turn, 7-9 AM, 3:30-6:30 PM" sign	Maintenance, N/A
	Add pavement markings (3 per lane)	$1,264.50
	Replace signal head	$1,000.00
	Switch signal heads	$400.00
Commercial Street at Charter Street	Repaint crosswalks and stop bars (about 280 feet of 12" white thermo)	$560.00
	Add backplate to signal head (1)	$120.00
Commercial Street at Foster Street	Repaint crosswalks, stop bars and bike lanes (about 275 feet 12" white thermo and 120 feet 6" white thermo)	$735.00
	Add visor to red indication	Maintenance, N/A
	Add backplates to Commercial Street signals (6)	$720.00
Commercial Street at Hanover Street	Repaint crosswalks, stop bars and bike lanes (about 400 feet 12" white thermo and 140 feet 6" white thermo)	$940.00
	Repair ADA ramp	Maintenance, N/A
	Repaint signal head assemblies	Maintenance, N/A
	Add backplates to Commecial Street signals (6)	$720.00
Commercial Street at Battery Street	Restripe crosswalks, stop bars, and bike lanes (about 915 feet 12" white thermo and 180 feet 6" white thermo)	$2,010.00
	Repaint signal head assemblies	Maintenance, N/A
	Add backplate to signal head (1)	$120.00
Commercial Street at Atlantic Avenue	Restripe crosswalks, stop bars, and bike lanes (about 860 feet 12" white thermo and 160 feet 6" white thermo)	$1,880.00
	Repaint signal head assemblies	Maintenance, N/A
	Add visor to yellow indication	Maintenance, N/A
	Add backplates to signal heads (4)	$480.00
Atlantic Avenue at Commercial Wharf	Repaint crosswalks and stop bars (about 815 feet 12" white thermo)	$1,630.00
	Repaint signal head assemblies	Maintenance, N/A
	Reconstruct all ADA sidewalk ramps	Maintenance, N/A
	Add backplates to mast arm mounted signal heads (2)	$240.00
Atlantic Avenue at Richmond Street	Repaint crosswalks and stop bars (about 540 feet 12" thermo)	$1,080.00
	Reconstruct all ADA sidewalk ramps	Maintenance, N/A
	Relocate signal head	$200.00
	Replace old pedestrian pushbuttons	Maintenance, N/A
	Add backplates to signal heads (2)	$240.00
Signal Equipment Cost that can be annualized over 15 years		**$6,360**
Signing and Pavement Marking Cost that can be annualized over 5 years		**$10,344**
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

11 intersections with clearance time changes (0.5 hour per intersection at $125 per hour)	$687.50
Travel time for Contractor (4 hours at $125 per hour)	$500.00
BTD Contractor cost for signal phasing changes at Causeway/N Washington St (add exc. Ped phase) and Atlantic/Richmond (remove NB lead phase)	$5,000.00
Total BTD Contractor costs =	**$6,187.50**

COST CALCULATIONS (Continued)

Engineering Costs, Signs and Pavement Marking Costs	
Engineering Fee for Work Order 2	$43,395.00
BTD Engineering Costs (105 hours at $50/hour)	$5,250.00
Signs and Pavement marking Costs	$10,344
BTD Contractor costs	$6,188
Sum of above costs	$65,176.09
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	$65,176
Assume i=3.0 (CPI)	
N = 5	
Numerator = 0.03*(1+0.03)^5 =	$0.03
Denominator = (1+0.03)^5 -1 =	$0.16
A = P *(Numerator/Denominator)	$14,231.50
Total Annual Engineering/Signs/Markings Cost =	**$14,231.50**

Signal Equipment Costs		
Signal equipment costs		$6,360
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		$6,360
Assume i=3.0 (CPI)	N= 15	
Numerator = 0.03*(1+0.03)^15 =		$0.05
Denominator = (1+0.03)^15 -1 =		$0.56
A = P *(Numerator/Denominator)		$533
Total Annual Signal Equipment Costs =		**$533**

Annual Cost Summary	
Type	
Engineering/Signs/Pavement markings	$14,231.50
Signal Equipment	$533
Other Non-Annualized Costs	$0
Total	**$14,764**

COST BENEFIT RATIO CALCULATIONS

Benefit	$579,700	
Cost	$14,800	
Ratio		**39 to 1**

APPENDIX C

FY2013-3 (SOUTH BOSTON)

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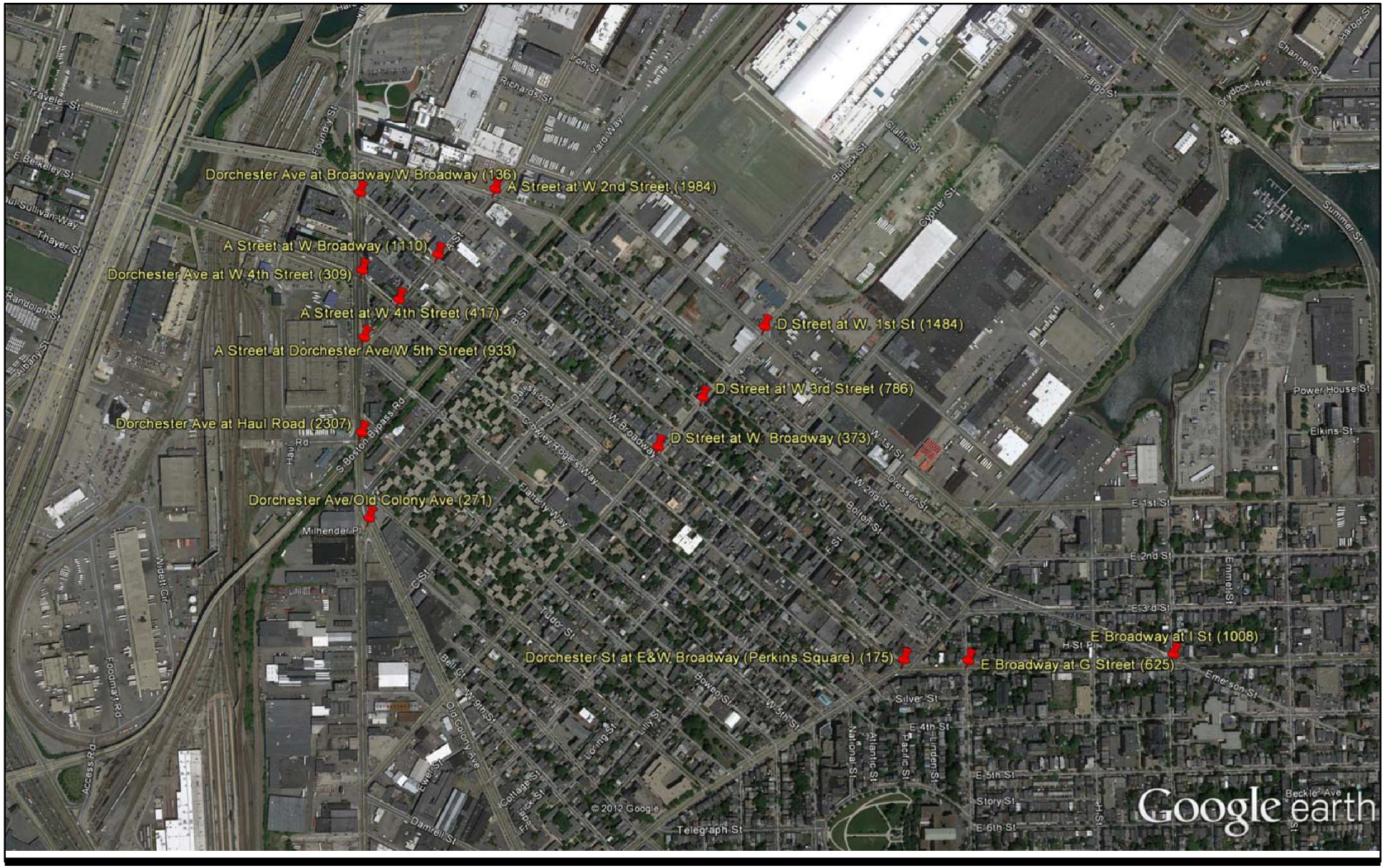


Not to Scale

FY2013-3
Boston, Massachusetts

TETRA TECH

Locus Map

Figure C

DATA

Data from Network MOE Summary Tables Submitted in Recommendations Technical memorandum								Totals for Final B-C report			
	AM Peak Hour		Midday Peak Hour		PM Peak Hour		Difference				
	Existing	Improved	Existing	Improved	Existing	Improved		Existing	Improved	Δ	Δ%
Total Delay (Hr.)	235	178	91	76	284	216	**-140**	**610**	**470**	**-140**	**-23%**
Stops/Vehicle	0.54	0.53	0.56	0.54	0.57	0.53	**-0.07**				
Average Speed (mph)	6	7	9	10	5	6	**3**				
Fuel Consumed (gal)	300	257	158	145	340	284	**-112**	**798**	**686**	**112**	**14%**
Fuel Economy (mpg)	5.6	6.6	7.5	8.2	4.9	5.9	**2.7**				
CO Emissions (Kg)	21	17.98	11.06	10.11	23.75	19.88	**-7.84**	**55.81**	**47.97**	**7.84**	**14%**
NOx Emissions (Kg)	4.09	3.5	2.15	1.97	4.62	3.87	**-1.52**	**10.86**	**9.34**	**1.52**	**14%**
VOC Emissions (Kg)	4.87	4.17	2.56	2.34	5.5	4.61	**-1.81**	**12.93**	**11.12**	**1.81**	**14%**

Truck Percentages				
Location	**AM**	**MD**	**PM**	**Average**
D Street & West 1st Street	13.4%	14.7%	5.5%	11.2%
D Street & West 3rd Street	6.4%	4.7%	3.2%	4.8%
D Street & West Broadway Street	7.5%	5.3%	2.5%	5.1%
East Broadway Street & Emerson Street/I Street	7.9%	5.2%	2.8%	5.3%
East Broadway Street & G Street	10.9%	6.9%	3.8%	7.2%
Dorchester Street & East Broadway Street/West Broadway Street	9.9%	5.7%	2.5%	6.0%
A Street & West Second Street	8.2%	11.9%	3.6%	7.9%
A Street & West Broadway Street	9.1%	8.0%	3.1%	6.7%
A Street & West Fourth Street	7.9%	5.8%	2.9%	5.5%
Dorchester Avenue & Old Colony Avenue	5.4%	7.8%	2.3%	5.2%
A Street & Dorchester Avenue/West 5th Street	5.8%	9.3%	5.1%	6.7%
Dorchester Avenue & West Forth Street	7.4%	8.8%	4.2%	6.8%
Dorchester Avenue & Broadway Street/West Broadway Street	8.3%	9.5%	4.6%	7.5%
Dorchester Avenue & Haul Road	5.5%	9.7%	4.2%	6.5%
Average				**6.6%**

Crash Data																
Location (BTD Intersection Numbers)																
Severity	**1484**	**786**	**373**	**1008**	**625**	**175**	**1984**	**1110**	**417**	**271**	**933**	**309**	**136**	**2307**	**Total**	**per Year**
Property Damage	3	1	0	2	2	0	1	1	0	1	2	2	2	0	17	**6**
Personal Injury	0	0	3	0	0	0	0	1	2	1	0	1	2	0	10	**3**
Fatality	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Other	0	0	2	2	1	0	1	1	0	0	0	1	2	0	10	**3**
Total	3	1	5	4	3	0	2	3	2	2	2	4	6	0	37	**12**

Benefits Performance Measures values					
Category	**Performance Measures**	**Unit of measure**	**Value per unit in 2009 dollars**	**Value per unit in 2012 dollars**	**Value per unit in 2015 dollars**
Delay	Intersection Delay	Person Hours (Cars)	$16.09	$17.22	$17.69
	Intersection Delay	person Hours (Trucks)	$106.24	$113.68	$94.15
Crashes	Property Damage Only (PDO) Crash	Number of Crashes	$3,165	$3,387	$6,605
	Minor Injury Crash	Number of Crashes	$18,771	$20,085	$47,765
	Moderate Injury Crash	Number of Crashes	$392,755	$420,248	$434,393
	Severe Injury Crash	Number of Crashes	$3,003,746	$3,214,008	$6,065,040
	Fatality Crash	Number of Crashes	$4,207,985	$4,502,544	$9,941,700
Emissions	Carbon Monoxide (CO)	Metric ton	$138	$148	$138
	Nitrous Oxide (Nox)	Metric ton	$7,490	$8,014	$7,482
	Volatile Organic Compounds (VOC)	Metric ton	$5,682	$6,080	$5,676
Energy	Fuel	Gallon	$2.64	$3.60	$2.40

1. 2014 Delay value per unit taken from 2015 Urban Mobility Report
2. 2010 Crash unit value taken from May 2015 (revised) "The Economic and Societal Impact of Motor Vehicle Crashes" Report
3. 2000 Emission value per unit taken from HERS-ST Highway Economic Requirements System – State Version: Technical Report . No 2015 updates were found on FHWA website. Still referring to 2000 $ values
   - Consumer Price Index increased from 2000 to 2015 by 37.6%, from 2010 to 2015 by 8.7%, and from 2014 to 2015 by 0.12%. All values (except fuel price) were adjusted accordingly to calculate equivalent 2015 values.
   - National average Fuel price in 2015 ($2.40) according to AAA

BENEFIT CALCULATIONS

Calculation of Delay Reduction Per Year

Assuming
Truck Percentage: 6.6%
Vehicle Occupancy 1.25
Delay decreased by: 140 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 (93.4%)	131 hrs.	163	x	260 days/year =	**42,380**	$17.69	$749,753.23
Truck Delay (6.6%)	10 hrs.		x	260 days/year =	**2,600**	$94.15	$244,797.40
							$994,550.63

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	6	0.08	**1.00**	$6,604.61	$6,604.61
Personal Injury Accidents	3	0.08	**1.00**	$47,764.95	$47,764.95
Fatality Accidents	0	0.08	**-**	$9,941,700	$0.00

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	7.84	0.00784	x	260 days/year =	**2.0384**	$137.60	$280.48
Nox Reduction	1.52	0.00152	x	260 days/year =	**0.3952**	$7,482.00	$2,956.89
VOC Reduction	1.81	0.00181	x	260 days/year =	**0.4706**	$5,676.00	$2,671.13

Calculation of Fuel Reduction Per Year

	Gal. per day		Annual Reduction		Cost per Gal.	Benefit per Year
Fuel reduction in gallons =	112	x	260 days/year =	**29,120**	$2.40	$69,888.00

Benefits Summary

Category	Performance Measure	Unit	Value per unit in 2015 dollars	Benefits in Appropriate Units	Benefits Value
Delay	Intersection Delay	Person Hours (Cars)	$17.69	42380	$749,753
		Person Hours (Trucks)	$94.15	2600	$244,797
Crashes	Property Damage Only (PDO) Crash	Number of Crashes	$6,605	1	$6,605
	Minor Injury Crash	Number of Crashes	$47,765	1	$47,765
	Moderate Injury Crash	Number of Crashes	$434,393	0	$0
	Severe Injury Crash	Number of Crashes	$6,065,040	0	$0
	Fatality Crash	Number of Crashes	$9,941,700	0	$0
Emissions	Carbon Monoxide (CO)	Metric ton	$138	2.0384	$280
	Nitrous Oxide (Nox)	Metric ton	$7,482	0.3952	$2,957
	Volatile Organic Compounds (VOC)	Metric ton	$5,676	0.4706	$2,671
Energy	Fuel	Gallon	$2.40	29120	$69,888
TOTAL					**$1,124,717**

COST CALCULATIONS

Intersection Improvements Cost Calculations

Intersection	Needed Items	Cost Estimate
D Street & West 1st Street	· Add visor over green indication of the right most signal facing D Street northbound traffic	Maintenance, N/A
	· Restripe crosswalks and lane use markings as most are worn or faded	$3,514.50
	· Repair or replace bent visor over yellow indication on right most signal facing D Street northbound traffic	Maintenance, N/A
	· Add backplates to all signals except those facing D Street southbound traffic to reduce solar glare	$720.00
	· Consider adding advanced lane use marking signs to improve clarification for drivers	$1,110.00
	· Replace 5 section signal head facing W. 1st St EB vehicles with 3 section head, as phasing has been changed to permissive operations	Maintenance, N/A
D Street & West 3rd Street/Athens Street	· Repaint the portion of the crosswalk across the D Street southbound approach that has been paved over	$110.00
	· Repair landing area for ADA ramps, as it is in poor condition at many locations	Maintenance, N/A
	· Replace small green indications on signals facing D Street northbound traffic at Athens Street	Maintenance, N/A
D Street & West Broadway Street	· Repaint faded crosswalks, and stop bars. Also repaint double yellow center lines on both D Street approaches	$1,830.00
	· Mount “no turn on red” (sign code R11b) lower on mast arm support facing D Street southbound approach	Maintenance, N/A
East Broadway Street & Emerson Street/I Street	· Repaint left most signal facing East Broadway eastbound traffic	Maintenance, N/A
	· Install backplates on East Broadway approaches to reduce glare	$480.00
East Broadway Street & G Street	· Install visor over yellow indication in signal facing East Broadway Street westbound traffic	Maintenance, N/A
Dorchester Street & East Broadway St/West Broadway St	· Repaint Dorchester Avenue northeast bound stop bar and accompanying crosswalk	$610.00
	· Paint left turn only and shared through/right lane pavement markings on northeast bound approach	$735.00
	· Replace left turn only/right turn only sign with left turn only/through-right sign on northeast bound approach	$185.00
A Street & West 2nd Street	· Repaint faded and cracking crosswalks, stop bars and pavement markings	$1,600.00
	· Install visors on all signal heads, many are missing	Maintenance, N/A
	· Install backplates on all signals to reduce glare	$960.00
	· Reconstruct ADA ramps to line up better with crosswalk striping	Maintenance, N/A
	· Repaint faded vehicular signal heads, pedestrian signal heads and chipping/faded pedestal mounts	Maintenance, N/A
A Street & West Broadway Street	· A St SB lane configuration changed from a RT only lane and LT/TH lanr to a TH/RT and LT only lane. Restripe pavement to reflect this change	$735.00
	· Reconstruct ADA ramps to smooth out transitions and better align with crosswalk striping	Maintenance, N/A
	· Install visor over red indication facing West Broadway Street westbound traffic	Maintenance, N/A
A Street & West 4th Street	· Repaint faded vehicular signal heads, pedestrian signal heads and chipping/faded pedestal mounts	Maintenance, N/A
	· Replace old style pedestrian push button (very small button) with newer more user friendly style button	Maintenance, N/A
Dorchester Avenue & Old Colony Avenue	· Add backplates to the three signal heads that do not have any	$360.00
A Street & Dorchester Avenue/West 5th Street	· Replace both SB and leftmost NB green ball lenses with green vertical ball lenses to indicate that no turns are allowed from those lanes	Maintenance, N/A
	· Add standard “no turns” sign (sign code R3-2) to Dorchester Avenue southbound approach as the current sign and text are very small	$185.00
	· Add “no u-turns” sign (sign code R3-4) to medians on Dorchester Avenue in both directions	$370.00
	· Add visor to green indication facing A Street westbound traffic	Maintenance, N/A
Dorchester Avenue & West 4th Street	· Add yield on green signage (sign code R10-12). Many drivers don't yield on green on Dot Ave in the NB direction, dangerous for concurrent peds	$127.00
Dorchester Avenue & Broadway St/West Broadway St	· Secure leftmost signal facing Dorchester Avenue northbound vehicles as it appears unstable	Maintenance, N/A
	· Restripe pavement markings and crosswalks on Broadway Street eastbound approach, and Dorchester Avenue southbound approach	$1,641.60
	· Restripe pavement markings on West Broadway Street westbound approach	$562.00
	· Add backplates to signal heads, especially those facing the Broadway and West Broadway Street approaches	$960.00
Dorchester Avenue & Haul Road	· Dorchester Avenue southbound right most signal’s yellow indication is out	Maintenance, N/A
	· Replace 5 section signal head facing Dot Avet NB vehicles with 3 section head, as phasing has been changed to permissive operations	$1,000.00
	· Repaint signal head facing Dorchester Avenue northbound vehicles. This signal also appears unstable	Maintenance, N/A
	· Add visors to green indications which do not have them	Maintenance, N/A
	· Rehabilitate ADA ramps that are in disrepair	Maintenance, N/A
	· Add crosswalk across Haul Road	$420.00
Signal Equipment Cost that can be annualized over 15 years		**$4,480**
Signing and Pavement Marking Cost that can be annualized over 5 years		**$13,735**
Costs that cannot be annualized		**$0**
NOTE - Improvements considered above are based on Table 1 of Recommendations Technical memorandum		
Total BTD Contractor costs (Including signal phasing and timing changes and travel time) =		**$13,700.00**

COST CALCULATIONS (Continued)

Engineering Costs, Signs and Pavement Marking Costs	
Engineering Fee for Work Order 1	$55,580.00
BTD Engineering Costs (200 hours at $50/hour)	$13,700.00
Signs and Pavement marking Costs	$13,735.10
BTD Contractor costs	$13,700.00
Sum of above costs	$96,715.10
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	$96,715.10
Assume i=3.0 (CPI)	
N = 5	
Numerator = 0.03*(1+0.03)^5 =	$0.03
Denominator = (1+0.03)^5 -1 =	$0.16
A = P *(Numerator/Denominator)	$21,118.18
Total Annual Engineering/Signs/Markings Cost =	**$21,118.18**

Signal Equipment Costs		
Signal equipment costs		$4,480
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		$4,480
Assume i=3.0 (CPI)	N= 15	
Numerator = 0.03*(1+0.03)^15 =		$0.05
Denominator = (1+0.03)^15 -1 =		$0.56
A = P *(Numerator/Denominator)		$375
Total Annual Signal Equipment Costs =		**$375**

