The Benefits of Retiming/ Rephasing Traffic Signals in the Back Bay

BENEFIT COST EVALUATION
OF SIGNAL IMPROVEMENTS

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CREATIVE SOLUTIONS
EFFECTIVE PARTNERING

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Executive Summary

In an effort to improve traffic operations and safety on Boston's roadways and garner the associated benefits of those improvements, the Boston Transportation Department (BTD) selected Howard/Stein-Hudson Associates (HSH) to provide technical assistance in improving traffic signal operation throughout the City. Starting in 2007, the effort was managed through a series of 8 work orders, focusing on approximately 280 signals in over 20 travel corridors, representing about one-third of the traffic signals in Boston. Each consecutive work order concentrated on a different area of Boston. After the analysis in each area was complete, an associated report was prepared and submitted to BTD with recommendations for signal improvements. Each work order report focused on 2 phases of recommendations:

- **Phase 1** included signal timing recommendations only and did not include any physical changes to the signal or intersection, other than improvements to interconnection or detector loop maintenance. Phase I recommendations can be implemented directly from the City's Traffic Management Center (TMC).[1]

- **Phase 2** included both the signal timing recommendations in Phase 1 and physical improvement recommendations such as revised signal phasing, signal face changes, curbside use changes, geometric improvements, and/or pavement marking improvements.

Each work order report, published separately, presented detailed analysis of intersection and corridor operation under existing conditions and with proposed improvements. Proper design, operation, and maintenance of traffic signals can yield economic and social benefits by reducing delay, vehicle emissions, and fuel consumption while improving safety conditions.

Signal retiming is a cost effective tool to generate quantifiable traveler benefits as measured by decreased vehicle delay, increased safety, lower emissions and reduced fuel consumption. Qualitative benefits, such as decreased cut-through traffic on alternate routes, reduced traveler frustration, and reduced pedestrian delay can also be realized. A focused signal retiming program can provide municipalities with additional opportunities to examine intersection operations and corridor progression and identify related maintenance issues.

To document the magnitude of the benefits produced by the proposed signal improvements in the City of Boston, BTD collaborated with HSH to assess the analysis results for each work order, developed a methodology for quantifying the benefits and costs, and calculated the associated benefit-cost ratio.

While the study team has estimated the benefit-cost ratio for each of the eight work order areas, this report focuses on the Back Bay neighborhood of Boston as assessed under Work Order #1. (Note that Appendix A includes a summary of daily benefits and benefit-cost data with improvements for all work order areas.) Performance measures associated with delay, safety, emissions, and energy were evaluated for 60 study intersections in the Back Bay under existing and improved conditions. The change in value of these measures, combined with the associated BTD implementation costs and contractual costs, yielded

[1] The Boston Transportation Department manages traffic signals from the Traffic Management Center (TMC) located at City Hall. BTD engineers monitor and control traffic flow throughout the City, using a combination of traffic software, video monitoring, real time information and technical experience. At the Center, engineers can adjust signal timings in response to time of day travel patterns, weather conditions, or as part of incident management.

benefit-cost ratios for Phase 1 and Phase 2 implementation, as summarized in **Table 1.**

Table 1. Benefit-cost Ratios of Signal Improvements in the Back Bay

Condition	Number of Intersections	Benefit-cost Ratio [1)]
Phase 1 Signal Retiming Only	60	83:1
Phase 2 Signal Retiming and Physical Improvements	60	61:1

[1)] The ratios reflect estimated benefits for only the 3 weekday peak hours and do not account for benefits that would occur during off-peak hours, weekends or holidays. While non-peak hour benefits have not been included, it should be noted that the resulting ratios would be higher than shown here. Likewise, substantial city employee staff time is not included as part of the cost. Additional benefits that could not be calculated for Phase 2 improvements are improved reliability of the signal system and reduced pedestrian delay.

The benefits of implementing the Phase 1 signal timing improvements in the Back Bay are estimated to be $1,205,400 annually. The cost of HSH's contract for Work Order #1 is $66,400. For each B/C calculation, the engineering costs were annualized over a five-year period (the period of time before signals should be re-evaluated), resulting in an annual cost of $14,502 and yielding a benefit-cost ratio of 83:1. On a daily basis, the Phase 1 improvements would yield benefits valued at $4,637.

The annual benefits associated with Phase 2 improvements (which also include Phase 1 retiming improvements), are estimated to be $1,718,000. The Phase 2 implementation costs are higher because BTD spent $162,000 to upgrade signal equipment. Equipment improvements are annualized over a fifteen year period, resulting in an annual cost of $13,600. This combined with the engineering cost results in an annual cost of $28,102. The resulting benefit-cost ratio is 61:1. Daily benefits associated with the Phase 2 improvements are estimated to be $6,608.

In summary, the monetary investment in signal improvements can be recaptured many times over in terms of economic and social benefits.

The following sections present the background and description of the work order analysis, the methodology and quantitative components of the benefit-cost ratios for the Back Bay study intersections, and a comparison of implementation costs to those in other cities.

Background

Research has shown that proper design, operation, and maintenance of traffic signals can yield economic and social benefits by reducing delay, improving safety, and reducing vehicle emissions and fuel consumption. In an effort to maximize these benefits on Boston's roadways, the Boston Transportation Department (BTD) selected Howard/Stein-Hudson Associates (HSH) to provide technical assistance in retiming traffic signals throughout the City. The signal retiming effort commenced in August 2007 and, to date has included 8 study areas as listed below:

- Work Order #1 - Back Bay;
- Work Order #2 - Allston, Dorchester, East Boston, Roslindale;
- Work Order #3 - Jamaica Plain/Roxbury;
- Work Order #4 - Hyde Park Avenue;
- Work Order #5 - Brighton/Roxbury;
- Work Order #6 - South End;
- Work Order #7 - Financial District; and
- Central Artery Work Order #1 - Central Artery.

The final report produced for each work order includes 2 levels of recommendations to improve safety and/or signal operations and progression. Phase 1 recommendations include signal timing improvements that can be implemented from the City's Traffic Management Center (TMC),[2] without any physical changes to the signal or intersection, other than interconnection and loop detector maintenance. Phase 2 recommendations include improvements requiring physical changes such as revised phasing, signal face changes, curbside use changes, geometric improvements, or pavement marking improvements.

This report focuses on the benefit-cost analysis for Work Order #1 in the Back Bay, including 60 intersections along the following nine corridors:

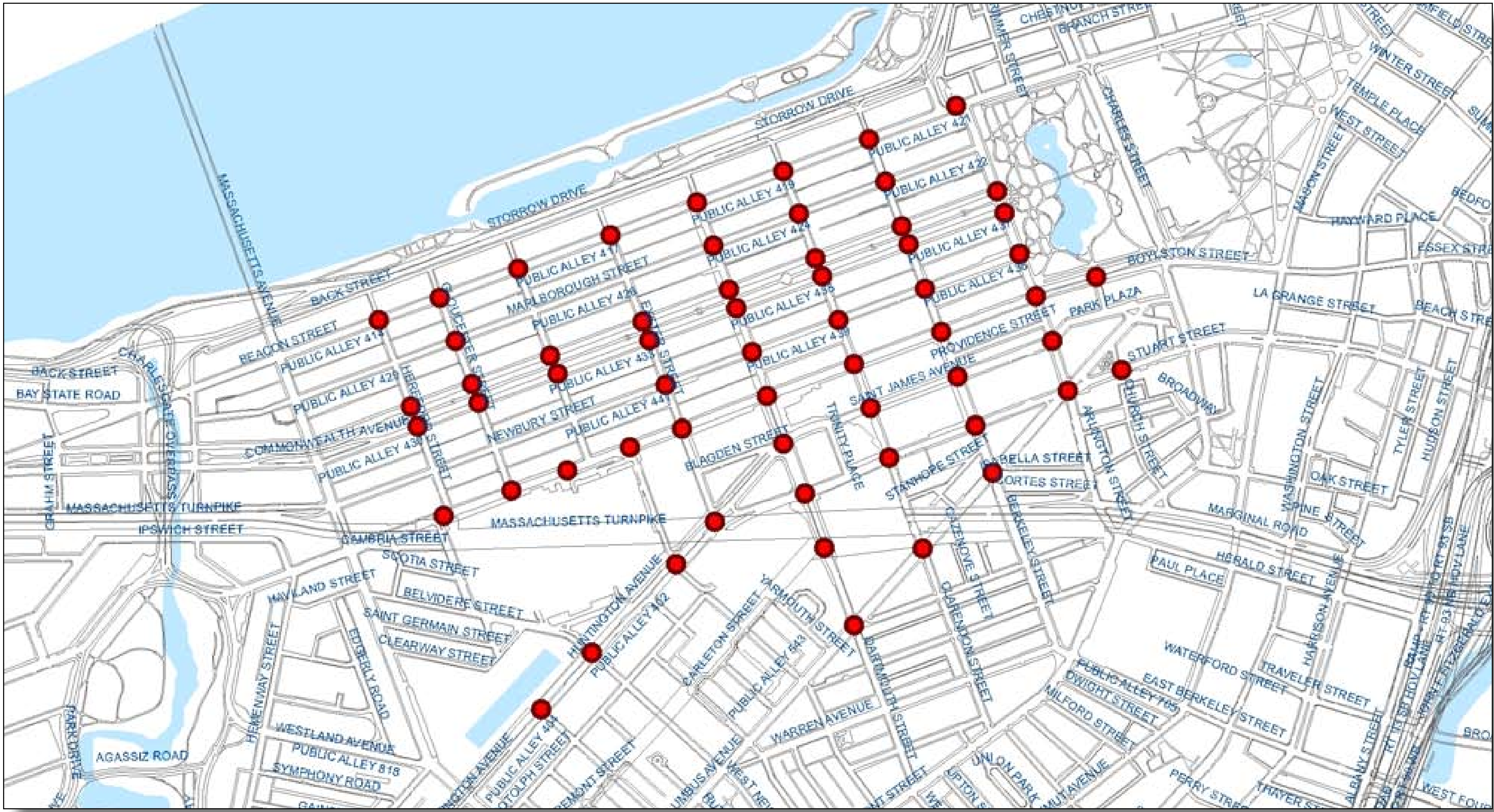
- Boylston Street;
- Commonwealth Avenue;
- Huntington Avenue;
- Stuart Street;
- Beacon Street;
- Berkeley Street;
- Dartmouth Street;
- Arlington Street; and
- Clarendon Street.

The study intersections in the Back Bay area are shown in **Figure 1.**

The technical processes used to analyze intersection and corridor operation in each work order study area are presented below. The processes for each study area are generally the same.

[2] Ibid.

Figure 1. Study Intersections in Work Order #1 – Back Bay



Not to scale.

Task Descriptions

Each work order has a similar overall approach and task description. The study team collected field data, provided an analysis of existing conditions, developed recommendations for improvements/settings for existing controllers, and provided implementation assistance and post-evaluation for various study locations. Major tasks included review of existing conditions, analysis of existing conditions, and implementation and evaluation of recommendations. The detailed scope of work, generally applicable to each work order, is presented below.

Task 1. Review of Existing Conditions

For this task, the study team collected weekday, 11-hour manual vehicle (with heavy vehicle percentages) and bicycle turning movement and pedestrian counts at signalized intersections within the study areas. BTD furnished existing timing sheets, existing coordination plans, and existing traffic signal drawings and timing preferences for the area. The study team collected field data to be used in the evaluation model and to fully understand the function of each location. Data included lane geometry, speed limits, parking regulations, storage lengths, signal phasing, signal face/equipment conditions and operations, and existing queue lengths.

The study team observed peak-period traffic patterns for each coordination pattern and factors that impact progression and operation, such as over-saturated conditions, lane distributions, presence of trucks, buses and pedestrians, impacts of parking maneuvers, regulation enforcement issues, and transit impacts. Activities such as jaywalking, double-parking, and illegal traffic movements were documented in field notes.