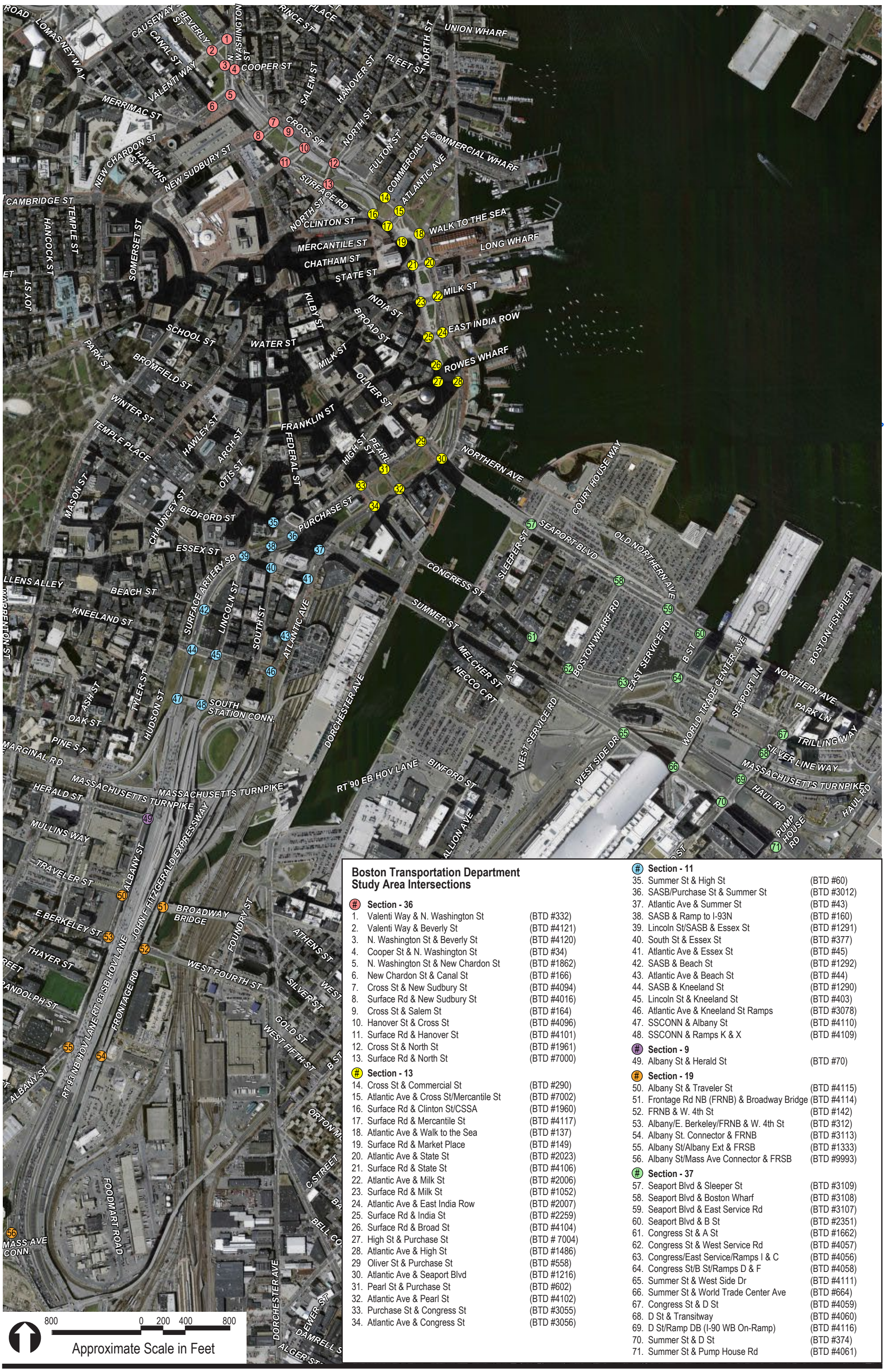
Annual Cost Summary	
Type	
Engineering/Signs/Pavement markings	$21,118
Signal Equipment	$375
Other Non-Annualized Costs	$0
Total	**$21,493**

COST BENEFIT RATIO CALCULATIONS

Benefit	$1,124,700	
Cost	$21,495	
Ratio		**52 to 1**

APPENDIX D

FY2014-2 (CAT)



Boston Transportation Department
Study Area Intersections

Section - 36

1. Valenti Way & N. Washington St (BTD #332)
2. Valenti Way & Beverly St (BTD #4121)
3. N. Washington St & Beverly St (BTD #4120)
4. Cooper St & N. Washington St (BTD #34)
5. N. Washington St & New Chardon St (BTD #1862)
6. New Chardon St & Canal St (BTD #166)
7. Cross St & New Sudbury St (BTD #4094)
8. Surface Rd & New Sudbury St (BTD #4016)
9. Cross St & Salem St (BTD #164)
10. Hanover St & Cross St (BTD #4096)
11. Surface Rd & Hanover St (BTD #4101)
12. Cross St & North St (BTD #1961)
13. Surface Rd & North St (BTD #7000)

Section - 13

14. Cross St & Commercial St (BTD #290)
15. Atlantic Ave & Cross St/Mercantile St (BTD #7002)
16. Surface Rd & Clinton St/CSSA (BTD #1960)
17. Surface Rd & Mercantile St (BTD #4117)
18. Atlantic Ave & Walk to the Sea (BTD #137)
19. Surface Rd & Market Place (BTD #149)
20. Atlantic Ave & State St (BTD #2023)
21. Surface Rd & State St (BTD #4106)
22. Atlantic Ave & Milk St (BTD #2006)
23. Surface Rd & Milk St (BTD #1052)
24. Atlantic Ave & East India Row (BTD #2007)
25. Surface Rd & India St (BTD #2259)
26. Surface Rd & Broad St (BTD #4104)
27. High St & Purchase St (BTD # 7004)
28. Atlantic Ave & High St (BTD #1486)
29. Oliver St & Purchase St (BTD #558)
30. Atlantic Ave & Seaport Blvd (BTD #1216)
31. Pearl St & Purchase St (BTD #602)
32. Atlantic Ave & Pearl St (BTD #4102)
33. Purchase St & Congress St (BTD #3055)
34. Atlantic Ave & Congress St (BTD #3056)

Section - 11

35. Summer St & High St (BTD #60)
36. SASB/Purchase St & Summer St (BTD #3012)
37. Atlantic Ave & Summer St (BTD #43)
38. SASB & Ramp to I-93N (BTD #160)
39. Lincoln St/SASB & Essex St (BTD #1291)
40. South St & Essex St (BTD #377)
41. Atlantic Ave & Essex St (BTD #45)
42. SASB & Beach St (BTD #1292)
43. Atlantic Ave & Beach St (BTD #44)
44. SASB & Kneeland St (BTD #1290)
45. Lincoln St & Kneeland St (BTD #403)
46. Atlantic Ave & Kneeland St Ramps (BTD #3078)
47. SSCONN & Albany St (BTD #4110)
48. SSCONN & Ramps K & X (BTD #4109)

Section - 9

49. Albany St & Herald St (BTD #70)

Section - 19

50. Albany St & Traveler St (BTD #4115)
51. Frontage Rd NB (FRNB) & Broadway Bridge (BTD #4114)
52. FRNB & W. 4th St (BTD #142)
53. Albany/E. Berkeley/FRNB & W. 4th St (BTD #312)
54. Albany St. Connector & FRNB (BTD #3113)
55. Albany St/Albany Ext & FRSB (BTD #1333)
56. Albany St/Mass Ave Connector & FRSB (BTD #9993)

Section - 37

57. Seaport Blvd & Sleeper St (BTD #3109)
58. Seaport Blvd & Boston Wharf (BTD #3108)
59. Seaport Blvd & East Service Rd (BTD #3107)
60. Seaport Blvd & B St (BTD #2351)
61. Congress St & A St (BTD #1662)
62. Congress St & West Service Rd (BTD #4057)
63. Congress/East Service/Ramps I & C (BTD #4056)
64. Congress St/B St/Ramps D & F (BTD #4058)
65. Summer St & West Side Dr (BTD #4111)
66. Summer St & World Trade Center Ave (BTD #664)
67. Congress St & D St (BTD #4059)
68. D St & Transitway (BTD #4060)
69. D St/Ramp DB (I-90 WB On-Ramp) (BTD #4116)
70. Summer St & D St (BTD #374)
71. Summer St & Pump House Rd (BTD #4061)

TETRA TECH
One Grant Street
Framingham, MA 01701-9005
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www.tetratech.com

Central Artery Intersections (FY 2014-2)
Boston Transportation Department (BTD)
Boston, Massachusetts
BTD Intersection Locations

Figure **D**

DATA

Data from Network MOE Summary Tables After Fine Tuning Changes								Totals for Final B-C report			
	AM Peak Hour		Midday Peak Hour		PM Peak Hour		Combined				
	Existing	Improved	Existing	Improved	Existing	Improved	Difference	Existing	Improved	Δ	Δ%
Total Delay (Hr.)	1065	884	599	531	1593	1224	**-618**	**3257**	**2639**	**-618**	**-19%**
Stops/Vehicle	0.58	0.54	0.55	0.5	0.59	0.55	**-0.13**				
Average Speed (mph)	7	8	9	10	5	6	**3**				
Fuel Consumed (gal)	1498	1339	1016	945	1954	1664	**-520**	**4468**	**3948**	**520**	**12%**
Fuel Economy (mpg)	6.2	6.9	7.6	8.2	5.2	6.1	**2.2**				
CO Emissions (Kg)	104.7	93.63	71.03	66.06	136.59	116.33	**-36.3**	**312.32**	**276.02**	**36.3**	**12%**
NOx Emissions (Kg)	20.37	18.22	13.82	12.85	26.58	22.63	**-7.07**	**60.77**	**53.70**	**7.07**	**12%**
VOC Emissions (Kg)	24.27	21.7	16.46	15.31	31.66	26.96	**-8.42**	**72.39**	**63.97**	**8.42**	**12%**

Truck Percentages

Location	AM	MD	PM	Average	Location	AM	MD	PM	Average
Valenti Way & N. Washington St (BTD #332)	9.5%	8.9%	6.8%	**8.4%**	Atlantic Ave & Summer St (BTD #43)	9.1%	8.4%	4.4%	7.3%
Valenti Way & Beverly St (BTD #4121	11.2%	6.7%	10.1%	**9.3%**	Surface St & Ramp to I-93N (BTD #160)	0.0%	0.0%	0.0%	0.0%
N. Washington & Beverly St (BTD #4120)	9.7%	9.4%	7.4%	**8.8%**	Lincoln St/SASB & Essex St (BTD #1291)	10.3%	8.2%	5.4%	8.0%
Cooper St & N. Washington St (BTD #34)	9.7%	9.4%	7.4%	**8.8%**	South St & Essex St (BTD #377)	10.5%	8.6%	4.9%	8.0%
Surface Artery SB(SASB) & New Chardon St(BTD #1862)	7.7%	6.4%	5.4%	**6.5%**	Atlantic Ave & Essex St (BTD #45)	6.6%	6.3%	3.6%	5.5%
New Chardon St & Canal St (BTD #166)	7.7%	6.4%	5.4%	**6.5%**	SASB & Beach St (BTD #1292)	13.6%	6.8%	5.7%	8.7%
Cross St & New Sudbury St (BTD #4094)	9.8%	9.3%	4.9%	**8.0%**	Atlantic Ave & Beach St (BTD #44)	4.0%	5.3%	5.2%	4.8%
SASB & New Sudbury St (BTD #4016)	13.3%	8.4%	7.8%	**9.8%**	SASB & Kneeland St (BTD #1290)	9.9%	7.1%	4.4%	7.1%
Cross St & Salem St (BTD #164)	9.8%	9.3%	4.9%	**8.0%**	Lincoln St & Kneeland St (BTD #403)	6.4%	5.1%	3.6%	5.0%
Hanover St & Cross St (BTD #4096)	7.8%	8.7%	2.1%	**6.2%**	Atlantic Ave & Kneeland St Ramps (BTD #3078)	6.1%	7.0%	4.3%	5.8%
SASB & Hanover (BTD #4101)	7.1%	8.4%	3.6%	**6.4%**	South Station Connector (SSCONN) & Albany St (BTD #4110)	13.8%	8.4%	4.5%	8.9%
Cross St & North St (BTD #1961)	7.7%	7.4%	1.7%	**5.6%**	SSCONN & Ramps K & X (BTD #4109)	9.4%	6.2%	7.6%	7.7%
SASB & North St (BTD #7000)	4.4%	6.9%	5.3%	**5.5%**	Albany St & Herald St (BTD #70)	8.3%	6.3%	4.5%	6.4%
Cross St & Commercial St (BTD #290)	12.2%	9.4%	3.2%	**8.3%**	Albany St & Traveler St (BTD #4115)	7.4%	8.4%	3.0%	6.3%
Atlantic Ave & Cross St/Mercantile St (BTD #7002)	12.6%	9.4%	3.1%	**8.4%**	Frontage Rd NB (FRNB) & Broadway Bridge (BTD #4114)	7.3%	8.2%	3.3%	6.3%
SASB & Clinton St/CSSA (BTD #1960)	4.6%	6.4%	4.6%	**5.2%**	FRNB & W. 4th St (BTD #142)	7.8%	9.0%	3.0%	6.6%
SASB & Mercantile St (BTD #4117)	4.3%	7.9%	5.2%	**5.8%**	Albany/E. Berkeley/FRNB & W. 4th St (BTD #312)	7.8%	9.0%	3.0%	6.6%
Atlantic Ave & Walk to the Sea (BTD #137)	14.0%	11.5%	3.9%	**9.8%**	Albany St. Connector & FRNB (BTD #3113)	6.9%	7.9%	5.8%	6.9%
SASB & Market Place (BTD #149)	4.3%	7.9%	5.2%	**5.8%**	Albany St/Albany Ext & FRSB (BTD #1333)	6.8%	7.9%	6.2%	7.0%
Atlantic Ave & State St (BTD #2023)	14.0%	11.5%	3.9%	**9.8%**	Albany St/Mass Ave Connector & FRSB (BTD #9993)	8.5%	9.9%	6.7%	8.4%
SASB & State St (BTD #4106)	5.3%	7.0%	5.3%	**5.9%**	Seaport Blvd & Sleeper St (BTD #3109)	7.9%	11.1%	3.6%	7.5%
Atlantic Ave & Milk St (BTD #2006)	12.5%	10.8%	3.7%	**9.0%**	Seaport Blvd & Boston Wharf (BTD #3108)	9.3%	10.7%	2.6%	7.5%
SASB & Milk St (BTD #1052)	3.7%	6.5%	5.2%	**5.1%**	Seaport Blvd & East Service Rd (BTD #3107)	8.5%	9.3%	3.0%	6.9%
Atlantic Ave & East India Row (BTD #2007)	13.0%	10.7%	3.8%	**9.2%**	Seaport Blvd & B St (BTD #2351)	11.2%	10.8%	3.7%	8.6%
SASB & India St (BTD #2259)	4.1%	6.5%	5.3%	**5.3%**	Congress St & A St (BTD #1662)	7.7%	7.2%	2.5%	5.8%
Broad St & Purchase St (BTD #4104)	4.5%	6.3%	6.7%	**5.8%**	Congress St & West Service Rd (BTD #4057)	7.9%	9.1%	3.0%	6.7%
High St & Purchase St (BTD # 7004)	4.6%	6.2%	3.1%	**4.6%**	Congress/East Service/Ramps I & C (BTD #4056)	3.9%	5.7%	2.7%	4.1%
Atlantic Ave & High St (BTD #1486)	11.7%	10.2%	3.5%	**8.5%**	Congress St/B St/Ramps D & F (BTD #4058)	7.7%	10.0%	3.1%	6.9%
Oliver St & Purchase St (BTD #558)	4.3%	7.3%	4.0%	**5.2%**	Summer St & West Side Dr (BTD #4111)	9.7%	8.3%	4.7%	7.6%
Atlantic Ave & Seaport Blvd (BTD #1216)	10.0%	10.5%	3.6%	**8.0%**	Summer St & World Trade Center Ave (BTD #664)	10.3%	9.8%	4.5%	8.2%
Pearl St & Purchase St (BTD #602)	5.0%	8.2%	3.6%	**5.6%**	Congress St & D St (BTD #4059)	9.3%	12.0%	3.2%	8.2%
Atlantic Ave & Pearl St (BTD #4102)	7.3%	6.2%	2.1%	**5.2%**	D St & Transitway (BTD #4060)	12.9%	14.2%	5.4%	10.8%
Purchase St & Congress St (BTD #3055)	7.9%	7.5%	3.5%	**6.3%**	D St/Ramp DB (I-90 WB On-Ramp) (BTD #4116)	8.3%	11.7%	2.3%	7.4%
Atlantic Ave & Congress St (BTD #3056)	8.8%	7.4%	3.6%	**6.6%**	Summer St & D St (BTD #374)	10.2%	12.4%	3.9%	8.8%
Summer St & High St (BTD #60)	11.7%	10.0%	8.8%	**10.2%**	Summer St & Pump House Rd (BTD #4061)	9.8%	14.1%	3.3%	9.1%
SASB/Purchase St & Summer St (BTD #3012)	3.8%	5.2%	2.9%	**4.0%**	**Average**				**7.1%**

Crash Data

Location (BTD Intersection Numbers)														
Severity	**4102**	**602**	**1216**	**558**	**1486**	**7004**	**4104**	**2007**	**2259**	**2006**	**1052**	**2023**	**4106**	**7002**
Property Damage	3	0	4	4	0	3	0	1	0	1	0	3	0	3
Personal Injury	3	1	3	1	1	0	0	0	0	0	0	1	1	2
Fatality	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other	0	0	2	4	1	2	0	0	0	0	0	2	0	0
Total	6	1	9	9	2	5	0	1	0	1	0	6	1	5

Crash Data Continued

Location (BTD Intersection Numbers)														
Severity	**4117**	**209**	**1960**	**1290**	**1292**	**1291**	**377**	**3012**	**3055**	**4110**	**403**	**7000**	**1961**	**4101**
Property Damage	2	5	2	10	0	4	1	8	16	8	5	3	4	3
Personal Injury	0	1	2	4	2	7	1	0	6	1	5	0	2	2
Fatality	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Other	0	0	0	2	3	5	3	1	5	1	1	1	0	0
Total	2	6	4	16	5	16	5	9	28	10	11	4	6	5

Crash Data Continued

Location (BTD Intersection Numbers)														
Severity	**4096**	**4016**	**4094**	**1862**	**34**	**4120**	**4121**	**332**	**3056**	**43**	**45**	**44**	**3078**	**3113**
Property Damage	3	0	3	3	3	1	0	1	4	8	5	0	5	3
Personal Injury	1	1	0	0	1	1	0	2	4	3	5	0	4	2
Fatality	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other	1	0	0	1	2	1	1	0	1	5	3	1	1	1
Total	5	1	3	4	6	3	1	3	9	16	13	1	10	6

Crash Data Continued

Location (BTD Intersection Numbers)														
Severity	**1662**	**4061**	**3108**	**374**	**4116**	**4060**	**4059**	**4058**	**4056**	**4057**	**2351**	**3107**	**3109**	**4114**
Property Damage	2	0	1	4	1	0	3	5	2	0	0	2	0	16
Personal Injury	0	0	0	2	1	0	2	0	1	0	0	0	0	9
Fatality	0	0	0	0	0	0	0	0	0	0	0	1*	0	0
Other	0	0	0	1	0	0	2	0	0	0	0	2	0	2
Total	2	0	1	7	2	0	7	5	3	0	0	4	0	27

Crash Data Continued

Location (BTD Intersection Numbers)														
Severity	**60**	**4109**	**312**	**4115**	**70**	**1333**	**9993**	**4111**	**664**	**137**	**149**	**160**	**142**	**164**
Property Damage	1	2	3	12	6	10	2	0	1	0	0	3	9	4
Personal Injury	1	3	4	4	2	6	2	0	1	0	0	0	15	1
Fatality	0	0	0	1*	0	0	0	0	0	0	0	0	0	0
Other	0	0	0	8	3	1	0	0	0	0	0	0	1	1
Total	2	5	7	24	11	17	4	0	2	0	0	3	25	6

Crash Data Continued

Location (BTD Intersection Numbers)			
Severity	**166**	**Total**	**per Year**
Property Damage	0	221	**74**
Personal Injury	2	126	**42**
Fatality	0	1*	**0.33**
Other	1	73	**24**
Total	3	421	140

* Two out of three fatalities were excluded as they were not signal related

Benefits Performance Measures values

Category	Performance Measures	Unit of measure	Value per unit in 2009 dollars	Value per unit in 2012 dollars	Value per unit in 2015 dollars
Delay	Intersection Delay	Person Hours (Cars)	$16.09	$17.22	$17.69
	Intersection Delay	person Hours (Trucks)	$106.24	$113.68	94.152848
Crashes	Property Damage Only (PDO) Crash	Number of Crashes	$3,165	$3,387	$6,605
	Minor Injury Crash	Number of Crashes	$18,771	$20,085	$47,765
	Moderate Injury Crash	Number of Crashes	$392,755	$420,248	$434,393
	Severe Injury Crash	Number of Crashes	$3,003,746	$3,214,008	$6,065,040
	Fatality Crash	Number of Crashes	$4,207,985	$4,502,544	$9,941,700
Emissions	Carbon Monoxide (CO)	Metric ton	$138	$148	$138
	Nitrous Oxide (Nox)	Metric ton	$7,490	$8,014	$7,482
	Volatile Organic Compounds (VOC)	Metric ton	$5,682	$6,080	$5,676
Energy	Fuel	Gallon	$2.64	$3.60	$2.40

1. 2014 Delay value per unit taken from 2015 Urban Mobility Report
2. 2010 Crash unit value taken from May 2015 (revised) "The Economic and Societal Impact of Motor Vehicle Crashes" Report
3. 2000 Emission value per unit taken from HERS-ST Highway Economic Requirements System – State Version: Technical Report . No 2015 updates were found on FHWA website. Still referring to 2000 $ values
 - Consumer Price Index increased from 2000 to 2015 by 37.6%, from 2010 to 2015 by 8.7%, and from 2014 to 2015 by 0.12%. All values (except fuel price) were adjusted accordingly to calculate equivalent 2015 values.
 - National average Fuel price in 2015 ($2.40) according to AAA

BENEFIT CALCULATIONS

Calculation of Delay Reduction Per Year

Assuming
Truck Percentage: 7.1%
Vehicle Occupancy 1.25
Delay decreased by: 618 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 (92.9%)	574 hrs.	718	x	260 days/year =	**186,680**	$17.69	$3,302,593.96
Truck Delay (7.1%)	44 hrs.		x	260 days/year =	**11,440**	$94.15	$1,077,108.58
							$4,379,702.54

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	74	0.08		**6.00**	$6,605	$39,627.67
Personal Injury Accidents	42	0.08		**4.00**	$47,765	$191,059.82
Fatality Accidents	0.33	0.08		**0.03**	$9,941,700	$265,112.00

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	36.3	0.0363	x	260 days/year =	**9.4380**	$138	$1,298.67
Nox Reduction	7.07	0.00707	x	260 days/year =	**1.8382**	$7,482	$13,753.41
VOC Reduction	8.42	0.00842	x	260 days/year =	**2.1892**	$5,676	$12,425.90

Calculation of Fuel Reduction Per Year

	Gal. per day		Annual Reduction		Cost per Gal.	Benefit per Year
Phase II fuel reduction in gallons =	520	x	260 days/year =	**135,200**	$2.40	$324,480.00

Benefits Summary

Category	Performance Measure	Unit	Value per unit in 2015 dollars	Benefits in Appropriate Units	Benefits Value
Delay	Intersection Delay	Person Hours (Cars)	$17.69	186680	$3,302,593.96
		Person Hours (Trucks)	$94.15	11440	$1,077,108.58
Crashes	Property Damage Only (PDO) Crash	Number of Crashes	$6,605	6	$39,628
	Minor Injury Crash	Number of Crashes	$47,765	4	$191,060
	Moderate Injury Crash	Number of Crashes	$434,393	0	$0
	Severe Injury Crash	Number of Crashes	$6,065,040	0	$0
	Fatality Crash	Number of Crashes	$9,941,700	0	$265,112
Emissions	Carbon Monoxide (CO)	Metric ton	$138	9.4380	$1,299
	Nitrous Oxide (Nox)	Metric ton	$7,482	1.8382	$13,753
	Volatile Organic Compounds (VOC)	Metric ton	$5,676	2.1892	$12,426
Energy	Fuel	Gallon	$2.40	135200	$324,480.00
TOTAL					**$5,227,460**

COST CALCULATIONS

Engineering Cost	
Engineering Fee for FY2014-2	$250,000
BTD Contractor cost (Implementation of new timings)	$57,000
BTD Engineering cost	$25,000
Sum of above cost	$332,000
Assume BTD retime signals every 5 years	
Assume signs and pavement markings are replaced every 5 years.	N/A
Annualized Cost Per Year =P{ [i*(1+i)^n] / [(1+i)^n - 1] }	
P = Present Worth	$332,000
Assume i=3.0 (CPI)	
N = 5	
Numerator = 0.03*(1+0.03)^5 =	$0.03
Denominator = (1+0.03)^5 -1 =	$0.16
A = P *(Numerator/Denominator)	$72,494
Total Annual Cost =	**$72,494**

Signal Equipment Cost	**N/A**
Signal equipment cost	
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	
Assume i=3.0 (CPI) N= 15	
Numerator = 0.03*(1+0.03)^15 =	
Denominator = (1+0.03)^15 -1 =	
A = P *(Numerator/Denominator)	
Total Annual Signal Equipment Cost =	

Annual Cost Summary	
Type	
Engineering Cost	$72,494
Signal Equipment Cost	N/A
Other Non-Annualized Cost	N/A
Total	**$72,494**

BENEFIT COST RATIO CALCULATIONS

Benefit	$5,227,450	
Cost	$72,495	
Ratio		**72 to 1**

APPENDIX E

FY2014-3 (HUMBOLDT)

TETRA TECH
One Grant Street
Framingham, MA 01701-9005
508.903.2000
www.tetratech.com

Work Order (FY 2014-3)
Boston Transportation Department (BTD)
Roxbury, Massachusetts

Site Locus Map

Figure **E**

DATA

Data from Synchro 7.0 Network MOE Table	AM Peak Hour		Midday Peak Hour		PM Peak Hour		Combined Difference	Totals for Final B-C report			
	Existing	Improved	Existing	Improved	Existing	Improved		Existing	Improved	Δ	Δ%
Total Delay (Hr.)	73	51	38	35	78	61	**-42**	**189**	**147**	**-42**	**-22%**
Stops/Vehicle	0.61	0.53	0.61	0.56	0.61	0.56	**-0.18**				
Average Speed (mph)	9	11	11	12	9	11	**5**				
Fuel Consumed (gal)	119	100	78	73	130	115	**-39**	**327**	**288**	**39**	**12%**
Fuel Economy (mpg)	8	9.6	9.3	9.8	8.1	9.2	**3.2**				
CO Emissions (Kg)	8.32	6.98	5.42	5.1	9.07	8.05	**-2.68**	**22.81**	**20.13**	**2.68**	**12%**
NOx Emissions (Kg)	1.62	1.36	1.05	0.99	1.77	1.57	**-0.52**	**4.44**	**3.92**	**0.52**	**12%**
VOC Emissions (Kg)	1.93	1.62	1.26	1.18	2.1	1.86	**-0.63**	**5.29**	**4.66**	**0.63**	**12%**

Truck Percentages				
Location	**AM**	**MD**	**PM**	**Average**
Humboldt Avenue & Martin Luther King Boulevard (MLK) (BTD #1561)	6.3%	5.8%	3.5%	5.2%
Humboldt Avenue & Townsend Street (BTD #556)	6.0%	13.7%	6.8%	8.8%
Humboldt Avenue & Walnut Avenue (BTD #572)	4.0%	4.9%	6.6%	5.2%
Humboldt Avenue & Waumbeck Street (BTD #947)	5.7%	7.8%	3.9%	5.8%
Humboldt Avenue & Wyoming Street (BTD #1723)	5.9%	8.0%	6.7%	6.9%
Humboldt Avenue & Crawford Street (BTD #520)	7.0%	6.9%	3.8%	5.9%
Martin Luther King Boulevard (MLK) & Walnut Avenue (BTD #1595)	5.0%	4.3%	2.1%	3.8%
Townsend Street & Walnut Avenue (BTD #393)	3.7%	3.8%	1.9%	3.1%
Average				**5.6%**

Crash Data (January 1, 2008 - December 31, 2011)										
Location (BTD Intersection Numbers)	**1561**	**556**	**572**	**947**	**1723**	**520**	**1595**	**393**	**Total**	**per Year**
Severity										
Property Damage	3	1	0	1	0	0	1	0	6	**2**
Personal Injury	1	1	0	1	0	0	2	3	8	**2**
Fatality	0	0	0	0	0	0	0	0	0	**0**
Other	0	0	0	0	0	1	1	1	3	**1**
Total	4	2	0	2	0	1	4	4	17	**4**

Benefits Performance Measures values						
Category	**Performance Measures**	**Unit of measure**	**Value per unit**	**Value per unit in 2013 dollars**	**Value per unit in 2015**
Delay	Intersection Delay	Person Hours (Cars) [1]	$16.79	$17.93	$17.69
	Intersection Delay	Person Hours (Trucks)[1]	$86.81	$92.71	$94.15
Crashes	Property Damage Only (PDO) Crash	Number of Crashes [2]	$6,076	$6,295	$6,605
	Minor Injury Crash	Number of Crashes [2]	$46,020	$47,677	$47,765
	Moderate Injury Crash	Number of Crashes [2]	$445,846	$461,896	$434,393
	Severe Injury Crash	Number of Crashes [2]	$5,679,122	$5,883,570	$6,065,040
	Fatality Crash	Number of Crashes [2]	$9,145,998	$9,475,254	$9,941,700
Emissions	Carbon Monoxide (CO)	Metric ton [3]	$138	$150	$138
	Nitrous Oxide (NOx)	Metric ton [3]	$7,490	$8,134	$7,482
	Volatile Organic Compounds (VOC)	Metric ton [3]	$5,682	$6,171	$5,676
Energy	Fuel	Gallon	$2.64	$3.60	$2.40

1. 2014 Delay value per unit taken from 2015 Urban Mobility Report
2. 2010 Crash unit value taken from May 2015 (revised) "The Economic and Societal Impact of Motor Vehicle Crashes" Report
3. 2000 Emission value per unit taken from HERS-ST Highway Economic Requirements System – State Version: Technical Report . No 2015 updates were found on FHWA website. Still referring to 2000 $ values
 - Consumer Price Index increased from 2000 to 2015 by 37.6%, from 2010 to 2015 by 8.7%, and from 2014 to 2015 by 0.12%. All values (except fuel price) were adjusted accordingly to calculate equivalent 2015 values.
 - National average Fuel price in 2015 ($2.40) according to AAA

BENEFIT CALCULATIONS

Calculation of Delay Reduction Per Year

Assuming

Truck Percentage: 5.6%

Vehicle Occupancy 1.25

Delay decreased by: 42 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 (94.4%)	40 hrs.	50	x	260 days/year =	**12,870**	$17.69	$227,685.80
Truck Delay (5.6%)	2 hrs.		x	260 days/year =	**610**	$94.15	$57,447.83
							$285,133.63

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	2	0.08	**0.12**	$6,605	$793
Personal Injury Accidents	2	0.08	**0.16**	$47,765	$7,642
Fatality Accidents	0	0.08	**-**	$9,941,700	$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	2.68	0.00268	x	260 days/year =	**0.6968**	$138	$96
NOx Reduction	0.52	0.00052	x	260 days/year =	**0.1352**	$7,482	$1,012
VOC Reduction	0.63	0.00063	x	260 days/year =	**0.1638**	$5,676	$930

Calculation of Fuel Reduction Per Year

	Gal. per day		Annual Reduction		Cost per Gal.	Benefit per Year
Fuel reduction in gallons =	39	x	260 days/year =	**10,140**	$2.40	$24,336.00

Benefits Summary

Category	Performance Measure	Unit	Value per unit in 2015 dollars	Benefits in Appropriate Units	Benefits Value
Delay	Intersection Delay	Person Hours (Cars)	$17.69	12870	$227,685.80
		Person Hours (Trucks)	$94.15	610	$57,447.83
Crashes	Property Damage Only (PDO) Crash	Number of Crashes	$6,605	0.12	$793
	Minor Injury Crash	Number of Crashes	$47,765	0.16	$7,642
	Moderate Injury Crash	Number of Crashes	$434,393	0.00	$0
	Severe Injury Crash	Number of Crashes	$6,065,040	0.00	$0
	Fatality Crash	Number of Crashes	$9,941,700	0.00	$0
Emissions	Carbon Monoxide (CO)	Metric ton	$138	0.6968	$96
	Nitrous Oxide (NOx)	Metric ton	$7,482	0.1352	$1,012
	Volatile Organic Compounds (VOC)	Metric ton	$5,676	0.1638	$930
Energy	Fuel	Gallon	$2.40	10140	$24,336.00
TOTAL					**$319,941.75**

COST CALCULATIONS

Intersection Improvements Cost Calculations

Intersection	Needed Items	Cost Estimate
Humboldt Avenue & MLK Blvd (BTD #1561)	· Install lane striping and lane use markings along Humboldt Avenue northbound and southbound approaches to provide a short right turn pocket on each approach.	Maintenance, N/A
Humboldt Avenue & Townsend Street (BTD #556)	· Add backplates to both pedestal mounted signals in the southeast corner of the intersection.	$240.00
	· Repaint faded crosswalks and stop lines. Also repaint double yellow center lines on both Townsend Street approaches.	$2,350.00
Humboldt Avenue & Walnut Avenue (BTD #572)	· Restrict parking on Humboldt Avenue southbound near Walnut Street and restripe pavement to include a short right turn lane. Right turn overlap is not effective with the current lane configuration, since there is only a shared through/right lane on this approach due to on street parking.	Maintenance, N/A
	· Replace damaged backplates with new ones for the two 5-section signal heads facing Humboldt Avenue southbound approaches.	$300.00
Humboldt Avenue & Waumbeck Street (BTD #947)	· Remove and reset "Do Not Enter" (R5-1) and "One Way" (R6-1L) signs closer to Humboldt Avenue to improve the visibility of the signs.	$100.00
Humboldt Avenue & Wyoming Street (BTD #1723)	· Replace faded "No Parking 7am – 4pm SCHOOL DAYS" signs.	$220.00
	· Restripe faded crosswalks and stop lines.	$310.00
Humboldt Avenue & Crawford Street (BTD 3520)	· No action necessary	N/A
Martin Luther King Blvd & Walnut Avenue (BTD #1595)	· No action necessary	N/A
Townsend Street & Walnut Avenue (BTD #393)	· Restripe faded crosswalks and stop lines in the south leg along Walnut Avenue.	$480.00
	· Install double yellow centerline striping along westbound approach of Townsend Street.	$200.00
	· Add backplates to all signal heads.	$960.00
Signal Equipment Cost that can be annualized over 15 years		**$1,500.00**
Signing and Pavement Marking Cost that can be annualized over 5 years		**$3,660.00**
Costs that cannot be annualized		**$0.00**

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 (1 hour per intersection at $125 per hour)	$1,000.00
Travel time for Contractor (8 hours at $125 per hour)	$1,000.00
Signal phasing changes - none	$0.00
Total BTD Contractor costs (Including signal phasing and timing changes and travel time) =	**$2,000.00**

COST CALCULATIONS (Continued)

Engineering Costs, Signs and Pavement Marking Costs	
Engineering Fee for WO #FY 2014-3	$31,600.00
BTD Engineering Costs (100 hours at $50/hour)	$5,000.00
Signs and Pavement marking Costs	$3,660.00
BTD Contractor costs	$2,000.00
Sum of above costs	$42,260.00
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	$42,260.00
Assume i=3 (CPI)	
N = 5	
Numerator = 0.03*(1+0.03)^5 =	$0.03
Denominator = (1+0.03)^5 -1 =	$0.16
A = P *(Numerator/Denominator)	$9,227.66
Total Annual Engineering/Signs/Markings Cost =	**$9,228**

Signal Equipment Costs		
Signal equipment costs		$1,500.00
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		$1,500.00
Assume i=3 (CPI)	N= 15	
Numerator = 0.03*(1+0.03)^15 =		$0.05
Denominator = (1+0.03)^15 -1 =		$0.56
A = P *(Numerator/Denominator)		$125.65
Total Annual Signal Equipment Costs =		**$126**

Annual Cost Summary	
Type	
Engineering/Signs/Pavement markings	$9,228
Signal Equipment	$126
Other Non-Annualized Costs	$0
Total	**$9,353**

COST BENEFIT RATIO CALCULATIONS

Benefit	$319,940	
Cost	$9,355	
Ratio		**34 to 1**

DATA

Data from Synchro 7.0 Network MOE Table After Fine Tuning Changes

	AM Peak Hour		Midday Peak Hour		PM Peak Hour		Combined Difference	Totals for Final B-C report			
	Existing	Improved	Existing	Improved	Existing	Improved		Existing	Improved	Δ	Δ%
Total Delay (Hr.)	90	81	41	38	113	77	**-48**	**244**	**196**	**-48**	**-20%**
Stops/Vehicle	0.60	0.55	0.51	0.51	0.60	0.55	**-0.1**				
Average Speed (mph)	10	11	12	13	9	11	**4**				
Fuel Consumed (gal)	167	156	90	89	186	156	**-42**	**443**	**401**	**42**	**9%**
Fuel Economy (mpg)	8.5	9.1	10	10.2	7.9	9.4	**2.3**				
CO Emissions (Kg)	11.64	10.92	6.32	6.2	12.97	10.89	**-2.92**	**30.93**	**28.01**	**2.92**	**9%**
NOx Emissions (Kg)	2.26	2.13	1.23	1.21	2.52	2.12	**-0.55**	**6.01**	**5.46**	**0.55**	**9%**
VOC Emissions (Kg)	2.7	2.53	1.46	1.44	3.01	2.52	**-0.68**	**7.17**	**6.49**	**0.68**	**9%**

Truck Percentages

Location	AM	MD	PM	Average
South St & Robert Street (BTD #771)	2.8%	2.6%	1.4%	2.3%
South St & Walter Street (BTD #770)	2.5%	1.6%	2.4%	2.2%
Winship Street & Union Street (BTD #681)	9.3%	6.3%	4.7%	6.8%
Parsons Street & Arlington Street (BTD #391)	2.5%	2.2%	0.7%	1.8%
Parsons Street & Faneuil Street (BTD #561)	3.1%	2.4%	1.1%	2.2%
Chestnut Hill Avenue & Hatherly Road (BTD #2070)	6.8%	5.4%	2.1%	4.8%
Chestnut Hill Avenue & Embassy Road (BTD #713)	6.1%	7.8%	1.6%	5.2%
Chestnut Hill Avenue & Strathmore Road (BTD #631)	6.2%	7.4%	1.3%	5.0%
Western Avenue & North Harvard Street (BTD #188)	10.9%	9.6%	3.7%	8.1%
Summer Street & Drydock Avenue (BTD #2249)	7.0%	16.3%	3.0%	8.8%
Average				**4.7%**

Crash Data (Jan 1, 2008 to Dec 31, 2011)

Location (BTD Intersection Numbers)	771	770	681	391	561	2070	713	631	188	2249	Total	per Year
Severity												
Property Damage	0	1	1	6	0	0	2	1	10	1	22	**6**
Personal Injury	1	1	2	2	2	1	0	1	1	1	12	**3**
Fatality	0	0	0	0	0	0	0	0	0	0	0	**0**
Other	0	0	1	2	0	0	1	2	0	0	6	**2**
Total	1	2	4	10	2	1	3	4	11	2	40	**10**

Benefits Performance Measures values

Category	Performance Measures	Unit of measure	Value per unit	Value per unit in 2013 dollars	Value per unit in 2015 dollars
Delay	Intersection Delay	Person Hours (Cars) [1]	$16.79	$17.93	$17.69
	Intersection Delay	Person Hours (Trucks)[1]	$86.81	$92.71	$94.15
Crashes	Property Damage Only (PDO) Crash	Number of Crashes [2]	$6,076	$6,295	$6,605
	Minor Injury Crash	Number of Crashes [2]	$46,020	$47,677	$47,765
	Moderate Injury Crash	Number of Crashes [2]	$445,846	$461,896	$434,393
	Severe Injury Crash	Number of Crashes [2]	$5,679,122	$5,883,570	$6,065,040
	Fatality Crash	Number of Crashes [2]	$9,145,998	$9,475,254	$9,941,700
Emissions	Carbon Monoxide (CO)	Metric ton [3]	$138	$150	$138
	Nitrous Oxide (Nox)	Metric ton [3]	$7,490	$8,134	$7,482
	Volatile Organic Compounds (VOC)	Metric ton [3]	$5,682	$6,171	$5,676
Energy	Fuel	Gallon	$2.64	$3.60	$2.40

1. 2014 Delay value per unit taken from 2015 Urban Mobility Report
2. 2010 Crash unit value taken from May 2015 (revised) "The Economic and Societal Impact of Motor Vehicle Crashes" Report
3. 2000 Emission value per unit taken from HERS-ST Highway Economic Requirements System – State Version: Technical Report . No 2015 updates were found on FHWA website. Still referring to 2000 $ values
   - Consumer Price Index increased from 2000 to 2015 by 37.6%, from 2010 to 2015 by 8.7%, and from 2014 to 2015 by 0.12%. All values (except fuel price) were adjusted accordingly to calculate equivalent 2015 values.
   - National average Fuel price in 2015 ($2.40) according to AAA

APPENDIX F

FY2014-4 (VARIOUS)

1 inch = 2000 feet

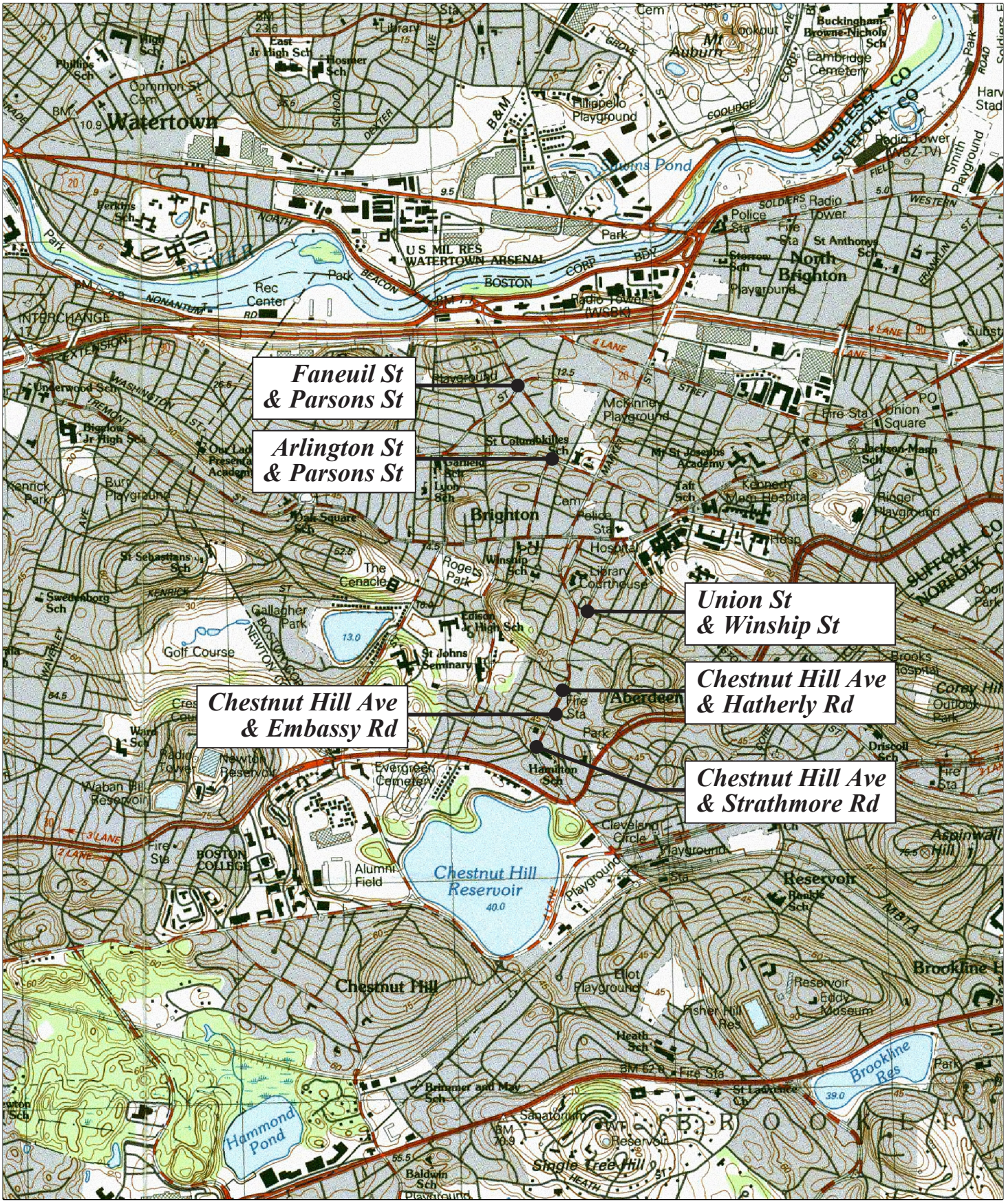
N

TETRA TECH
One Grant Street
Framingham, MA 01701-9005
508.903.2000
www.tetratech.com