Travel time studies were conducted along the arterial roadways during the a.m., mid-day, and p.m. peak hours to set existing conditions benchmarks for future comparisons. The floating car method with BTD's travel time/delay worksheet was used for up to 4 runs for each direction during each study period.

Crash analysis was conducted using the latest data available in the MassDOT Crash Data System (CDS), which is based on ArcGIS. Information relating to many factors was reviewed, including severity, number of vehicles, fatal and non-fatal injuries, types of collision, road surface condition, ambient light, and weather condition. This information was used to identify locations that could be made safer through signal timing and phasing adjustments or other improvements.

Task 2. Analysis of Existing Conditions

The study team created a base vehicular network using the Synchro and SimTraffic software analysis package. The networks were calibrated as necessary and served as benchmarks for future analysis. Traffic operations analysis was summarized and furnished to BTD with operational metrics such as delay, average queues, v/c ratios, level-of-service, travel times, and number of stops. The results from the model were reviewed with actual field conditions and the model was calibrated, as necessary, to reflect actual conditions.

The study team prepared reports for each Work Order that detailed the modeling analysis, physical observations, crash analysis, and calibration methodology. HSH provided BTD with all traffic volume and travel time data in a format similar to that used in prior studies.

Task 3. Development of Recommendations

Under this task, the study team worked with BTD to designate timing, cycle lengths, split, and offset programs for existing controllers at the study intersection. Using the existing conditions network as a base, the study team developed Phase 1 recommendations and evaluated several alternatives to the traffic signal timing and offsets for a.m., mid-day, and p.m. peak hours. Phase 2 recommendations included other suggested refinements such as phasing, signal head changes, and changes to curbside uses and/or potential geometric improvements, lane use, and/or pavement marking improvements that could improve safety and/or signal operations and progression.

Upon completion of the Recommended Changes model, HSH prepared a technical memorandum that presented all proposed changes and the methodology used in the analysis and time-space diagrams for all major corridors, All Synchro analysis, and intersection data worksheets that show the timing, phasing, and offsets by pattern. All measures of effectiveness were compared to that completed in the existing conditions analysis. HSH identified signal equipment changes required to accommodate changes in phasing at each intersection. HSH prepared signal timing and sequence charts in BTD standard format and submitted them to BTD for review and approval.

Task 4. Implementation and Evaluation

HSH provided technical expertise in the analysis of any revisions to the original recommendations. Where appropriate, travel time studies were completed and compared to existing conditions. Upon final implementation of each work order, HSH provided BTD with an updated Synchro model, updated timing and sequence charts, and a technical memorandum that discusses the changes in several measures of effectiveness over existing conditions. It should be noted that travel-time results were within an acceptable range as compared to model projections.

Methodology for Benefit-cost Estimation

In general terms, a benefit-cost ratio is an indicator of the overall value of a proposed project. The ratio is expressed as the benefits, in monetary units, relative to the costs, in monetary units. A ratio greater than 1 indicates the project is worth considering, while a ratio of less than 1 indicates the project is monetarily unjustifiable.

Benefit-cost ratios for the Back Bay intersections were based on performance measures related to delay, safety, emissions, and energy as presented in the Work Order #1 report. The peak-hour measures of effectiveness for delay, emissions, and energy were obtained from the Synchro output produced during the Phase 1 and Phase 2 evaluation. The safety benefits were forecast by assessing the historical crash rate summaries and applying a crash reduction factor.

Table 2 lists the performance measures, units of measure, and values used to estimate the benefit-cost ratios. The measures and their associated values and reference sources are described below.

Timeframe

The Synchro models reflect travel conditions during 3 weekday peak hours, including the a.m., mid-day, and p.m. peak hours. While the signal improvements will also generate benefits during non-peak hours and weekend days, the study team conservatively designated the daily value as the sum of values from only the 3 weekday peak hours. Annual values are based on 260 travel days (workdays) per year and do not include weekend days.

Table 2. Performance Measures, Values, and Sources

Category	Performance Measure	Unit of Measure	Value per Unit Measure (2009 dollars)	Reference Source for Value
Delay	Intersection Delay	Person Hours (car) Person Hours (truck)	$16.09 $106.24	(1)
Safety	Property Damage Only (PDO) Crash Minor Injury Crash Moderate Injury Crash Severe Injury Crash Fatality Crash	Number of crashes Number of crashes Number of crashes Number of crashes Number of crashes	$3,165 $18,771 $392,755 $3,003,746 $4,207,985	(2,3)
Emissions	Carbon Monoxide (CO) Nitrous Oxide (NOx) Volatile Organic Compounds (VOC)	Metric ton Metric ton Metric ton	$138 $7,490 $5,682	(4)
Energy	Fuel	Gallon	$2.64	(5)

Sources:

(1) *2009 Mobility Report,* Texas Transportation Institute, July 2009. Appendix A,
Exhibit A1 - "National Congestion Constants for 2009 Urban Mobility Report."

Automobiles: Convert vehicle delay (from Synchro) into person delay by assuming 1.25 persons per vehicle. Cost per person hour is $15.47. Convert value from Year 2007 to Year 2009 by Consumer Price Index of 1.04. The result is $15.47 x 1.04 = $16.09.

Trucks: Cost per truck vehicle hour, $102.15, is from Exhibit A-1. Convert value from Year 2007 to Year 2009 by Consumer Price Index of 1.04. The result is $102.15 x 1.04 = $106.24

(2) *The Economic Impact of Motor Vehicle Crashes 2000,* U.S. Department of Transportation/National Highway Traffic Safety Administration (NHTSA); 2002.
Table A1 - "Summary of Unit Costs, 2000" for Injury and Non-Injury Related Costs.
Costs converted from Year 2000 to Year 2009 by Consumer Price Index of 1.25.

(3) *Desktop Reference for Crash Reduction Factors,* Report No. FHWA-SA-08-0111 by U.S. Department of Transportation/Federal Highway Administration, September 2008.
Crash reduction Factor of 0.08 is taken from "Desktop Reference for Crash Rate Reduction".
Note that 0.08 is the conservative estimate given the range of 0.08 to 0.18 shown in Table A1 for Crash Type =All and Crash Severity = All

(4) HERS-ST 2.0 (Highway Economic Requirements System – State Version) Technical Reports, U.S. Department of Transportation/Federal Highway Administration, 2002.
Table E5 - "Air Pollution Damage Costs and Adjustment Factors Used in HERS."
Costs converted from Year 2000 to Year 2009 by Consumer Price Index of 1.25.

(5) Energy Information Administration Web site,
http://www.eia.doe.gov/oil_gas/petroleum/data_publications/wrgp/mogas_home_page.html.
Data for Massachusetts. Viewed December 2009.

Delay

Intersection delay is a measure of time spent by motorists at traffic signals. The Work Order #1 analysis included intersection delay summaries from Synchro for existing conditions and Phase 1 and Phase 2 recommendations for the a.m., mid-day, and p.m. peak hours. When compared to existing conditions, Phase 1 intersection delays are reduced by 11% during the a.m. peak hour, 14% during the mid-day peak hour and 21% during the p.m. peak hour. Phase 2 improvements will reduce intersection delay by 21% during the a.m. peak hour, 18% during the mid-day peak hour and 28% during the p.m. peak hour relative to existing conditions. Synchro intersection delay, typically expressed in terms of vehicle seconds, was converted into vehicle hours for the benefit-cost analysis.

Because value of time data are available for both automobile passengers and trucks transporting commodities, a separate value was applied to each group of vehicles. Intersection volumes were disaggregated into 98.4% automobiles and 1.6% trucks, based on traffic counts. The automobile hours of delay were converted to person hours by using an average vehicle occupancy (AVO) of 1.25 persons per vehicle.

The change in annual delay costs was based on 260 travel days (workdays) per year.