Work Order FY 2014-4
Boston Transportation Department (BTD)
Roslindale, Massachusetts

Site Locus Map

Figure **F-1**



1 inch = 2000 feet

N

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Framingham, MA 01701-9005
508.903.2000
www.tetratech.com

Work Order FY 2014-4
Boston Transportation Department (BTD)
Brighton, Massachusetts

Site Locus Map

Figure **F-2**

1 inch = 2000 feet

N

TETRA TECH
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Framingham, MA 01701-9005
508.903.2000
www.tetratech.com

Work Order FY 2014-4
Boston Transportation Department (BTD)
North Allston, Massachusetts

Site Locus Map

Figure **F-3**

1 inch = 2000 feet

N

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One Grant Street
Framingham, MA 01701-9005
508.903.2000
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Work Order FY 2014-4
Boston Transportation Department (BTD)
South Boston, Massachusetts

Site Locus Map

Figure **F-4**

BENEFIT CALCULATIONS

Calculation of Delay Reduction Per Year

Assuming

Truck Percentage:	4.7%						
Vehicle Occupancy	1.25						
Delay decreased by:	48 Vehicle hours per weekday						
	Veh. Hours Per Day	Passenger Hours Per Day			Year	Cost per Hour	Benefit per Year
Vehicle and Passenger Car Delay (95.3%)	46 hrs.	57	x	260 days/year =	**14,846**	$17.69	$262,643.61
Truck Delay (4.7%)	2 hrs.		x	260 days/year =	**586**	$94.15	$55,147.96
							$317,791.57

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	6	0.08	**1.00**	$6,605	$6,604.61
Personal Injury Accidents	3	0.08	**1.00**	$47,765	$47,764.95
Fatality Accidents	0	0.08	-	$9,941,700	$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	2.92	0.00292	x	260 days/year =	**0.7592**	$138	$104
NOx Reduction	0.55	0.00055	x	260 days/year =	**0.1430**	$7,482	$1,070
VOC Reduction	0.68	0.00068	x	260 days/year =	**0.1768**	$5,676	$1,004

Calculation of Fuel Reduction Per Year

	Gal. per day			Annual Reduction		Cost per Gal.	Benefit per Year
Fuel reduction in gallons =	42		x	260 days/year =	**10,920**	$2.40	$26,208.00

Benefits Summary

Category	Performance Measure	Unit	Value per unit in 2015 dollars	Benefits in Appropriate Units	Benefits Value
Delay	Intersection Delay	Person Hours (Cars)	$17.69	14846	$262,643.61
		Person Hours (Trucks)	$94.15	586	$55,147.96
Crashes	Property Damage Only (PDO) Crash	Number of Crashes	$6,605	1	$6,605
	Minor Injury Crash	Number of Crashes	$47,765	1	$47,765
	Moderate Injury Crash	Number of Crashes	$434,393	0	$0
	Severe Injury Crash	Number of Crashes	$6,065,040	0	$0
	Fatality Crash	Number of Crashes	$9,941,700	0	$0
Emissions	Carbon Monoxide (CO)	Metric ton	$138	0.7592	$104
	Nitrous Oxide (Nox)	Metric ton	$7,482	0.1430	$1,070
	Volatile Organic Compounds (VOC)	Metric ton	$5,676	0.1768	$1,004
Energy	Fuel	Gallon	$2.40	10920	$26,208.00
TOTAL					**$400,547.05**

COST CALCULATIONS

Intersection Improvements Cost Calculations

Intersection	Needed Items	Cost Estimate
South Street & Robert Street (BTD 3771)	· Install speed limit signs along South Street and Robert Street in both directions.	$600.00
	· Restripe the faded crosswalk along the Robert Street westbound approach.	$690.00
	· Install lane use pavement markings along northbound approach of the South Street.	Maintenance, N/A
	· Install a lane use sign along the northbound approach of the South Street.	Maintenance, N/A
	· Consider marking the northbound South Street lane as a through lane with a 50-foot long right turn only pocket lane.	Maintenance, N/A
South Street & Walter Street (BTD #770)	· Install speed limit signs along South Street and Walter Street in both directions.	$1,200.00
	· Repaint the faded double yellow centerline along South Street westbound approach.	$200.00
	· Install street-name signs along the westbound and the southbound approaches.	$144.00
Winship Street & Union Street (BTD #681)	· Install speed limit signs along Union Street.	$600.00
Parsons Street & Arlington Street (BTD 33391)	· Install visor over the green indication for the rightmost signal facing the Parsons Street northbound approach.	Maintenance, N/A
Parsons Street & Faneuil Street (BTD #561)	· Install speed limit signs along Faneuil Street in both directions.	$600.00
	· Restripe the faded stop line along the Faneuil Street eastbound approach.	$40.00
	· Replace the vandalized “No Turn on Red” sign facing the westbound approach of the Faneuil Street.	$55.00
Chestnut Hill Avenue & Hatherly Road (BTD #2070)	· Replace the malfunctioning signal head facing eastbound Hatherly Road located on the right side of the roadway.	Maintenance, N/A
	· Install speed limit signs along Chestnut Hill Avenue in both directions.	$600.00
Chestnut Hill Avenue & Embassy Road (BTD #713)	· Install speed limit signs along Chestnut Hill Avenue in both directions.	$600.00
Chestnut Hill Avenue & South Street/Strathmore Rd (BTD #631)	· Replace the speed limit sign for school zones along Chestnut Hill Avenue with others to say “Speed Limit 20 MPH during school days only” rather than “…when children are present”.	$300.00
	· Repaint the faded double center line along the South Street eastbound approach.	$200.00
	· Restripe the faded school pavement marking along the Chestnut Hill Avenue southbound approach.	$300.00
	· Replace the bent street name signs for Chestnut Hill Avenue and Strathmore Road.	$144.00
	· Install a One-Way sign along the Strathmore Road westbound approach.	$133.00
Western Avenue & North Harvard Street (BTD #188)	· Install speed limit signs along Western Avenue and North Harvard Street.	$600.00
	· Repaint the faded bike lane lines along the North Harvard Street southbound approach.	$325.00
	· Restripe the faded pavement markings along the Western Avenue westbound approach.	$980.00
Summer Street & Drydock Avenue/Pappas Way (BTD #2249)	· Install back-plates for the 5-section signal head facing the Summer Street westbound left-turning vehicles.	$150.00
	· Install speed limit signs along Summer Street, Drydock Avenue, and Pappas Way.	$1,200.00
	· Restripe the faded lane-use pavement markings, crosswalks and stop lines on all four approaches.	$4,423.00
	· Replace the bent lane-use sign posted along the Summer Street westbound approach.	$110.00
Signal Equipment Cost that can be annualized over 15 years		**$150.00**
Signing and Pavement Marking Cost that can be annualized over 5 years		**$14,044.00**
Costs that cannot be annualized		**$0.00**

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 (1 hour per intersection at $125 per hour)	$1,250.00
Travel time for Contractor (8 hours at $125 per hour)	$1,000.00
Signal phasing changes - none	$0.00
Total BTD Contractor costs (Including signal phasing and timing changes and travel time) =	**$2,250.00**

COST CALCULATIONS (Continued)

Engineering Costs, Signs and Pavement Marking Costs	
Engineering Fee for WO #FY 2014-4	$36,500.00
BTD Engineering Costs (120 hours at $50/hour)	$6,000.00
Signs and Pavement marking Costs	$14,044.00
BTD Contractor costs	$2,250.00
Sum of above costs	$58,794.00
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	$58,794.00
Assume i=3 (CPI)	
N = 5	
Numerator = 0.03*(1+0.03)^5 =	$0.03
Denominator = (1+0.03)^5 -1 =	$0.16
A = P *(Numerator/Denominator)	$12,837.94
Total Annual Engineering/Signs/Markings Cost =	**$12,838**

Signal Equipment Costs		
Signal equipment costs		$150.00
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		$150.00
Assume i=3 (CPI)	N= 15	
Numerator = 0.03*(1+0.03)^15 =		$0.05
Denominator = (1+0.03)^15 -1 =		$0.56
A = P *(Numerator/Denominator)		$12.56
Total Annual Signal Equipment Costs =		**$13**

Annual Cost Summary	
Type	
Engineering/Signs/Pavement markings	$12,838
Signal Equipment	$13
Other Non-Annualized Costs	$0
Total	**$12,851**

COST BENEFIT RATIO CALCULATIONS

Benefit	$400,550	
Cost	$12,850	
Ratio		**31 to 1**

APPENDIX G

FY2014-5 (FINANCIAL DISTRICT)

P:\3946\127.3946.12001\SupportDocs\FY2014-5 Finacial\BTD Intersections Overall (FY2014-5.ai

Boston Transportation Department
Study Area Intersections

#		
	Section - 36	
1.	New Chardon St & Merrimac St	(BTD #311)
2.	Congress St/Merrimac St & New Sudbury St	(BTD #1685)
3.	Congress St & Hanover St	(BTD #4035)
4.	Congress St & North St	(BTD #26)
5.	North St & Union St	(BTD # 26)
6.	Clinton St & North St	(BTD #4108)
7.	Congress St & State St	(BTD #52)
8.	Court St/State St & Washington St	(BTD #25)
	Section - 14	
9.	Congress St & Water St	(BTD #51)
10.	Devonshire St & Water St	(BTD #54)
11.	School St & Washington St	(BTD #24)
12.	Milk St & Washington St	(BTD #23)
13.	Devonshire St & Milk St	(BTD #55)
14.	Congress St & Milk St	(BTD #1520)
15.	Pearl St & Milk St	(BTD #327)
16.	Pearl St & Franklin St	(BTD #548)
17.	Congress St & Franklin St	(BTD #362)
18.	Federal St & Franklin St	(BTD #49)
19.	Devonshire St & Franklin St	(BTD #56)
20.	Arch St & Franklin St	(BTD #550)
	Section - 13	
21.	Oliver St & High St	(BTD #566)
22.	Pearl St & High St	(BTD #1197)
23.	Congress St & High St	(BTD #47)
	Section - 11	
24.	Federal St & High St	(BTD #48)
25.	Summer St & Lincoln St	(BTD #58)
26.	Kingston St/Otis St & Summer St	(BTD #605)
27.	Arch St/Chauncy St & Summer St	(BTD #59)
28.	Kingston St & Bedford St	(BTD #101)
29.	Chauncy St & Avenue DeLafayette	(BTD #3085)
30.	Essex St & Kingston St	(BTD #375)

350 0 175 350
Approximate Scale in Feet

TETRA TECH
One Grant Street
Framingham, MA 01701-9005
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Work Order FY 2014-5 (Financial District)
Boston Transportation Department (BTD)
Boston, Massachusetts

BTD Intersection Locations

Figure **G**

DATA

Data from Synchro 7.0 Network MOE Table After Fine Tuning Changes	AM Peak Hour		Midday Peak Hour		PM Peak Hour		Combined Difference	Totals for Final B-C report			
	Existing	Improved	Existing	Improved	Existing	Improved		Existing	Improved	Δ	Δ%
Total Delay (Hr.)	229	221	159	133	250	192	**-92**	**638**	**546**	**-92**	**-14%**
Stops/Vehicle	0.49	0.48	0.5	0.47	0.48	0.46	**-0.06**				
Average Speed (mph)	7	7	7	8	6	7	**2**				
Fuel Consumed (gal)	324	316	242	220	332	288	**-74**	**898**	**824**	**74**	**8%**
Fuel Economy (mpg)	6.3	6.5	6.7	7.4	6.1	7	**1.8**				
CO Emissions (Kg)	22.61	22.12	16.92	15.37	23.22	20.12	**-5.14**	**62.75**	**57.61**	**5.14**	**8%**
NOx Emissions (Kg)	4.4	4.3	3.29	2.99	4.52	3.91	**-1.01**	**12.21**	**11.20**	**1.01**	**8%**
VOC Emissions (Kg)	5.24	5.13	3.92	3.56	5.38	4.66	**-1.19**	**14.54**	**13.35**	**1.19**	**8%**

Truck Percentages									
Location	**AM**	**MD**	**PM**	**Average**	**Location**	**AM**	**MD**	**PM**	**Average**
New Chardon Street & Merrimac Street (BTD #311)	5.3%	5.5%	3.6%	4.8%	Pearl Street & Franklin Street (BTD #548)	4.9%	4.3%	1.2%	3.5%
Congress Street/Merrimac Street & New Sudbury Street (BTD #1685)	6.6%	6.2%	3.8%	5.5%	Congress Street & Franklin Street (BTD #362)	8.9%	6.1%	2.6%	5.9%
Congress Street & Hanover Street (BTD #4035)	6.6%	6.2%	4.2%	5.7%	Federal Street & Franklin Street (BTD #49)	14.4%	10.2%	10.7%	11.8%
Congress Street & North Street (BTD #26)	5.7%	6.8%	3.9%	5.5%	Devonshire Street & Franklin Street (BTD #56)	11.8%	9.7%	12.1%	11.2%
North Street & Union Street (BTD # 26)	3.5%	5.2%	2.9%	3.9%	Arch Street & Franklin Street (BTD #550)	7.2%	7.5%	4.3%	6.3%
Clinton Street & North Street (BTD #4108)	3.7%	5.4%	2.8%	4.0%	Oliver Street & High Street (BTD #566)	6.6%	5.6%	1.3%	4.5%
Congress Street & State Street (BTD #52)	8.1%	8.2%	4.3%	6.9%	Pearl Street & High Street (BTD #1197)	5.4%	5.8%	2.4%	4.5%
Court Street/State Street & Washington Street (BTD #25)	8.7%	7.9%	3.6%	6.7%	Congress Street & High Street (BTD #47)	8.8%	6.5%	2.3%	5.9%
Congress Street & Water Street (BTD #51)	6.9%	6.2%	4.0%	5.7%	Federal Street & High Street (BTD #48)	9.3%	9.9%	11.3%	10.2%
Devonshire Street & Water Street (BTD #54)	9.2%	7.5%	7.5%	8.1%	Summer Street & Lincoln Street (BTD #58)	8.1%	10.0%	9.3%	9.1%
School Street & Washington Street (BTD #24)	7.1%	5.9%	5.3%	6.1%	Kingston Street/Otis Street & Summer Street (BTD #605)	14.1%	10.6%	12.6%	12.4%
Milk Street & Washington Street (BTD #23)	19.9%	8.2%	11.0%	13.0%	Arch Street/Chauncy Street & Summer Street (BTD #59)	9.1%	10.4%	4.0%	7.8%
Devonshire Street & Milk Street (BTD #55)	14.1%	11.6%	7.7%	11.1%	Kingston Street & Bedford Street (BTD #101)	11.4%	6.4%	7.8%	8.5%
Congress Street & Milk Street (BTD #1520)	8.3%	6.8%	4.3%	6.5%	Chauncy Street & Avenue DeLafayette (BTD #3085)	8.6%	8.1%	4.5%	7.1%
Pearl Street & Milk Street (BTD #327)	9.3%	5.6%	4.0%	6.3%	Essex Street & Kingston Street (BTD #375)	11.9%	7.1%	5.5%	8.2%
					Average				**7.2%**

Crash Data (Jan 1, 2009 to Dec 31, 2011)														
Location (BTD Intersection Numbers)	**311**	**1685**	**4035**	**26**	**26**	**4108**	**23**	**24**	**566**	**48**	**49**	**25**	**58**	**56**
Severity														
Property Damage	4	3	1	4	2	0	0	1	0	0	0	2	1	1
Personal Injury	5	2	0	1	0	1	2	2	0	0	2	2	0	0
Fatality	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other	4	1	0	2	1	0	1	1	0	1	0	2	1	1
Total	13	6	1	7	3	1	3	4	0	1	2	6	2	2

Crash Data (Jan 1, 2009 to Dec 31, 2011) Continued														
Location (BTD Intersection Numbers)	**55**	**54**	**101**	**375**	**605**	**3085**	**59**	**550**	**1197**	**548**	**327**	**52**	**47**	**362**
Severity														
Property Damage	0	0	0	2	0	0	0	0	0	1	0	0	3	0
Personal Injury	0	1	0	0	0	0	1	1	0	1	0	0	4	0
Fatality	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other	0	0	0	0	2	1	0	0	1	0	1	3	2	2
Total	0	1	0	2	2	1	1	1	1	2	1	3	9	2

Crash Data (Jan 1, 2009 to Dec 31, 2011) Continued				
Location (BTD Intersection Numbers)	**1520**	**51**	**Total**	**per Year**
Severity				
Property Damage	1	0	26	**9**
Personal Injury	0	0	25	**8**
Fatality	0	0	0	**0**
Other	0	3	30	**10**
Total	1	3	81	**27**

Benefits Performance Measures values						
Category	**Performance Measures**	**Unit of measure**	**Value per unit**	**Value per unit in 2013 dollars**	**Value per unit in 2015 dollars**
Delay	Intersection Delay	Person Hours (Cars) [1]	$16.79	$17.93	$17.69
	Intersection Delay	Person Hours (Trucks)[1]	$86.81	$92.71	$94.15
Crashes	Property Damage Only (PDO) Crash	Number of Crashes [2]	$6,076	$6,295	$6,605
	Minor Injury Crash	Number of Crashes [2]	$46,020	$47,677	$47,765
	Moderate Injury Crash	Number of Crashes [2]	$445,846	$461,896	$434,393
	Severe Injury Crash	Number of Crashes [2]	$5,679,122	$5,883,570	$6,065,040
	Fatality Crash	Number of Crashes [2]	$9,145,998	$9,475,254	$9,941,700
Emissions	Carbon Monoxide (CO)	Metric ton [3]	$138	$150	$138
	Nitrous Oxide (NOx)	Metric ton [3]	$7,490	$8,134	$7,482
	Volatile Organic Compounds (VOC)	Metric ton [3]	$5,682	$6,171	$5,676
Energy	Fuel	Gallon	$2.64	$3.60	$2.40

1. 2014 Delay value per unit taken from 2015 Urban Mobility Report
2. 2010 Crash unit value taken from May 2015 (revised) "The Economic and Societal Impact of Motor Vehicle Crashes" Report
3. 2000 Emission value per unit taken from HERS-ST Highway Economic Requirements System – State Version: Technical Report . No 2015 updates were found on FHWA website. Still referring to 2000 $ values
 - Consumer Price Index increased from 2000 to 2015 by 37.6%, from 2010 to 2015 by 8.7%, and from 2014 to 2015 by 0.12%. All values (except fuel price) were adjusted accordingly to calculate equivalent 2015 values.
 - National average Fuel price in 2015 ($2.40) according to AAA

BENEFIT CALCULATIONS

Calculation of Delay Reduction Per Year

Assuming

Truck Percentage:	7.2%							
Vehicle Occupancy	1.25							
Delay decreased by:	92	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 (92.8%)	85	hrs.	107	x	260 days/year =	**27,716**	$17.69	$490,329.41
Truck Delay (7.2%)	7	hrs.		x	260 days/year =	**1,727**	$94.15	$162,579.20
								$652,908.61

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	9	0.08	**0.69**	$6,605	$4,579
Personal Injury Accidents	8	0.08	**0.67**	$47,765	$31,843
Fatality Accidents	0	0.08	-	$9,941,700	$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	5.14	0.00514	x	260 days/year =	**1.3364**	$138	$184
NOx Reduction	1.01	0.00101	x	260 days/year =	**0.2626**	$7,482	$1,965
VOC Reduction	1.19	0.00119	x	260 days/year =	**0.3094**	$5,676	$1,756

Calculation of Fuel Reduction Per Year

	Gal. per day		Annual Reduction		Cost per Gal.	Benefit per Year
Fuel reduction in gallons =	74	x	260 days/year =	**19,240**	$2.40	$46,176.00

Benefits Summary

Category	Performance Measure	Unit	Value per unit in 2015 dollars	Benefits in Appropriate Units	Benefits Value
Delay	Intersection Delay	Person Hours (Cars)	$17.69	27,716	$490,329.41
		Person Hours (Trucks)	$94.15	1,727	$162,579.20
Crashes	Property Damage Only (PDO) Crash	Number of Crashes	$6,605	0.69	$4,579
	Minor Injury Crash	Number of Crashes	$47,765	0.67	$31,843
	Moderate Injury Crash	Number of Crashes	$434,393	0.00	$0
	Severe Injury Crash	Number of Crashes	$6,065,040	0.00	$0
	Fatality Crash	Number of Crashes	$9,941,700	0.00	$0
Emissions	Carbon Monoxide (CO)	Metric ton	$138	1.3364	$184
	Nitrous Oxide (NOx)	Metric ton	$7,482	0.2626	$1,965
	Volatile Organic Compounds (VOC)	Metric ton	$5,676	0.3094	$1,756
Energy	Fuel	Gallon	$2.40	19,240	$46,176.00
TOTAL					$739,411.93
TOTAL BENEFITS					**$739,420**

BTD Contractor Costs For implementing Signal timing and phasing improvements	
29 intersections with clearance time changes (1 hour per intersection at $125 per hour)	$3,625.00
Travel time for Contractor (30 hours at $125 per hour)	$3,750.00
Signal phasing changes - none	$0.00
Total BTD Contractor costs (Including signal phasing and timing changes and travel time) =	**$7,375.00**

COST CALCULATIONS (Continued)

Engineering Costs, Signs and Pavement Marking Costs	
Engineering Fee for WO #FY 2014-5	$113,500.00
BTD Engineering Costs (350 hours at $50/hour)	$17,500.00
Signs and Pavement marking Costs	N/A
BTD Contractor costs	$7,375.00
Sum of above costs	$138,375.00
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	$138,375.00
Assume i=3 (CPI)	
N = 5	
Numerator = 0.03*(1+0.03)^5 =	$0.03
Denominator = (1+0.03)^5 -1 =	$0.16
A = P *(Numerator/Denominator)	$30,214.81
Total Annual Engineering/Signs/Markings Cost =	**$30,215**

Signal Equipment Costs	N/A
Signal equipment costs	
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	
Assume i=3 (CPI) N= 15	
Numerator = 0.03*(1+0.03)^15 =	
Denominator = (1+0.03)^15 -1 =	
A = P *(Numerator/Denominator)	
Total Annual Signal Equipment Costs =	

Annual Cost Summary	
Type	
Engineering/Signs/Pavement markings	$30,215
Signal Equipment	$0
Other Non-Annualized Costs	$0
Total	**$30,215**

COST BENEFIT RATIO CALCULATIONS

Benefit	$739,420	
Cost	$30,210	
Ratio		**24 to 1**

APPENDIX H

FY2015-1 (BACK BAY)

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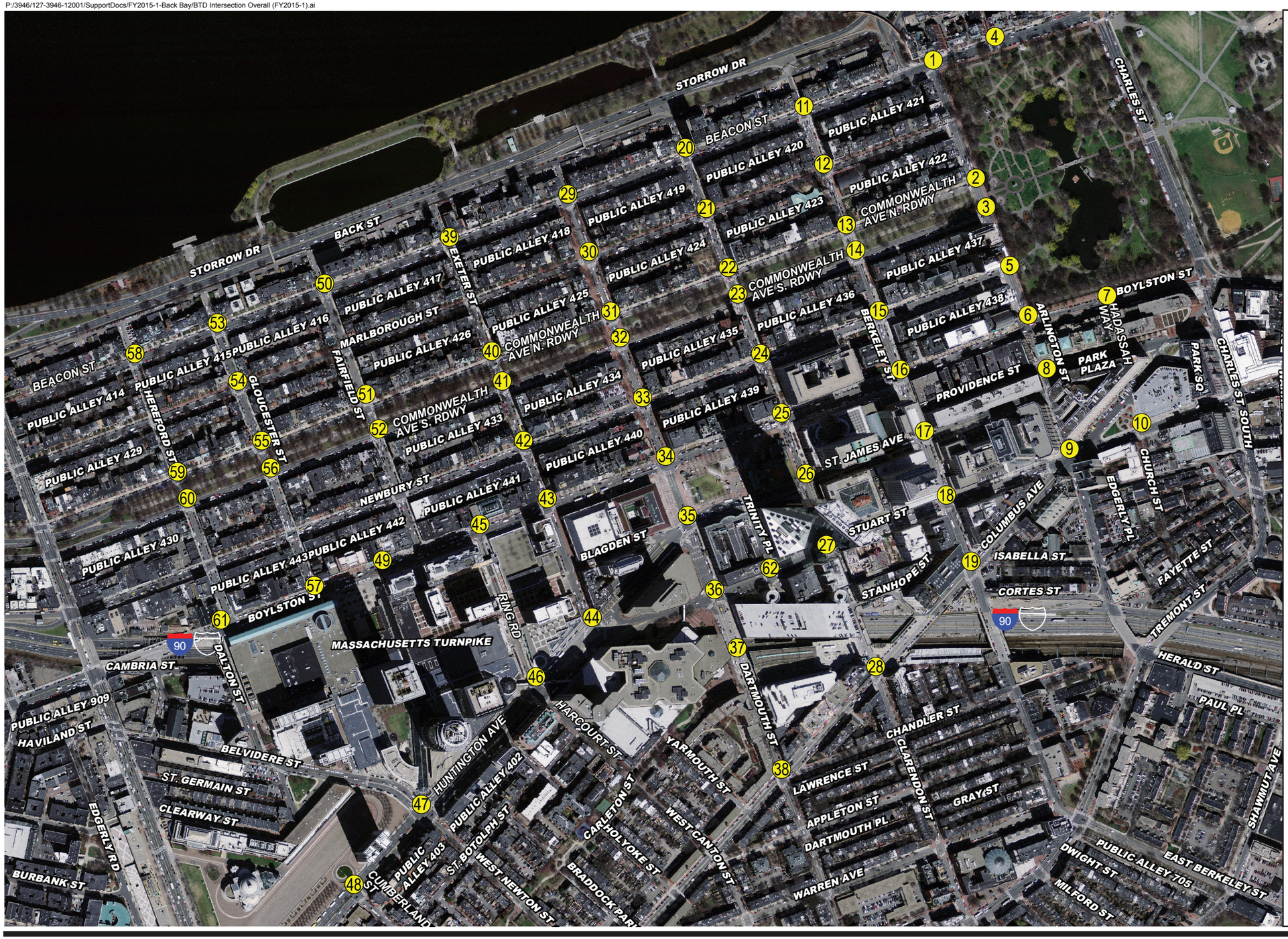


Boston Transportation Department Study Area Intersections

#	Back Bay Intersections	
1.	Beacon St / Arlington St / David G. Mugar Way	(BTD #71)
2.	Commonwealth Ave N.Rdwy / Arlington St	(BTD #73)
3.	Commonwealth Ave S.Rdwy / Arlington St	(BTD #73)
4.	Beacon St / Brimmer St	(BTD #4080)
5.	Newbury St / Arlington St	(BTD #73)
6.	Boylston St / Arlington St	(BTD #75)
7.	Boylston St / Hadassah Way	(BTD #123)
8.	St. James Ave / Park Plaza / Arlington St	(BTD #1378)
9.	Stuart St / Columbus Ave / Arlington St	(BTD #76)
10.	Stuart St / Church St	(BTD #347)
11.	Beacon St / Berkeley St	(BTD #283)
12.	Marlborough St / Berkeley St	(BTD #280)
13.	Commonwealth Ave N. Rdwy / Berkeley St	(BTD #106)
14.	Commonwealth Ave S. Rdwy / Berkeley St	(BTD #107)
15.	Newbury St / Berkeley St	(BTD #282)
16.	Boylston St / Berkeley St	(BTD #77)
17.	St. James Ave / Berkeley St	(BTD #281)
18.	Stuart St / Berkeley St	(BTD #279)
19.	Columbus Ave / Berkeley St	(BTD #278)
20.	Beacon St / Clarendon St	(BTD #336)
21.	Marlborough St / Clarendon St	(BTD #679)
22.	Commonwealth Ave N. Rdwy / Clarendon St	(BTD #3044)
23.	Commonwealth Ave S. Rdwy / Clarendon St	(BTD #3045)
24.	Newbury St / Clarendon St	(BTD #742)
25.	Boylston St / Clarendon St	(BTD #78)
26.	St. James Ave / Clarendon St	(BTD #707)
27.	Stuart St / Clarendon St	(BTD #466)
28.	Columbus Ave / Clarendon St	(BTD #1639)
29.	Beacon St / Dartmouth St	(BTD #104)
30.	Marlborough St / Dartmouth St	(BTD #750)
31.	Commonwealth Ave N. Rdwy / Dartmouth St	(BTD #3046)
32.	Commonwealth Ave S. Rdwy /Dartmouth St	(BTD #3047)
33.	Newbury St / Dartmouth St	(BTD #824)
34.	Boylston St / Dartmouth St	(BTD #79)
35.	St. James Ave / Dartmouth St / Huntington Ave	(BTD #81)
36.	Stuart St / Dartmouth St	(BTD #110)
37.	Back Bay Station / Dartmouth St	(BTD #7001)
38.	Columbus Ave / Dartmouth St	(BTD #319)
39.	Beacon St / Exeter St	(BTD #337)
40.	Commonwealth Ave N. Rdwy / Exeter St	(BTD #4010)
41.	Commonwealth Ave S. Rdwy / Exeter St	(BTD #4011)
42.	Newbury St / Exeter St	(BTD #793)
43.	Boylston St / Exeter St	(BTD #80)
44.	Stuart St / Exeter St / Huntington Ave	(BTD #82)
45.	Boylston St / Ring Rd	(BTD #3131)
46.	Huntington Ave / Ring Rd / Harcourt St	(BTD #4002)
47.	Huntington Ave / W. Newton St / Belvidere St	(BTD #102)
48.	Huntington Ave / Cumberland St	(BTD #4001)
49.	Boylston St / Prudential Center Service Rd	(BTD #3132)
50.	Beacon St / Fairfield St	(BTD #338)
51.	Commonwealth Ave N. Rdwy / Fairfield St	(BTD #4008)
52.	Commonwealth Ave S. Rdwy / Fairfield St	(BTD #4009)
53.	Beacon St / Gloucester St	(BTD #339)
54.	Marlborough St / Gloucester St	(BTD #865)
55.	Commonwealth Ave N. Rdwy / Gloucester St	(BTD #4006)
56.	Commonwealth Ave S. Rdwy / Gloucester St	(BTD #4007)
57.	Boylston St / Gloucester St	(BTD #1573)
58.	Beacon St / Hereford St	(BTD #340)
59.	Commonwealth Ave N. Rdwy / Hereford St	(BTD #4004)
60.	Commonwealth Ave S. Rdwy / Hereford St	(BTD #4005)
61.	Boylston St / Dalton St / Hereford St	(BTD #1357)
62.	Stuart St / Trinity Place	(BTD #1358)

TETRATECH
One Grant Street
Framingham, MA 01701-9005
508.903.2000
www.tetratech.com

500 0 125 250 500
Approximate Scale in Feet

Work Order FY 2015-1 (Back Bay)
Boston Transportation Department (BTD)
Boston, Massachusetts

Figure **H**

DATA

Data from Synchro 7.0 Network MOE Table After Fine Tuning Changes	AM Peak Hour		Midday Peak Hour		PM Peak Hour		Combined Difference	Totals for Final B-C report			
	Existing	Improved	Existing	Improved	Existing	Improved		Existing	Improved	Δ	Δ%
Total Delay (Hr.)	341	348	344	339	521	556	**37**	**1206**	**1243**	**37**	**3%**
Stops/Vehicle	0.46	0.44	0.48	0.46	0.47	0.47	**-0.04**				
Average Speed (mph)	11	11	11	11	9	9	**0**				
Fuel Consumed (gal)	693	691	671	661	909	935	**14**	**2273**	**2287**	**-14**	**-1%**
Fuel Economy (mpg)	9.6	9.6	9.4	9.4	8.7	8.5	**-0.2**				
CO Emissions (Kg)	48.45	48.3	46.92	46.18	63.54	65.32	**0.89**	**158.91**	**159.80**	**-0.89**	**-1%**
NOx Emissions (Kg)	9.43	9.4	9.13	8.98	12.36	12.74	**0.2**	**30.92**	**31.12**	**-0.2**	**-1%**
VOC Emissions (Kg)	11.23	11.19	10.87	10.7	14.73	15.14	**0.2**	**36.83**	**37.03**	**-0.2**	**-1%**

Truck Percentages

Location	AM	MD	PM	Average	Location	AM	MD	PM	Average
Beacon St / Arlington St / Embankment Rd (BTD #71)	2.6%	4.1%	1.4%	2.7%	Commonwealth Ave S. Rdwy /Dartmouth St (BTD #3047)	2.3%	4.0%	1.2%	2.5%
Commonwealth Ave N. Rdwy / Arlington St (BTD #73)	2.7%	4.3%	1.6%	2.9%	Newbury St / Dartmouth St (BTD #824)	7.5%	4.6%	0.8%	4.3%
Commonwealth Ave S. Rdwy / Arlington St (BTD #73)	2.6%	3.1%	2.6%	2.8%	Boylston St / Dartmouth St (BTD #79)	11.9%	6.8%	3.9%	7.5%
Beacon St / Brimmer St (BTD #4080)	4.8%	7.0%	1.9%	4.6%	St. James Ave / Dartmouth St / Huntington Ave (BTD #81)	8.5%	6.5%	4.3%	6.4%
Newbury St / Arlington St (BTD #73)	3.2%	3.0%	2.7%	3.0%	Stuart St / Dartmouth St (BTD #110)	5.6%	5.3%	3.0%	4.6%
Boylston St / Arlington St (BTD #75)	4.8%	6.6%	3.7%	5.0%	Back Bay Station / Dartmouth St (BTD #7001)	5.6%	5.9%	3.1%	4.9%
Boylston St / Hadassah Way (BTD #123)	6.9%	7.4%	3.4%	5.9%	Columbus Ave / Dartmouth St (BTD #319)	5.3%	5.5%	3.0%	4.6%
St. James Ave / Park Plaza / Arlington St (BTD #1378)	4.8%	4.7%	2.6%	4.0%	Beacon St / Exeter St (BTD #337)	6.6%	6.7%	1.6%	5.0%
Stuart St / Columbus Ave / Arlington St (BTD #76)	5.5%	6.5%	3.9%	5.3%	Commonwealth Ave N. Rdwy / Exeter St (BTD #4010)	3.2%	2.1%	1.0%	2.1%
Stuart St / Church St (BTD #347)	6.3%	6.1%	4.2%	5.5%	Commonwealth Ave S. Rdwy / Exeter St (BTD #4011)	3.5%	5.2%	2.6%	3.8%
Beacon St / Berkeley St (BTD #283)	2.0%	2.2%	0.7%	1.6%	Newbury St / Exeter St (BTD #793)	8.3%	6.3%	3.7%	6.1%
Marlborough St / Berkeley St (BTD #280)	1.7%	2.8%	0.4%	1.6%	Boylston St / Exeter St (BTD #80)	13.2%	6.6%	5.1%	8.3%
Commonwealth Ave N. Rdwy / Berkeley St (BTD #106)	1.8%	2.2%	0.6%	1.5%	Stuart St / Exeter St / Huntington Ave (BTD #82)	9.1%	6.7%	5.4%	7.1%
Commonwealth Ave S. Rdwy / Berkeley St (BTD #107)	2.3%	3.8%	0.9%	2.3%	Boylston St / Ring Rd (BTD #3131)	12.9%	7.9%	5.3%	8.7%
Newbury St / Berkeley St (BTD #282)	4.5%	4.5%	1.2%	3.4%	Huntington Ave / Ring Rd / Harcourt St (BTD #4002)	11.6%	7.1%	4.9%	7.9%
Boylston St / Berkeley St (BTD #77)	8.4%	7.3%	3.0%	6.2%	Huntington Ave / W. Newton St / Belvidere St (BTD #102)	7.1%	8.5%	4.0%	6.5%
St. James Ave / Berkeley St (BTD #281)	8.0%	8.3%	3.5%	6.6%	Huntington Ave / Cumberland St (BTD #4001)	7.0%	8.9%	3.9%	6.6%
Stuart St / Berkeley St (BTD #279)	7.3%	8.2%	3.3%	6.3%	Boylston St / Prudential Center Service Rd (BTD #3132)	12.9%	8.3%	4.3%	8.5%
Columbus Ave / Berkeley St (BTD #278)	5.6%	5.7%	2.8%	4.7%	Beacon St / Fairfield St (BTD #338)	7.0%	5.8%	1.6%	4.8%
Beacon St / Clarendon St (BTD #336)	3.8%	4.5%	1.1%	3.1%	Commonwealth Ave N. Rdwy / Fairfield St (BTD #4008)	2.6%	2.3%	0.4%	1.8%
Marlborough St / Clarendon St (BTD #679)	0.9%	4.6%	0.9%	2.1%	Commonwealth Ave S. Rdwy / Fairfield St (BTD #4009)	1.7%	1.8%	1.4%	1.6%
Commonwealth Ave N. Rdwy / Clarendon St (BTD #3044)	1.4%	4.5%	0.5%	2.1%	Beacon St / Gloucester St (BTD #339)	7.1%	6.9%	2.3%	5.4%
Commonwealth Ave S. Rdwy / Clarendon St (BTD #3045)	1.3%	4.5%	1.1%	2.3%	Marlborough St / Gloucester St (BTD #865)	1.8%	2.7%	2.0%	2.2%
Newbury St / Clarendon St (BTD #742)	3.9%	5.8%	1.9%	3.9%	Commonwealth Ave N. Rdwy / Gloucester St (BTD #4006)	2.1%	2.8%	0.3%	1.7%
Boylston St / Clarendon St (BTD #78)	8.3%	7.8%	4.5%	6.9%	Commonwealth Ave S. Rdwy / Gloucester St (BTD #4007)	2.2%	1.8%	1.3%	1.8%
St. James / Clarendon St (BTD #707)	8.1%	6.5%	5.3%	6.6%	Boylston St / Gloucester St (BTD #1573)	13.0%	10.1%	4.2%	9.1%
Stuart St / Clarendon St (BTD #466)	5.2%	4.8%	3.0%	4.3%	Beacon St / Hereford St (BTD #340)	7.4%	3.9%	2.0%	4.4%
Columbus Ave / Clarendon St (BTD #1639)	4.8%	7.0%	2.0%	4.6%	Commonwealth Ave N. Rdwy / Hereford St (BTD #4004)	3.1%	3.8%	0.2%	2.4%
Beacon St / Dartmouth St (BTD #104)	7.9%	6.9%	1.7%	5.5%	Commonwealth Ave S. Rdwy / Hereford St (BTD #4005)	1.5%	3.1%	1.2%	1.9%
Marlborough St / Dartmouth St (BTD #750)	5.0%	4.3%	0.5%	3.3%	Boylston St / Dalton St / Hereford St (BTD #1357)	11.0%	7.3%	4.7%	7.7%
Commonwealth Ave N. Rdwy / Dartmouth St (BTD #3046)	3.8%	4.6%	0.6%	3.0%	Stuart St / Trinity Place (BTD #1358)	4.1%	5.7%	2.8%	4.2%
					Average				**4.5%**

Crash Data (Jan 1, 2010 to Dec 31, 2012)

Location (BTD Intersection Numbers)	71	73.1	73.2	4080	73.3	75	123	1378	76	347	283	280	106	107
Severity														
Property Damage	5	1	0	0	1	2	2	0	1	1	1	1	1	0
Personal Injury	2	0	0	0	0	3	2	0	3	1	1	0	3	0
Fatality	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other	2	0	0	0	0	1	0	1	5	0	2	0	1	0
Total	9	1	0	0	1	6	4	1	9	2	4	1	5	0

Crash Data (Jan 1, 2010 to Dec 31, 2012)

Location (BTD Intersection Numbers)	282	77	281	279	278	336	679	3044	3045	742	78	707	466	1639
Severity														
Property Damage	0	0	0	1	2	1	0	1	0	0	0	0	1	0
Personal Injury	1	1	2	0	3	0	1	1	0	1	3	0	0	0
Fatality	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other	0	0	3	2	1	1	0	2	0	2	1	1	0	0
Total	1	1	5	3	6	2	1	4	0	3	4	1	1	0

Crash Data (Jan 1, 2010 to Dec 31, 2012)

Location (BTD Intersection Numbers)	104	750	3046	3047	824	79	81	110	7001	319	337	4010	4011	793
Severity														
Property Damage	0	0	1	0	0	0	2	0	0	0	0	0	0	1
Personal Injury	0	0	1	0	0	0	0	1	0	1	0	2	0	2
Fatality	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Other	0	0	3	0	1	0	0	0	0	0	0	2	0	0
Total	0	0	5	0	1	1	2	1	0	1	0	4	0	3

Crash Data (Jan 1, 2010 to Dec 31, 2012)

Location (BTD Intersection Numbers)	80	82	3131	4002	102	4001	3132	338	4008	4009	339	865	4006	4007
Severity														
Property Damage	0	0	0	3	1	0	0	1	1	0	0	0	0	0
Personal Injury	0	0	0	1	0	0	0	0	0	0	0	0	1	1
Fatality	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other	1	1	0	1	1	0	0	1	1	0	0	0	1	0
Total	1	1	0	5	2	0	0	2	2	0	0	0	2	1

Crash Data (Jan 1, 2010 to Dec 31, 2012)

Location (BTD Intersection Numbers)	1573	340	4004	4005	1357	1358	Total	per Year
Severity								
Property Damage	0	0	0	0	0	0	32	**11**
Personal Injury	0	1	0	0	0	0	39	**13**
Fatality	0	0	0	0	0	0	1	**0.3**
Other	0	0	1	0	1	0	40	**13**
Total	0	1	1	0	1	0	112	**37**

Benefits Performance Measures values

Category	Performance Measures	Unit of measure	Value per unit	Value per unit in 2014 dollars	Value per unit in 2015 dollars
Delay	Intersection Delay	Person Hours (Cars) [1]	$16.79	$17.66	$17.69
	Intersection Delay	Person Hours (Trucks)[1]	$86.81	$91.32	$94.15
Crashes	Property Damage Only (PDO) Crash	Number of Crashes [2]	$6,076	$6,599	$6,605
	Minor Injury Crash	Number of Crashes [2]	$46,020	$49,978	$47,765
	Moderate Injury Crash	Number of Crashes [2]	$445,846	$484,189	$434,393
	Severe Injury Crash	Number of Crashes [2]	$5,679,122	$6,167,526	$6,065,040
	Fatality Crash	Number of Crashes [2]	$9,145,998	$9,932,554	$9,941,700
Emissions	Carbon Monoxide (CO)	Metric ton [3]	$138	$152	$138
	Nitrous Oxide (NOx)	Metric ton [3]	$7,490	$8,261	$7,482
	Volatile Organic Compounds (VOC)	Metric ton [3]	$5,682	$6,267	$5,676
Energy	Fuel	Gallon	$3.49	$3.34	$2.40

1. 2014 Delay value per unit taken from 2015 Urban Mobility Report
2. 2010 Crash unit value taken from May 2015 (revised) "The Economic and Societal Impact of Motor Vehicle Crashes" Report
3. 2000 Emission value per unit taken from HERS-ST Highway Economic Requirements System – State Version: Technical Report . No 2015 updates were found on FHWA website. Still referring to 2000 $ values
 - Consumer Price Index increased from 2000 to 2015 by 37.6%, from 2010 to 2015 by 8.7%, and from 2014 to 2015 by 0.12%. All values (except fuel price) were adjusted accordingly to calculate equivalent 2015 values.
 - National average Fuel price in 2015 ($2.40) according to AAA

BENEFIT CALCULATIONS

Calculation of Delay Reduction Per Year

Assuming

Truck Percentage:	4.5%							
Vehicle Occupancy	1.25							
Delay decreased by:	(37)	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 (95.5%)	-35	hrs.	-44	x	260 days/year =	**(11,466)**	$17.69	($202,847.35)
Truck Delay (4.5%)	-2	hrs.		x	260 days/year =	**(432)**	$94.15	($40,632.16)
								($243,479.50)

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	11	0.08	**0.85**	$6,605	$5,636
Personal Injury Accidents	13	0.08	**1.04**	$47,765	$49,676
Fatality Accidents	0.3	0.08	**0.03**	$9,941,700	$265,112

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	-0.89	-0.00089	x	260 days/year =	**(0.2314)**	$138	($32)
NOx Reduction	-0.2	-0.0002	x	260 days/year =	**(0.0520)**	$7,482	($389)
VOC Reduction	-0.2	-0.0002	x	260 days/year =	**(0.0520)**	$5,676	($295)

Calculation of Fuel Reduction Per Year

	Gal. per day		Annual Reduction		Cost per Gal.	Benefit per Year
Fuel reduction in gallons =	-14	x	260 days/year =	**(3,640)**	$2.40	($8,736.00)

Benefits Summary

Category	Performance Measure	Unit	Value per unit in 2015 dollars	Benefits in Appropriate Units	Benefits Value
Delay	Intersection Delay	Person Hours (Cars)	$17.69	(11,466)	($202,847.35)
		Person Hours (Trucks)	$94.15	(432)	($40,632.16)
Crashes	Property Damage Only (PDO) Crash	Number of Crashes	$6,605	0.85	$5,636
	Minor Injury Crash	Number of Crashes	$47,765	1.04	$49,676
	Moderate Injury Crash	Number of Crashes	$434,393	0.00	$0
	Severe Injury Crash	Number of Crashes	$6,065,040	0.00	$0
	Fatality Crash	Number of Crashes	$9,941,700	0.03	$265,112
Emissions	Carbon Monoxide (CO)	Metric ton	$138	-0.2314	($32)
	Nitrous Oxide (NOx)	Metric ton	$7,482	-0.0520	($389)
	Volatile Organic Compounds (VOC)	Metric ton	$5,676	-0.0520	($295)
Energy	Fuel	Gallon	$2.40	(3,640)	($8,736.00)
TOTAL					$67,491.92
TOTAL BENEFITS					**$67,500**

BTD Contractor Costs For implementing Signal timing and phasing improvements	
62 intersections with clearance time changes (1 hour per intersection at $125 per hour)	$7,750
Travel time for Contractor (1/2 hour per intersection, total 31 hours at $125 per hour)	$3,875
Signal phasing changes - none	$0
Total BTD Contractor costs (Including signal phasing and timing changes and travel time) =	**$11,625**

COST CALCULATIONS (Continued)	
Engineering Costs, Signs and Pavement Marking Costs	
Engineering Fee for WO #FY 2014-5	$232,000.00
BTD Engineering Costs (500 hours at $50/hour)	$25,000.00
Signs and Pavement marking Costs	N/A
BTD Contractor costs	$11,625.00
Sum of above costs	$268,625.00
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	$268,625.00
i=3.0 (assume CPI)	
N = 5	
Numerator = 0.03*(1+0.03)^5 =	$0.03
Denominator = (1+0.03)^5 -1 =	$0.16
A = P *(Numerator/Denominator)	$58,655.50
Total Annual Engineering/Signs/Markings Cost =	**$58,655**

Signal Equipment Costs	**N/A**
Signal equipment costs	
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	
i=3.0 (assume CPI) N= 15	
Numerator = 0.03*(1+0.03)^15 =	
Denominator = (1+0.03)^15 -1 =	
A = P *(Numerator/Denominator)	
Total Annual Signal Equipment Costs =	

Annual Cost Summary	
Type	
Engineering/Signs/Pavement markings	$58,655
Signal Equipment	$0
Other Non-Annualized Costs	$0
Total	**$58,655**

BENEFIT- COST RATIO CALCULATIONS		
Benefit	$67,500	
Cost	$58,660	
Ratio		**1.2 to 1**

APPENDIX I

FY2016-1 (DORCHESTER AVE)

P:/3946/127-3946-12001/SupportDocs/FY2016-1-Dorchester Ave/BTD Intersections Overall (FY2016-1).ai

Boston Transportation Department
Study Area Intersections

1	Dorchester Ave/Crescent Ave	(BTD #523)
2	Dorchester Ave/Sudan St/Taft St	(BTD #4041)
3	Dorchester Ave/Belfort St/Victoria St	(BTD #960)
4	Dorchester Ave/Savin Hill Ave	(BTD #344)
5	Dorchester Ave/Hancock St/Hoyt St	
6	Dorchester Ave/East St/Freeport St	(BTD #222)
7	Dorchester Ave/Kimball St	(BTD #4026)
8	Dorchester Ave/Adams St (Field's Corner)	(BTD #228)
9	Dorchester Ave/Faulkner St/Lincoln St	(BTD #2301)
10	Dorchester Ave/Park St	(BTD #356)
11	Dorchester Ave/Gibson St	(BTD #1242)
12	Dorchester Ave/Melville Ave/Parkman St	(BTD #673)
13	Dorchester Ave/Centre St	(BTD #979)
14	Dorchester Ave/St. Marks Church	(BTD #468)
15	Dorchester Ave/Lonsdale St/Welles Ave	(BTD #1168)
16	Dorchester Ave/Talbot Ave (Peabody Square)	
17	Dorchester Ave/Ashmont St (Peabody Square)	(BTD #235)
18	Adams St/Park St	(BTD #357)
19	Adams St/Gibson St	(BTD #617)
20	Adams St/Neponset Ave/Parkman St	(BTD #567)

1000 0 250 500 1000

Approximate Scale in Feet

TETRATECH
100 Nickerson Road
Marlborough, MA 01752
508.786.2200
www.tetratech.com

Work Order FY 2016-1 (Dorchester Ave)
Boston Transportation Department (BTD)
Boston, Massachusetts

BTD Intersection Locations

Figure 1

DATA

Data from Synchro 7.0 Network MOE Table After Fine Tuning Changes

	AM Peak Hour		Midday Peak Hour		PM Peak Hour		Combined Difference	Totals for Final B-C report			
	Existing	Improved	Existing	Improved	Existing	Improved		Existing	Improved	Δ	Δ%
Total Delay (Hr.)	221	205	137	127	216	198	**-44**	**574**	**530**	**-44**	**-8%**
Stops/Vehicle	0.54	0.57	0.5	0.49	0.54	0.54	**0.02**				
Average Speed (mph)	9	9	12	12	10	10	**0**				
Fuel Consumed (gal)	357	336	276	259	369	343	**-64**	**1002**	**938**	**64**	**6%**
Fuel Economy (mpg)	8.2	8.7	9.9	10.6	8.6	9.2	**1.8**				
CO Emissions (Kg)	24.94	23.5	19.31	18.11	25.8	23.98	**-4.46**	**70.05**	**65.59**	**4.46**	**6%**
NOx Emissions (Kg)	4.85	4.57	3.76	3.52	5.02	4.67	**-0.87**	**13.63**	**12.76**	**0.87**	**6%**
VOC Emissions (Kg)	5.78	5.45	4.47	4.2	5.98	5.56	**-1.02**	**16.23**	**15.21**	**1.02**	**6%**

Truck Percentages

Location	AM	MD	PM	Average	Location	AM	MD	PM	Average
Dorchester Ave/Crescent Ave (BTD #523)	11.7%	9.7%	3.1%	8.2%	Dorchester Ave/Gibson St (BTD #617)	8.8%	6.3%	4.0%	6.4%
Dorchester Ave/Sudan St/Taft St (BTD #4041)	12.7%	10.8%	3.8%	9.1%	Dorchester Ave/Melville Ave/Parkman St (BTD #673)	7.0%	5.1%	3.7%	5.3%
Dorchester Ave/Belfort St/Victoria St (BTD #960)	11.4%	10.1%	4.0%	8.5%	Dorchester Ave/Centre St (BTD #979)	8.4%	7.3%	4.5%	6.7%
Dorchester Ave/Savin Hill Ave (BTD #344)	11.6%	9.6%	3.7%	8.3%	Dorchester Ave/St. Marks Church (BTD #468)	8.0%	6.3%	4.8%	6.4%
Dorchester Ave/Hancock St/Hoyt St (BTD #222)	8.9%	11.0%	6.1%	8.7%	Dorchester Ave/Lonsdale St/Welles Ave (BTD #1168)	8.1%	6.4%	4.4%	6.3%
Dorchester Ave/East St/Freeport St (BTD #222)	8.5%	6.6%	5.4%	6.8%	Dorchester Ave/Talbot Ave (BTD #235)	11.1%	10.4%	6.4%	9.3%
Dorchester Ave/Kimball St (BTD #4026)	8.0%	6.8%	2.8%	5.9%	Dorchester Ave/Ashmont St (BTD #235)	9.5%	10.1%	5.7%	8.4%
Dochester Ave/Adams St (BTD #228)	9.7%	5.6%	3.0%	6.1%	Adams St/Park St (BTD #357)	7.7%	5.8%	1.8%	5.1%
Dorchester Ave/Faulkner St/Lincoln St (BTD #2301)	7.5%	7.9%	4.5%	6.6%	Adams St/Gibson St (BTD #617)	8.4%	7.9%	5.7%	7.3%
Dorchester Ave/Park St (BTD #356)	7.4%	5.2%	4.1%	5.6%	Adams St/Neponset Ave/Parkman St (BTD #567)	7.4%	6.9%	3.0%	5.8%
					Average				**7.0%**

Crash Data (Jan 1, 2011 to Dec 31, 2013)

Location (BTD Intersection Numbers)	523	4041	960	344	222 - 1	222 - 2	4026	228	2301	356
Severity										
Property Damage	0	1	1	0	2	1	0	4	2	0
Personal Injury	0	3	0	3	3	4	2	6	3	5
Fatality	0	0	0	0	0	0	0	0	0	0
Other	1	2	0	1	2	4	0	2	2	2
Total	1	6	1	4	7	9	2	12	7	7

Crash Data (Jan 1, 2011 to Dec 31, 2013)

Location (BTD Intersection Numbers)	617	673	979	468	1168	235 - 1	235 - 2	357	617	567	Total	per Year
Severity												
Property Damage	0	0	0	0	0	1	4	1	1	1	19	**6**
Personal Injury	1	2	3	0	2	0	4	4	0	4	49	**16**
Fatality	0	0	0	0	0	0	0	0	0	0	0	**0**
Other	0	2	2	0	1	1	2	0	0	2	26	**9**
Total	1	4	5	0	3	2	10	5	1	7	94	**31**

Benefits Performance Measures values

Category	Performance Measures	Unit of measure	Value per unit	Value per unit in 2015 dollars
Delay	Intersection Delay	Person Hours (Cars) [1]	$17.67	$17.69
	Intersection Delay	Person Hours (Trucks)[1]	$94.04	$94.15
Crashes	Property Damage Only (PDO) Crash	Number of Crashes [2]	$6,076	$6,605
	Minor Injury Crash	Number of Crashes [2]	$43,942	$47,765
	Moderate Injury Crash	Number of Crashes [2]	$399,626	$434,393
	Severe Injury Crash	Number of Crashes [2]	$5,579,614	$6,065,040
	Fatality Crash	Number of Crashes [2]	$9,145,998	$9,941,700
Emissions (Air Pollutant Damage Costs)	Carbon Monoxide (CO)	Metric ton [3]	$100	$138
	Nitrous Oxide (NOx)	Metric ton [3]	$5,438	$7,482
	Volatile Organic Compounds (VOC)	Metric ton [3]	$4,125	$5,676
Energy	Fuel	Gallon	-	$2.40

1. 2014 Delay value per unit taken from 2015 Urban Mobility Report
2. 2010 Crash unit value taken from May 2015 (revised) "The Economic and Societal Impact of Motor Vehicle Crashes" Report
3. 2000 Emission value per unit taken from HERS-ST Highway Economic Requirements System – State Version: Technical Report . No 2015 updates were found on FHWA website. Still referring to 2000 $ values
 - Consumer Price Index increased from 2000 to 2015 by 37.6%, from 2010 to 2015 by 8.7%, and from 2014 to 2015 by 0.12%. All values (except fuel price) were adjusted accordingly to calculate equivalent 2015 values.
 - National average Fuel price in 2015 ($2.40) according to AAA

BENEFIT CALCULATIONS

Calculation of Delay Reduction Per Year

Assuming

Truck Percentage:	7.0%							
Vehicle Occupancy	1.25							
Delay decreased by:	44	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 (93.0%)	41	hrs.	51	x	260 days/year =	**13,286**	$17.69	$235,045.34
Truck Delay (7.0%)	3	hrs.		x	260 days/year =	**805**	$94.15	$75,774.59
								$310,819.93

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	6	0.08	**0.51**	$6,605	$3,346
Personal Injury Accidents	16	0.08	**1.31**	$47,765	$62,413
Fatality Accidents	0	0.08	-	$9,941,700	$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	4.46	0.00446	x	260 days/year =	**1.1596**	$138	$160
NOx Reduction	0.87	0.00087	x	260 days/year =	**0.2262**	$7,482	$1,692
VOC Reduction	1.02	0.00102	x	260 days/year =	**0.2652**	$5,676	$1,505

Calculation of Fuel Reduction Per Year

	Gal. per day		Annual Reduction		Cost per Gal.	Benefit per Year
Fuel reduction in gallons =	64	x	260 days/year =	**16,640**	$2.40	$39,936.00

Benefits Summary

Category	Performance Measure	Unit	Value per unit in 2015 dollars	Benefits in Appropriate Units	Benefits Value
Delay	Intersection Delay	Person Hours (Cars)	$17.69	13,286	$235,045.34
		Person Hours (Trucks)	$94.15	805	$75,774.59
Crashes	Property Damage Only (PDO) Crash	Number of Crashes	$6,605	0.51	$3,346
	Minor Injury Crash	Number of Crashes	$47,765	1.31	$62,413
	Moderate Injury Crash	Number of Crashes	$434,393	0.00	$0
	Severe Injury Crash	Number of Crashes	$6,065,040	0.00	$0
	Fatality Crash	Number of Crashes	$9,941,700	0.00	$0
Emissions	Carbon Monoxide (CO)	Metric ton	$138	1.1596	$160
	Nitrous Oxide (NOx)	Metric ton	$7,482	0.2262	$1,692
	Volatile Organic Compounds (VOC)	Metric ton	$5,676	0.2652	$1,505
Energy	Fuel	Gallon	$2.40	16,640	$39,936.00
TOTAL					$419,872.40
TOTAL BENEFITS					**$419,880**

COST CALCULATIONS

BTD Contractor Costs For implementing Signal timing and phasing improvements	
20 intersections with clearance time changes (1 hour per intersection at $125 per hour)	$2,500
Travel time for Contractor (1/2 hour per intersection, total 10 hours at $125 per hour)	$1,250
Signal phasing changes - none	$0
Total BTD Contractor costs (Including signal phasing and timing changes and travel time) =	**$3,750**

COST CALCULATIONS (Continued)

Engineering Costs, Signs and Pavement Marking Costs	
Engineering Fee for WO #FY 2016-1	$71,350.00
BTD Engineering Costs (300 hours at $50/hour)	$15,000.00
Signs and Pavement marking Costs	N/A
BTD Contractor costs	$3,750.00
Sum of above costs	$90,100.00
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	$90,100.00
i=3.0 (assume CPI)	
N = 5	
Numerator = 0.03*(1+0.03)^5 =	$0.03
Denominator = (1+0.03)^5 -1 =	$0.16
A = P *(Numerator/Denominator)	$19,673.75
Total Annual Engineering/Signs/Markings Cost =	**$19,680**

Signal Equipment Costs	N/A
Signal equipment costs	
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	
i=3.0 (assume CPI) N= 15	
Numerator = 0.03*(1+0.03)^15 =	
Denominator = (1+0.03)^15 -1 =	
A = P *(Numerator/Denominator)	
Total Annual Signal Equipment Costs =	

Annual Cost Summary	
Type	
Engineering/Signs/Pavement markings	$19,680
Signal Equipment	$0
Other Non-Annualized Costs	$0
Total	**$19,680**

BENEFIT- COST RATIO CALCULATIONS

Benefit	$419,880	
Cost	$19,680	
Ratio		**21 to 1**

APPENDIX J

FY2016-2 (ROSLINDALE, ROXBURY, DORCHESTER)

P:/3946/127-3946-12001/SupportDocs/FY2016-2-Roslindale Roxbury & Dorchester/BTD Intersections Overall Roslindale, Roxbury & Dorchester (FY2016-2).ai

Boston Transportation Department
Study Area Intersections

1	Washington St/Beech St/Walworth St	(Roslindale, BTD #579)
2	Washington St/Cornell St	(Roslindale, BTD #632)
3	Washington St/Metropolitan Ave	(Roslindale, BTD #582)
4	Washington St/Albano St	(Roslindale, BTD #1686)
5	Washington St/Corinth St/Poplar St	(Roslindale, BTD #251)
6	Washington St/Cummins Hwy	(Roslindale, BTD #252)
7	Washington St/South St/Firth Rd	(Roslindale, BTD #978)
8	Washington St/Archdale Rd	(Roslindale, BTD #762)
9	Washington St/McBride St/Rossmore Rd	(Jamaica Plain, BTD #986)
10	Washington St/Williams St	(Jamaica Plain, BTD #1285)
11	Washington St/Glen Rd/Green St	(Jamaica Plain, BTD #241)
12	Washington St/Forest Hills St/Montebello	(Jamaica Plain, BTD #711)
13	Washington St/School St (JP)	(Roxbury, BTD #954)
14	Washington St/Columbus Ave	(Roxbury, BTD #191)
15	Washington St/Dimock St	(Roxbury, BTD #4089)
16	Washington St/Brinton St/Marcella St	(Roxbury, BTD #683)
17	Washington St/MLK Blvd/Valentine St	(Roxbury, BTD #1592)
18	Washington St/Dale St/Oakland St	(Roxbury, BTD #846)
19	Washington St/Cedar St	(Roxbury, BTD #64)
20	Washington St/Dorchester Ave/Adams St (Pierce Sq)	(Dorchester, BTD #360)
21	Washington St/River St	(Dorchester, BTD #1488)
22	Washington St/Richmond St/Morton St	(Dorchester, BTD #1243)

Dorchester, BTD Intersections

1400 0 350 700 1400
Approximate Scale in Feet

TETRATECH
100 Nickerson Road
Marlborough, MA 01752
508.786.2200
www.tetratech.com

Work Order FY 2016-2 (Roslindale, Roxbury, & Dorchester)
Boston Transportation Department (BTD)
Boston, Massachusetts

BTD Intersection Locations

Figure **J**

DATA

Data from Synchro 7.0 Network MOE Table After Fine Tuning Changes

	AM Peak Hour		Midday Peak Hour		PM Peak Hour		Combined Difference	Totals for Final B-C report			
	Existing	Improved	Existing	Improved	Existing	Improved		Existing	Improved	Δ	Δ%
Total Delay (Hr.)	262	243	149	148	285	231	**-74**	**696**	**622**	**-74**	**-11%**
Stops/Vehicle	0.53	0.57	0.52	0.57	0.56	0.62	**0.15**				
Average Speed (mph)	9	10	12	12	8	10	**3**				
Fuel Consumed (gal)	408	400	290	295	426	394	**-35**	**1124**	**1089**	**35**	**3%**
Fuel Economy (mpg)	8.3	8.5	10	9.8	7.8	8.4	**0.6**				
CO Emissions (Kg)	28.54	27.94	20.26	20.63	29.75	27.57	**-2.41**	**78.55**	**76.14**	**2.41**	**3%**
NOx Emissions (Kg)	5.55	5.44	3.94	4.01	5.79	5.36	**-0.47**	**15.28**	**14.81**	**0.47**	**3%**
VOC Emissions (Kg)	6.61	6.48	4.7	4.78	6.89	6.39	**-0.55**	**18.2**	**17.65**	**0.55**	**3%**

Truck Percentages

Location	AM	MD	PM	Average	Location	AM	MD	PM	Average
Washington Street/Beech street/Walworth Street (BTD #579)	7.4%	7.6%	4.8%	6.6%	Washington Street/Forest Hills Street/Montebello Street (BTD #711)	6.2%	8.2%	7.4%	7.3%
Washington Street/Cornell Street (BTD #632)	7.0%	8.1%	3.3%	6.1%	Washington Street/School Street (BTD #954)	7.9%	7.2%	4.9%	6.7%
Washington Street/Metropolitan Avenue (BTD #582)	8.6%	7.5%	3.6%	6.6%	Washington Street/Columbus Avenue (BTD #191)	7.5%	8.2%	6.4%	7.4%
Washington Street/Albano Street (BTD #1686)	8.1%	6.8%	6.7%	7.2%	Washington Street/Dimock Street (BTD #4089)	5.8%	5.4%	4.5%	5.2%
Washington Street/Corinth Street/Poplar Street (BTD #251)	11.3%	7.4%	6.5%	8.4%	Washington Street/Brinton Street/Marcella Street (BTD #683)	5.7%	4.7%	3.3%	4.6%
Washington Street/Cummins Highway (BTD #252)	8.8%	6.2%	5.8%	6.9%	Washington Street/MLK Boulevard/Valentine Street (BTD #1592)	5.3%	5.0%	4.0%	4.8%
Washington Street/South Street/Firth Road (BTD #978)	10.8%	9.0%	7.8%	9.2%	Washington Street/Dale Street/Oakland Street (BTD #846)	5.1%	4.9%	3.8%	4.6%
Washington Street/Archdale Road (BTD #762)	12.6%	9.8%	9.6%	10.7%	Washington Street/Cedar Street (BTD #64)	4.6%	4.8%	4.4%	4.6%
Washington Street/McBride Street/Rossmore Road (BTD #986)	5.7%	7.7%	4.1%	5.8%					
Washington Street/Williams Street (BTD #1285)	5.8%	7.3%	5.5%	6.2%					
Washington Street/Glen Street/Green Street (BTD #241)	6.7%	8.5%	5.8%	7.0%					
					Average				**6.6%**

Crash Data (Jan 1, 2011 to Dec 31, 2013)

Location (BTD Intersection Numbers)	579	632	582	1686	251	252	978	762	986	1285	241	711
Severity												
Property Damage	1	1	0	2	1	0	0	0	0	0	2	1
Personal Injury	4	1	0	1	0	0	0	3	2	2	0	0
Fatality	0	0	0	0	0	0	0	0	0	0	0	0
Other	2	0	1	0	0	2	1	1	0	0	1	0
Total	7	2	1	3	1	2	1	1	2	2	3	1

Crash Data (Jan 1, 2011 to Dec 31, 2013)

Location (BTD Intersection Numbers)	954	191	4089	683	1592	846	64	Total	per Year
Severity									
Property Damage	0	1	0	0	1	0	0	10	**3**
Personal Injury	0	0	0	0	0	0	0	13	**4**
Fatality	0	0	0	0	0	0	0	0	**0**
Other	0	0	0	1	0	1	0	10	**3**
Total	0	1	0	1	1	1	0	33	**11**

Benefits Performance Measures values

Category	Performance Measures	Unit of measure	Value per unit	Value per unit in 2015 dollars
Delay	Intersection Delay	Person Hours (Cars) [1]	$17.67	$17.69
	Intersection Delay	Person Hours (Trucks)[1]	$94.04	$94.15
Crashes	Property Damage Only (PDO) Crash	Number of Crashes [2]	$6,076	$6,605
	Minor Injury Crash	Number of Crashes [2]	$43,942	$47,765
	Moderate Injury Crash	Number of Crashes [2]	$399,626	$434,393
	Severe Injury Crash	Number of Crashes [2]	$5,579,614	$6,065,040
	Fatality Crash	Number of Crashes [2]	$9,145,998	$9,941,700
Emissions	Carbon Monoxide (CO)	Metric ton [3]	$100	$138
	Nitrous Oxide (NOx)	Metric ton [3]	$5,438	$7,482
	Volatile Organic Compounds (VOC)	Metric ton [3]	$4,125	$5,676
Energy	Fuel	Gallon	-	$2.40

1. 2014 Delay value per unit taken from 2015 Urban Mobility Report
2. 2010 Crash unit value taken from May 2015 (revised) "The Economic and Societal Impact of Motor Vehicle Crashes" Report
3. 2000 Emission value per unit taken from HERS-ST Highway Economic Requirements System – State Version: Technical Report . No 2015 updates were found on FHWA website. Still referring to 2000 $ values
   - Consumer Price Index increased from 2000 to 2015 by 37.6%, from 2010 to 2015 by 8.7%, and from 2014 to 2015 by 0.12%. All values (except fuel price) were adjusted accordingly to calculate equivalent 2015 values.
   - National average Fuel price in 2015 ($2.40) according to AAA

BENEFIT CALCULATIONS

Calculation of Delay Reduction Per Year

Assuming

Truck Percentage: 6.6%

Vehicle Occupancy 1.25

Delay decreased by: 74 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 (93.4%)	69 hrs.	86	x	260 days/year =	**22,438**	$17.69	$396,955.24
Truck Delay (6.6%)	5 hrs.		x	260 days/year =	**1,274**	$94.15	$119,940.42
							$516,895.66
							$516,895.66

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	3	0.08	**0.27**	$6,605	$1,761
Personal Injury Accidents	4	0.08	**0.35**	$47,765	$16,559
Fatality Accidents	0	0.08	**-**	$9,941,700	$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	2.41	0.00241	x	260 days/year =	**0.6266**	$138	$86
NOx Reduction	0.47	0.00047	x	260 days/year =	**0.1222**	$7,482	$914
VOC Reduction	0.55	0.00055	x	260 days/year =	**0.1430**	$5,676	$812

Calculation of Fuel Reduction Per Year

	Gal. per day			Annual Reduction		Cost per Gal.	Benefit per Year
Fuel reduction in gallons =	35		x	260 days/year =	**9,100**	$2.40	$21,840.00

Benefits Summary

Category	Performance Measure	Unit	Value per unit in 2015 dollars	Benefits in Appropriate Units	Benefits Value
Delay	Intersection Delay	Person Hours (Cars)	$17.69	22,438	$396,955.24
		Person Hours (Trucks)	$94.15	1,274	$119,940.42
Crashes	Property Damage Only (PDO) Crash	Number of Crashes	$6,605	0.27	$1,761
	Minor Injury Crash	Number of Crashes	$47,765	0.35	$16,559
	Moderate Injury Crash	Number of Crashes	$434,393	0.00	$0
	Severe Injury Crash	Number of Crashes	$6,065,040	0.00	$0
	Fatality Crash	Number of Crashes	$9,941,700	0.00	$0
Emissions	Carbon Monoxide (CO)	Metric ton	$138	0.6266	$86
	Nitrous Oxide (NOx)	Metric ton	$7,482	0.1222	$914
	Volatile Organic Compounds (VOC)	Metric ton	$5,676	0.1430	$812
Energy	Fuel	Gallon	$2.40	9,100	$21,840.00
TOTAL					$558,867.59
TOTAL BENEFITS					**$558,870**

COST CALCULATIONS

BTD Contractor Costs For implementing Signal timing and phasing improvements	
19 intersections with clearance time changes (1 hour per intersection at $125 per hour) - Excluding 3 intersections in Lower Mills area	$2,375
Travel time for Contractor (1/2 hour per intersection, total 9.5 hours at $125 per hour)	$1,188
Signal phasing changes - none	$0
Total BTD Contractor costs (Including signal phasing and timing changes and travel time) =	**$3,563**

COST CALCULATIONS (Continued)

Engineering Costs, Signs and Pavement Marking Costs	
Engineering Fee for WO #FY 2016-2 (excluding 3 intersections)	$72,839.09
BTD Engineering Costs (300 hours at $50/hour)	$12,954.55
Signs and Pavement marking Costs	N/A
BTD Contractor costs	$3,562.50
Sum of above costs	$89,356.14
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	$89,356.14
i=3.0 (assume CPI)	
N = 5	
Numerator = 0.03*(1+0.03)^5 =	$0.03
Denominator = (1+0.03)^5 -1 =	$0.16
A = P *(Numerator/Denominator)	$19,511.32
Total Annual Engineering/Signs/Markings Cost =	**$19,511**

Signal Equipment Costs	N/A
Signal equipment costs	
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	
i=3.0 (assume CPI) N= 15	
Numerator = 0.03*(1+0.03)^15 =	
Denominator = (1+0.03)^15 -1 =	
A = P *(Numerator/Denominator)	
Total Annual Signal Equipment Costs =	

Annual Cost Summary	
Type	
Engineering/Signs/Pavement markings	$19,511
Signal Equipment	$0
Other Non-Annualized Costs	$0
Total	**$19,510**

BENEFIT- COST RATIO CALCULATIONS		
Benefit	$558,870	
Cost	$19,510	
Ratio		**29 to 1**

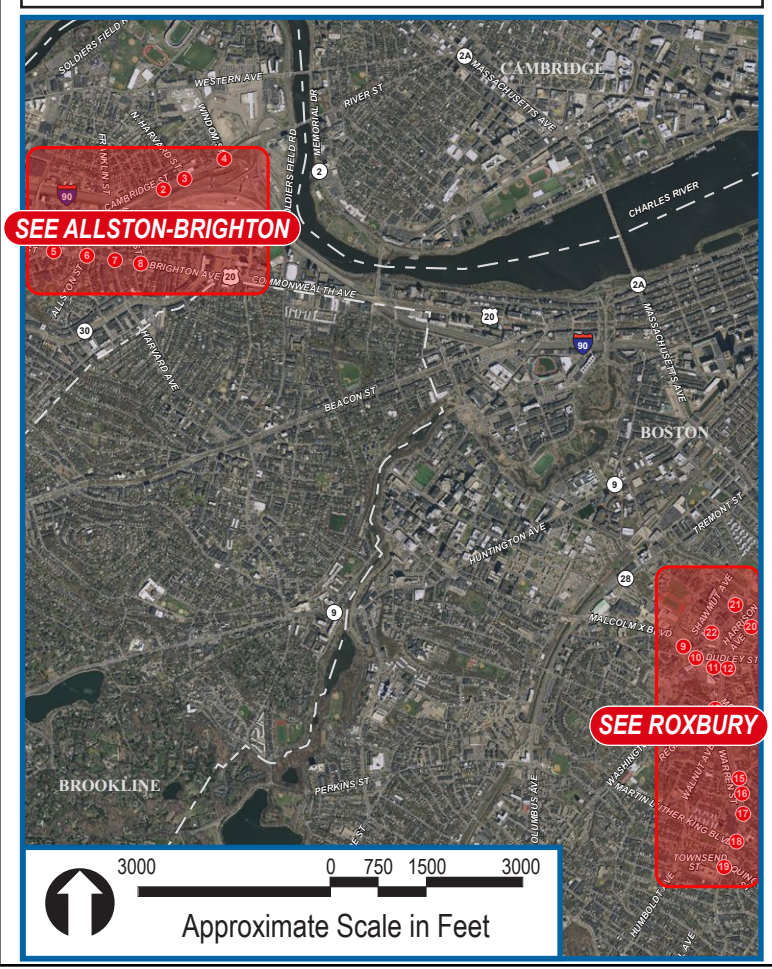
APPENDIX K

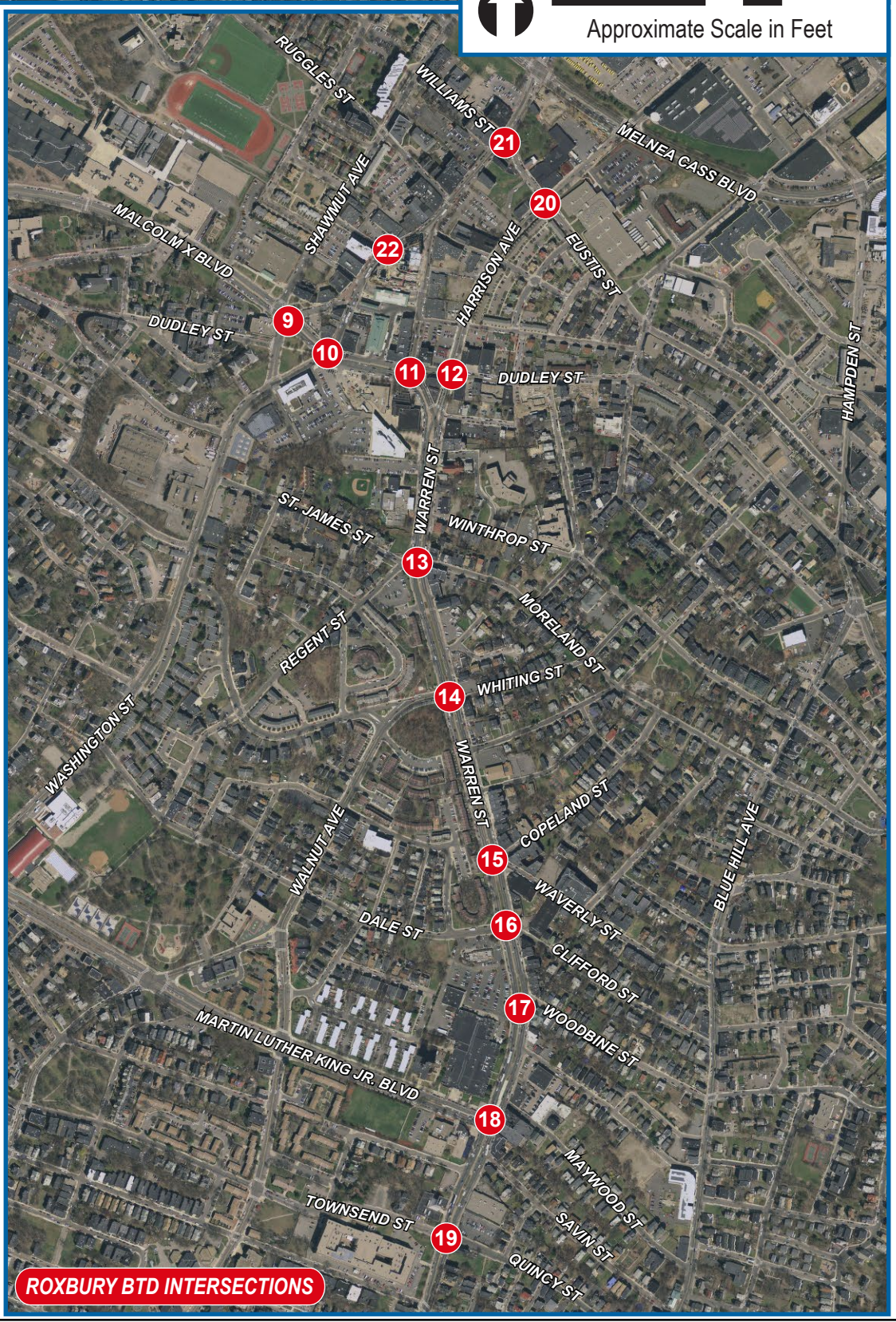
FY2016-3 (ALLSTON, ROXBURY)

P:/3946/127-3946-12001/SupportDocs/FY2016-3-Allston,Roxbury/BTD Intersections Allston,Roxbury (FY2016-3) - Overall Aerial Zoom.ai

Boston Transportation Department
Study Area Intersections

1	Cambridge St/Harvard Ave/Franklin St	(Allston-Brighton, BTD #621)
2	Cambridge St/Lincoln St	(Allston-Brighton, BTD #1325)
3	Cambridge St/N. Harvard St	(Allston-Brighton, BTD #803)
4	Cambridge St/Windom St	(Allston-Brighton, BTD #1326)
5	Cambridge St/Brighton Ave/N. Beacon St	(Allston-Brighton, BTD #186)
6	Brighton Ave/Allston St	(Allston-Brighton, BTD #1808)
7	Brighton Ave/Harvard Ave	(Allston-Brighton, BTD #185)
8	Brighton Ave/Linden St	(Allston-Brighton, BTD #1441)
9	Malcolm X Blvd/Shawmut Ave/Roxbury St	(Roxbury, BTD #2346)
10	Malcolm X Blvd/Washington St/Dudley St	(Roxbury, BTD #210)
11	Dudley St/Warren St	(Roxbury, BTD #209)
12	Dudley St/Harrison Ave	(Roxbury, BTD #208)
13	Warren St/Regent St/Moreland St	(Roxbury, BTD #386)
14	Warren St/Walnut Ave/Whiting St	(Roxbury, BTD #990)
15	Warren St/Copeland St/Waverly St	(Roxbury, BTD #712)
16	Warren St/Dale St/Clifford St	(Roxbury, BTD #1204)
17	Warren St/Shopping Mall Driveway near Woodbine St	(Roxbury, BTD #3141)
18	Warren St/Martin Luther King Jr. Blvd	(Roxbury, BTD #1611)
19	Warren St/Quincy St/Townsend St	(Roxbury, BTD #526)
20	Harrison Ave/Eustis St	(Roxbury, BTD #573)
21	Washington St/Eustis St/Williams St	(Roxbury, BTD #1007)
22	Washington St/Vernon St	(Roxbury, BTD #1970)





TETRATECH
100 Nickerson Road
Marlborough, MA 01752
508.786.2200
www.tetratech.com

Work Order FY 2016-3 (Allston & Roxbury)
Boston Transportation Department (BTD)
Boston, Massachusetts
BTD Intersection Locations
Figure **K**

DATA

Data from Synchro 7.0 Network MOE Table After Fine Tuning Changes

	AM Peak Hour		Midday Peak Hour		PM Peak Hour		Combined Difference	Totals for Final B-C report			
	Existing	Improved	Existing	Improved	Existing	Improved		Existing	Improved	Δ	Δ%
Total Delay (Hr.)	369	350	246	235	368	367	**-31**	**983**	**952**	**-31**	**-3%**
Stops/Vehicle	0.58	0.6	0.58	0.58	0.57	0.58	**0.03**				
Average Speed (mph)	8	8	10	10	9	8	**-1**				
Fuel Consumed (gal)	561	549	428	411	582	577	**-34**	**1571**	**1537**	**34**	**2%**
Fuel Economy (mpg)	7.3	7.3	8.2	8.2	7.7	7.5	**-0.2**				
CO Emissions (Kg)	39.21	38.37	29.9	28.75	40.71	40.33	**-2.37**	**109.82**	**107.45**	**2.37**	**2%**
NOx Emissions (Kg)	7.63	7.47	5.82	5.59	7.92	7.85	**-0.46**	**21.37**	**20.91**	**0.46**	**2%**
VOC Emissions (Kg)	9.09	8.89	6.93	6.66	9.44	9.35	**-0.56**	**25.46**	**24.90**	**0.56**	**2%**

Truck Percentages

Location	AM	MD	PM	Average	Location	AM	MD	PM	Average
Cambridge St/Harvard Ave/Franklin St (BTD #621)	6.2%	7.7%	3.1%	5.7%	Dudley St/Harrison Ave (BTD #208)	7.5%	5.4%	6.5%	6.5%
Cambridge St/Lincoln St (BTD #1325)	4.9%	8.3%	2.2%	5.1%	Warren St/Regent St/Moreland St (BTD #386)	7.3%	6.8%	4.9%	6.3%
Cambridge St/N. Harvard St (BTD #803)	6.5%	8.2%	3.0%	5.9%	Warren St/Walnut Ave/Whiting St (BTD #990)	7.4%	7.3%	7.5%	7.4%
Cambridge St/Windom St (BTD #1326)	5.0%	5.7%	1.3%	4.0%	Warren St/Copeland St/Waverly St (BTD #712)	7.9%	7.2%	6.8%	7.3%
Cambridge St/Brighton Ave/N. Beacon St (BTD #186)	6.8%	6.8%	3.5%	5.7%	Warren St/Dale St/Clifford St (BTD #1204)	6.9%	5.4%	6.3%	6.2%
Brighton Ave/Allston St (BTD #1808)	6.7%	7.3%	3.2%	5.7%	Warren St/Shopping Mall Driveway near Woodbine St (BTD #3141	7.4%	5.0%	5.1%	5.8%
Brighton Ave/Harvard Ave (#185)	8.0%	7.6%	3.3%	6.3%	Warren St/Martin Luther King Jr. Blvd (BTD #1611)	7.5%	5.0%	6.3%	6.3%
Brighton Ave/Linden St (BTD #1441)	5.6%	6.4%	2.5%	4.8%	Warren St/Quincy St/Townsend St (Btd #526)	7.5%	5.1%	6.8%	6.5%
Malcolm X Blvd/Shawmut Ave/Roxbury St (BTD #2346)	11.3%	7.9%	4.3%	7.8%	Harrison Ave/Eustis St (BTD #573)	5.1%	5.6%	5.2%	5.3%
Malcolm X Blvd/Washington St/Dudley St (BTD #210)	13.4%	10.1%	7.0%	10.2%	Washington St/Eustis St/Williams St (BTD #1007)	11.2%	9.7%	9.1%	10.0%
Dudley St/Warren St (BTD #209)	12.2%	9.6%	7.5%	9.8%	Washington St/Vernon St (BTD #1970)	13.8%	11.0%	5.7%	10.2%
					Average				**6.8%**

Crash Data (Jan 1, 2011 to Dec 31, 2013)

Location (BTD Intersection Numbers)	621	1325	803	1326	186	1808	185	1441	2346	210	209	208
Severity												
Property Damage	1	0	1	3	4	1	1	3	0	1	0	2
Personal Injury	0	3	3	2	1	0	2	0	1	1	2	10
Fatality	0	0	0	0	0	0	1	0	0	0	0	0
Other	0	1	1	0	1	2	2	0	1	2	2	7
Total	1	4	5	5	6	3	6	3	2	4	4	19

Crash Data (Jan 1, 2011 to Dec 31, 2013)

Location (BTD Intersection Numbers)	386	990	712	1204	3141	1611	526	573	1007	1970	Total	per Year
Severity												
Property Damage	0	0	0	0	0	0	0	1	0	0	18	**6**
Personal Injury	0	0	0	1	1	1	3	1	2	0	34	**11**
Fatality	0	0	0	0	0	0	0	0	0	0	1	**0.3**
Other	0	1	1	1	0	0	1	1	0	0	24	**8**
Total	0	1	1	2	1	1	4	3	2	0	77	**26**

Benefits Performance Measures values

Category	Performance Measures	Unit of measure	Value per unit	Value per unit in 2015 dollars
Delay	Intersection Delay	Person Hours (Cars) [1]	$17.67	$17.69
	Intersection Delay	Person Hours (Trucks)[1]	$94.04	$94.15
Crashes	Property Damage Only (PDO) Crash	Number of Crashes [2]	$6,076	$6,605
	Minor Injury Crash	Number of Crashes [2]	$43,942	$47,765
	Moderate Injury Crash	Number of Crashes [2]	$399,626	$434,393
	Severe Injury Crash	Number of Crashes [2]	$5,579,614	$6,065,040
	Fatality Crash	Number of Crashes [2]	$9,145,998	$9,941,700
Emissions	Carbon Monoxide (CO)	Metric ton [3]	$100	$138
	Nitrous Oxide (NOx)	Metric ton [3]	$5,438	$7,482
	Volatile Organic Compounds (VOC)	Metric ton [3]	$4,125	$5,676
Energy	Fuel	Gallon	-	$2.40

1. 2014 Delay value per unit taken from 2015 Urban Mobility Report
2. 2010 Crash unit value taken from May 2015 (revised) "The Economic and Societal Impact of Motor Vehicle Crashes" Report
3. 2000 Emission value per unit taken from HERS-ST Highway Economic Requirements System – State Version: Technical Report . No 2015 updates were found on FHWA website. Still referring to 2000 $ values
   - Consumer Price Index increased from 2000 to 2015 by 37.6%, from 2010 to 2015 by 8.7%, and from 2014 to 2015 by 0.12%. All values (except fuel price) were adjusted accordingly to calculate equivalent 2015 values.
   - National average Fuel price in 2015 ($2.40) according to AAA

BENEFIT CALCULATIONS

Calculation of Delay Reduction Per Year

Assuming

Truck Percentage: 6.8%

Vehicle Occupancy 1.25

Delay decreased by: 31 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 (93.2%)	29 hrs.	36	x	260 days/year =	**9,386**	$17.69	$166,049.64
Truck Delay (6.8%)	2 hrs.		x	260 days/year =	**545**	$94.15	$51,315.84
							$217,365.48

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	6	0.08	**0.48**	$6,605	$3,170
Personal Injury Accidents	11	0.08	**0.91**	$47,765	$43,307
Fatality Accidents	0.3	0.08	**0.03**	$9,941,700	$265,112

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	2.37	0.00237	x	260 days/year =	**0.6162**	$138	$85
NOx Reduction	0.46	0.00046	x	260 days/year =	**0.1196**	$7,482	$895
VOC Reduction	0.56	0.00056	x	260 days/year =	**0.1456**	$5,676	$826

Calculation of Fuel Reduction Per Year

	Gal. per day		Annual Reduction		Cost per Gal.	Benefit per Year
Fuel reduction in gallons =	34	x	260 days/year =	**8,840**	$2.40	$21,216.00

Benefits Summary

Category	Performance Measure	Unit	Value per unit in 2015 dollars	Benefits in Appropriate Units	Benefits Value
Delay	Intersection Delay	Person Hours (Cars)	$17.69	9,386	$166,049.64
		Person Hours (Trucks)	$94.15	545	$51,315.84
Crashes	Property Damage Only (PDO) Crash	Number of Crashes	$6,605	0.48	$3,170
	Minor Injury Crash	Number of Crashes	$47,765	0.91	$43,307
	Moderate Injury Crash	Number of Crashes	$434,393	0.00	$0
	Severe Injury Crash	Number of Crashes	$6,065,040	0.00	$0
	Fatality Crash	Number of Crashes	$9,941,700	0.03	$265,112
Emissions	Carbon Monoxide (CO)	Metric ton	$138	0.6162	$85
	Nitrous Oxide (NOx)	Metric ton	$7,482	0.1196	$895
	Volatile Organic Compounds (VOC)	Metric ton	$5,676	0.1456	$826
Energy	Fuel	Gallon	$2.40	8,840	$21,216.00
TOTAL					$551,976.64
TOTAL BENEFITS					**$551,980**

COST CALCULATIONS

BTD Contractor Costs For implementing Signal timing and phasing improvements	
22 intersections with clearance time changes (1 hour per intersection at $125 per hour)	$2,750
Travel time for Contractor (1/2 hour per intersection, total 11 hours at $125 per hour)	$1,375
Signal phasing changes - none	$0
Total BTD Contractor costs (Including signal phasing and timing changes and travel time) =	**$4,125**

COST CALCULATIONS (Continued)

Engineering Costs, Signs and Pavement Marking Costs	
Engineering Fee for WO #FY 2016-3	$86,525.00
BTD Engineering Costs (300 hours at $50/hour)	$15,000.00
Signs and Pavement marking Costs	N/A
BTD Contractor costs	$4,125.00
Sum of above costs	$105,650.00
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	$105,650.00
i=3.0 (assume CPI)	
N = 5	
Numerator = 0.03*(1+0.03)^5 =	$0.03
Denominator = (1+0.03)^5 -1 =	$0.16
A = P *(Numerator/Denominator)	$23,069.16
Total Annual Engineering/Signs/Markings Cost =	**$23,069**

Signal Equipment Costs	N/A
Signal equipment costs	
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	
i=3.0 (assume CPI) N= 15	
Numerator = 0.03*(1+0.03)^15 =	
Denominator = (1+0.03)^15 -1 =	
A = P *(Numerator/Denominator)	
Total Annual Signal Equipment Costs =	

Annual Cost Summary	
Type	
Engineering/Signs/Pavement markings	$23,069
Signal Equipment	$0
Other Non-Annualized Costs	$0
Total	**$23,069**

BENEFIT- COST RATIO CALCULATIONS		
Benefit	$551,980	
Cost	$23,070	
Ratio		**24 to 1**

APPENDIX L

TRAVEL TIME RUN SUMMARIES – BEFORE AND AFTER IMPROVEMENTS

FY2013-1 (Dorchester, Roslindale) - Travel Time Summary

	Average Travel Times (min:sec)											
	Morning				Midday				Afternoon			
Study Corridor	Pre-Timing Changes	Post-Timing Changes	Change	Percent Change	Pre-Timing Changes	Post-Timing Changes	Change	Percent Change	Pre-Timing Changes	Post-Timing Changes	Change	Percent Change
Columbia Rd SB from Dorchester Ave to Edward Everett Square (MA Ave)	03:07	01:36	0:01:31	-49%	02:22	02:34	0:00:12	8%	02:48	01:59	00:49	-29%
Columbia Rd SB from Edward Everett Square (MA Ave) to Seaver St	08:22	06:43	0:01:39	-20%	10:56	06:00	0:04:56	-45%	11:58	09:11	02:47	-23%
Columbia Rd NB from Seaver St to Edward Everett Square (MA Ave)	09:52	08:14	0:01:38	-17%	05:44	06:05	0:00:21	6%	09:39	08:42	00:57	-10%
Columbia Rd NB from Edward Everett Square (MA Ave) to Dorchester Ave	02:18	03:12	0:00:54	39%	02:00	01:14	0:00:46	-38%	02:00	03:41	01:41	84%
Blue Hill Ave SB from Seaver St to American Legion Hwy	02:41	02:45	0:00:04	2%	02:23	02:15	0:00:08	-6%	03:02	02:33	00:29	-16%
Blue Hill Ave NB from American Legion Hwy to Seaver St	02:34	02:22	0:00:12	-8%	02:02	02:39	0:00:37	30%	02:41	04:37	01:56	72%
American Legion Hwy SB from Franklin Park Ave to Mt Hope St	03:12	03:02	0:00:10	-5%	03:17	03:08	0:00:09	-5%	03:47	04:25	00:38	17%
American Legion Hwy NB from Mt Hope St to Franklin Park Ave	03:24	04:04	0:00:40	20%	03:54	03:01	0:00:53	-23%	03:44	03:09	00:35	-16%
Total - All Corridors	35:30	31:58	03:32	-10%	32:38	26:56	05:42	-17%	39:39	38:17	01:22	-3%

FY2013-2 (North End) - Travel Time Summary

	Average Travel Times (min:sec)											
	Morning				Midday				Afternoon			
Study Corridor	Pre-Timing Changes	Post-Timing Changes	Change	Percent Change	Pre-Timing Changes	Post-Timing Changes	Change	Percent Change	Pre-Timing Changes	Post-Timing Changes	Change	Percent Change
Causeway/Commercial Street Northbound from Merrimac Street to Richmond Street	06:35	05:50	00:45	-11%	05:39	05:45	00:06	2%	05:57	05:58	00:01	0%
Causeway/Commercial Street Southbound from Richmond Street to Street Merrimac	06:13	06:05	00:08	-2%	05:33	05:37	00:04	1%	05:27	05:46	00:19	6%
Total - All Corridors	12:48	11:55	00:53	-7%	11:12	11:22	00:10	1%	11:24	11:44	00:20	3%

FY2013-3 (South Boston) - Travel Time Summary

	Average Travel Times (min:sec)											
	Morning				Midday				Afternoon			
Study Corridor	Pre-Timing Changes	Post-Timing Changes	Change	Percent Change	Pre-Timing Changes	Post-Timing Changes	Change	Percent Change	Pre-Timing Changes	Post-Timing Changes	Change	Percent Change
Dorchester Ave NB from Old Colony Ave to Traveler St/W.Broadway	01:56	01:30	00:26	-22%	01:18	00:57	00:21	-27%	02:10	01:27	00:43	-33%
Dorchester Ave SB from Traveler St/W.Broadway to Old Colony Ave	02:19	01:07	01:12	-52%	02:36	01:21	01:15	-48%	01:28	00:51	00:37	-42%
A St EB from Dorchester Ave to West 2nd St	00:55	01:01	00:06	11%	01:05	00:52	00:13	-20%	01:29	01:10	00:19	-21%
A St WB from West 2nd St to Dorchester Ave	02:05	01:53	00:12	-10%	01:08	01:20	00:12	18%	02:13	01:14	00:59	-44%
Total - All Corridors	07:15	05:31	01:44	-24%	06:07	04:30	01:37	-26%	07:20	04:42	02:38	-36%

FY2014-2 (CAT) - Travel Time Summary

	Average Travel Times (min:sec)											
	Morning				Midday				Afternoon			
Study Corridor	Pre-Timing Changes	Post-Timing Changes	Change	Percent Change	Pre-Timing Changes	Post-Timing Changes	Change	Percent Change	Pre-Timing Changes	Post-Timing Changes	Change	Percent Change
Atlantic Ave/Cross St NB from Kneeland St to North Washington St	10:16	07:19	02:57	-29%	08:41	06:31	02:10	-25%	14:01	06:21	07:40	-55%
Surface Rd/Purchase St SB from Valenti Way to Kneeland St	08:08	07:07	01:01	-13%	08:58	06:35	02:23	-27%	21:39	12:06	09:33	-44%
Seaport Blvd EB from Sleeper St to B St	01:01	01:14	00:13	21%	01:11	01:19	00:08	11%	02:15	01:21	00:54	-40%
Seaport Blvd WB from B St to Sleeper St	01:14	00:53	00:21	-28%	01:26	00:53	00:33	-38%	01:28	00:54	00:34	-39%
Congress St EB from Atlantic Ave to D St	03:55	03:32	00:23	-10%	04:02	03:28	00:34	-14%	04:48	03:12	01:36	-33%
Congress St WB from D St to Atlantic Ave	04:39	04:22	00:17	-6%	04:58	03:53	01:05	-22%	04:02	04:48	00:46	19%
Summer St EB from Atlantic Ave to Pump House Rd	02:43	02:49	00:06	4%	03:55	01:43	02:12	-56%	02:37	03:30	00:53	34%
Summer St WB from Pump House Rd to Atlantic Ave	03:21	02:34	00:47	-23%	04:34	02:57	01:37	-35%	04:53	05:25	00:32	11%
D St NB from Summer St to Congress St	01:10	01:24	00:14	20%	01:21	01:28	00:07	9%	00:50	00:31	00:19	-38%
D St SB from Congress St to Summer St	00:41	01:22	00:41	100%	00:50	01:00	00:10	20%	00:50	00:51	00:01	2%
Total - All Corridors	37:08	32:36	04:32	-12%	39:56	29:47	10:09	-25%	57:23	38:59	18:24	-32%

FY2014-3 (Humboldt) - Travel Time Summary

	Average Travel Times (min:sec)											
	Morning				Midday				Afternoon			
Study Corridor	Pre-Timing Changes	Post-Timing Changes	Change	Percent Change	Pre-Timing Changes	Post-Timing Changes	Change	Percent Change	Pre-Timing Changes	Post-Timing Changes	Change	Percent Change
Dorchester Ave NB from Old Colony Ave to Traveler St/W.Broadway	02:31	02:22	00:09	-6%	02:13	02:17	00:04	3%	02:55	02:56	00:01	1%
Dorchester Ave SB from Traveler St/W.Broadway to Old Colony Ave	03:14	02:48	00:26	-13%	01:55	02:28	00:33	29%	02:44	02:25	00:19	-12%
A St EB from Dorchester Ave to West 2nd St	00:49	00:29	00:20	-41%	00:44	00:44	00:00	0%	00:31	00:20	00:11	-35%
A St WB from West 2nd St to Dorchester Ave	00:39	00:36	00:03	-8%	01:00	00:35	00:25	-42%	01:07	00:23	00:44	-66%
Total - All Corridors	07:13	06:15	00:58	-13%	05:52	06:04	00:12	3%	07:17	06:04	01:13	-17%

FY2014-4 (Various Locations) - No Travel Time Runs Conducted

FY2014-5 (Financial District) - Travel Time Summary

	Average Travel Times (min:sec)											
	Morning				Midday				Afternoon			
Study Corridor	Pre-Timing Changes	Post-Timing Changes	Change	Percent Change	Pre-Timing Changes	Post-Timing Changes	Change	Percent Change	Pre-Timing Changes	Post-Timing Changes	Change	Percent Change
Congress Street SB from New Chardon Street to Purchase Street	04:25	03:01	01:24	-32%	04:13	03:57	00:16	-6%	05:25	04:32	00:53	-16%
Pearl Street/Congress Street NB from Purchase Street to New Chardon Street	05:19	04:14	01:05	-20%	06:54	05:20	01:34	-23%	06:56	06:14	00:42	-10%
North Street WB from Surface Road to Congress Street	01:26	01:22	00:04	-5%	02:13	01:37	00:36	-27%	01:36	00:49	00:47	-49%
North Street EB from Congress Street to Surface Road	01:00	00:54	00:06	-10%	01:37	01:11	00:26	-27%	00:57	01:05	00:08	14%
Devonshire Street/Otis Street/Kingston Street from State Street to Essex Street	04:11	03:36	00:35	-14%	04:15	03:20	00:55	-22%	04:04	04:47	00:43	18%
Total - All Corridors	16:21	13:07	03:14	-20%	19:12	15:25	03:47	-20%	18:58	17:27	01:31	-8%

FY2015-1 (Back Bay) - Travel Time Summary

Study Corridor	Average Travel Times (min:sec)											
	Morning				Midday				Afternoon			
	Pre-Timing Changes	Post-Timing Changes	Change	Percent Change	Pre-Timing Changes	Post-Timing Changes	Change	Percent Change	Pre-Timing Changes	Post-Timing Changes	Change	Percent Change
Arlington SB - From Beacon St to Stuart St / Columbus Ave	02:01	02:11	00:10	8%	01:57	02:49	00:52	44%	02:29	02:30	00:01	1%
Beacon St WB - From Arlington St to Hereford St	02:29	02:21	00:08	-5%	02:56	02:26	00:30	-17%	03:21	03:26	00:05	2%
Commonwealth EB - From Hereford St to Arlington St	03:34	03:01	00:33	-15%	04:21	04:05	00:16	-6%	04:32	05:35	01:03	23%
Commonwealth WB - From Arlington St to Hereford St	03:15	03:18	00:03	2%	03:35	03:02	00:33	-15%	03:05	02:30	00:35	-19%
Boylston EB - From Hereford St to Hadassah Way	03:25	04:14	00:49	24%	04:28	05:17	00:49	18%	05:51	05:29	00:22	-6%
Huntington Ave/Stuart St EB - From Cumberland St to Church St	07:32	05:06	02:26	-32%	05:37	04:43	00:54	-16%	06:48	06:10	00:38	-9%
St. James Ave/Huntington Ave WB - From Dartmouth St to Cumberland St	05:08	04:29	00:39	-13%	04:48	04:37	00:11	-4%	05:26	05:05	00:21	-6%
Columbus Ave EB from Dartmouth St to Arlington St	02:45	02:09	00:36	-22%	02:41	02:14	00:27	-17%	02:54	02:43	00:11	-6%
Columbus Ave WB from Arlington St to Dartmouth St	02:24	02:47	00:23	16%	01:38	01:46	00:08	8%	02:22	02:14	00:08	-6%
Berkeley St NB from Columbus Ave to Beacon St	02:44	02:12	00:32	-20%	02:19	02:26	00:07	5%	03:25	03:42	00:17	8%
Clarendon St SB from Beacon St to Columbus Ave	03:12	03:12	00:00	0%	04:11	03:58	00:13	-5%	03:58	04:18	00:20	8%
Dartmouth St NB from Columbus Ave to Beacon St	03:08	03:43	00:35	19%	03:42	03:05	00:37	-17%	04:06	04:14	00:08	3%
Exeter St SB from Commonwealth Ave (North) to Huntington Ave	01:26	01:18	00:08	-9%	01:30	01:22	00:08	-9%	02:13	01:33	00:40	-30%
Total - All Corridors	43:03	40:01	03:02	-7%	43:43	41:50	01:53	-4%	50:30	49:29	01:01	-2%

FY2016-1 (Dorchester Ave) - Travel Time Summary

Study Corridor	Average Travel Times (min:sec)											
	Morning				Midday				Afternoon			
	Pre-Timing Changes	Post-Timing Changes	Change	Percent Change	Pre-Timing Changes	Post-Timing Changes	Change	Percent Change	Pre-Timing Changes	Post-Timing Changes	Change	Percent Change
Dorchester Avenue NB - From Ashmont Street to Melville Ave/Parkman Street	06:27	03:05	03:22	-52%	02:40	02:21	00:19	-12%	04:37	03:15	01:22	-30%
Dorchester Avenue NB - From Melville Avenue/Parkman Street to East Street/Freeport Street	03:53	04:33	00:40	17%	05:34	05:17	00:17	-5%	04:26	06:09	01:43	39%
Dorchester Avenue NB - From East Street/Freeport Street to East Cottage Street/Crescent Avenue	05:58	05:50	00:08	-2%	03:49	03:24	00:25	-11%	04:18	04:10	00:08	-3%
Dorchester Avenue SB - From East Cottage Street/Crescent Avenue to East Street/Freeport Street	04:42	04:35	00:07	-2%	04:10	04:02	00:08	-3%	07:15	08:52	01:37	22%
Dorchester Avenue SB - From East Street/Freeport Street to Melville Avenue/Parkman Street	04:01	03:30	00:31	-13%	05:14	05:43	00:29	9%	05:06	05:39	00:33	11%
Dorchester Avenue SB - From Melville Ave/Parkman Street to Ashmont Street	02:42	02:40	00:02	-1%	02:59	03:14	00:15	8%	04:28	04:14	00:14	-5%
Entire Corridor												
Dorchester Avenue NB - Ashmont Street to Crescent Avenue/East Cottage Street	16:17	13:29	02:48	-17%	12:03	11:01	01:02	-9%	13:21	13:33	00:12	1%
Dorchester Avenue SB - Crescent Avenue/East Cottage Street to Ashmont Street	11:24	10:45	00:39	-6%	12:24	12:59	00:35	5%	16:48	18:45	01:57	12%
Total - All Corridors	55:24	48:27	06:57	-13%	48:53	48:01	00:52	-2%	1:00:19	1:04:37	04:18	7%

FY2016-2 (Roslindale, Roxbury,Dorchester) - Travel Time Summary

Study Corridor	Average Travel Times (min:sec)											
	Morning				Midday				Afternoon			
	Pre-Timing Changes	Post-Timing Changes	Change	Percent Change	Pre-Timing Changes	Post-Timing Changes	Change	Percent Change	Pre-Timing Changes	Post-Timing Changes	Change	Percent Change
Roxbury Area												
Washington Street NB - From Rossmore Road/McBride Street to Cedar Street	09:54	10:05	00:11	2%	07:04	08:26	01:22	19%	08:59	11:43	02:44	30%
Washington Street SB - From Cedar Street to Rossmore Road/McBride Street	08:11	07:28	00:43	-9%	07:37	09:25	01:48	24%	12:31	19:05	06:34	52%
Roslindale Area												
Washington Street NB – From Beech Street to Archdale Street	07:26	07:46	00:20	4%	05:24	05:59	00:35	11%	08:05	08:08	00:03	1%
Washington Street SB – From Archdale Street to Beech Street	05:12	05:13	00:01	0%	05:11	05:44	00:33	11%	08:03	10:07	02:04	26%
Total - All Corridors	30:43	30:32	00:11	-1%	25:16	29:34	04:18	17%	37:38	49:03	11:25	30%

FY2016-3 (Allston,Brighton,Roxbury) - Travel Time Summary

Study Corridor	Average Travel Times (min:sec)											
	Morning				Midday				Afternoon			
	Pre-Timing Changes	Post-Timing Changes	Change	Percent Change	Pre-Timing Changes	Post-Timing Changes	Change	Percent Change	Pre-Timing Changes	Post-Timing Changes	Change	Percent Change
Roxbury Area												
Cambridge Street EB - From Brighton Avenue/N. Beacon Street to Windom Street	06:50	04:49	02:01	-30%	05:11	05:00	00:11	-4%	06:40	06:20	00:20	-5%
Cambridge Street WB - From Windom Street to Brighton Avenue/N. Beacon Street	04:10	03:50	00:20	-8%	03:41	04:20	00:39	18%	03:55	04:37	00:42	18%
N. Beacon Street/Brighton Avenue EB – From Cambridge Street to Linden Street	02:59	01:41	01:18	-44%	02:33	01:55	00:38	-25%	04:02	02:39	01:23	-34%
N. Beacon Street/Brighton Avenue WB – From Linden Street to Cambridge Street	02:20	02:16	00:04	-3%	02:32	02:22	00:10	-7%	02:12	02:49	00:37	28%
Roslindale Area												
Warren Street NB – From Quincy Street/Townsend Street to Dudley Street	05:09	04:27	00:42	-14%	04:23	03:35	00:48	-18%	05:04	04:24	00:40	-13%
Warren Street SB – From Dudley Street to Quincy Street/Townsend Street	03:43	03:19	00:24	-11%	03:54	03:33	00:21	-9%	05:13	04:42	00:31	-10%
Total - All Corridors	25:11	20:22	04:49	-19%	22:14	20:45	01:29	-7%	27:06	25:31	01:35	-6%

Study Corridor	Average Travel Times (min:sec)											
	Morning				Midday				Afternoon			
	Pre-Timing Changes	Post-Timing Changes	Change	Percent Change	Pre-Timing Changes	Post-Timing Changes	Change	Percent Change	Pre-Timing Changes	Post-Timing Changes	Change	Percent Change
TOTAL TRAVEL TIMES - ALL WORK ORDERS	4:30:36	4:00:44	0:29:52	-11%	4:15:03	3:54:14	0:30:09	-12%	5:17:34	5:05:53	0:43:47	-14%