Calculation:

Daily Hours of Reduction in Vehicle Delay x Vehicle Occupancy = Daily Person Hour Delay

184 Passenger Vehicle Hours x 1.25 = *230 Daily Person Hours Delay (Phase 1)*
3 Truck Vehicle Hours x 1.0 = *3 Daily Hours Daily Person Hours Delay (Phase 1)*

269 Passenger Vehicle Hours x 1.25 = 336 *Daily Person Hours Delay (Phase 2)*
4 Truck Vehicle Hours x 1.0 = *4 Daily Person Hours Delay (Phase 2)*

Daily Person Hours Delay x 260 Days (work week) x Cost per Hour = Annual Delay Savings

230 x 260 x $16.09 = $962,182 (Phase 1)
3 x 260 x $106.24 = $82,867 (Phase 1)

= $1,045,049 Annual Benefit (Phase 1)

336 x 260 x $16.09 = $1,405,622 (Phase 2)
4 x 260 x $106.24 = $110,490 (Phase 2)

= $1,516,112 Annual Benefit (Phase 2)

Safety

Improved traffic signal operation can help reduce intersection crashes. For each work order, the study team compiled motor vehicle crash data for all study area intersections from the MassDOT Crash Records System for the most recent available 3-year period (2004–06). A total of 297 crashes occurred at the 60 Back Bay intersections. Five locations had 10 or more crashes during the period, accounting for 70 of the crashes. Only 2 intersections (Stuart Street/Columbus Avenue/Arlington Street and Newbury Street/ Dartmouth Street) had average crash rates above MassDOT's district wide average of 0.88 crashes per million entering vehicles. To be conservative, we removed the high crash locations from the analysis, as perhaps there are other factors contributing to the above-average numbers of crashes. The remaining 227 crashes were distributed over the remaining 55 intersections.

While it is difficult to quantify the potential safety improvements resulting from intersection improvements, a good resource is the *Desktop Reference for Crash Reduction Factors* compiled by the Federal Highway Administration. A full source citation is shown in **Table 2.** This report states that general signal timing improvements can yield an 8% to 18% reduction in all types of intersection crashes. Using a conservative estimate of 8%, the associated reduction in crashes per year at key study intersection was calculated.

For each work order, detailed crash information was tabulated. Because not all crash reports identified the type of crash that had occurred (property damage only, minor injury, moderate injury, etc.), the crash reduction factor of 8% was applied only to the number of crashes ***that were properly categorized*** (86%).

The comprehensive costs associated with each type of crash type were obtained from *The Economic Impact of Motor Vehicle Crashes 2000,* prepared by the National Highway Traffic Safety Administration. A full source citation is shown in **Table 2.** Comprehensive costs include both 1) the economic impact of purchasing goods and service as a result of the crash (automobile repair, health care, etc.) and lost productivity; and 2) the impact of "intangible consequences," such as pain and suffering. For estimating purposes, a crash that involved a personal injury was categorized as a minor injury crash, because the crash report does not indicate the extent of personal injury. When escalated to Year 2009 dollars using the Consumer Price Index (CPI), the average crash cost ranges from $3,165 for minor property damage only (PDO) to over $4 million for a fatal crash. Note that we have also assumed that the reduction in crashes as a result of retiming is the same as for Phase 2 implementation.

Calculation:

Average Property Damage Only crashes = 53.7 annually
Average Minor Injury crashes = 21.3 annually

Crashes x Reduction Factor = Number of potentially eliminated crashes annually

53.7 x 0.08 = 4.3 PDO Crashes x $3,165 = $13,588
21.3 x 0.08 = 1.7 MI Crashes x $18,771 = $32,036

= ***$45,624 annually and about 6 fewer crashes***

Emissions

The Synchro output reports from each work order contained a summary of carbon monoxide, nitrous oxide, and volatile organic compounds emissions for the a.m., mid-day, and p.m. peak hour. When compared to existing conditions, Phase 1 emissions at the study intersections will be reduced by 4% during the a.m. peak hour, 6% during the mid-day peak hour and 10% during the p.m. peak hour. Phase 2 improvements will reduce emissions by 8% during the a.m. peak hour, 7% during the mid-day peak hour and 12% during the p.m. peak hour relative to existing conditions. The difference in daily emissions under existing, Phase 1, and Phase 2 conditions was calculated and the units converted from kilogram (kg) to metric tons.

Human health and property damage costs per metric ton of each emission were based on data from the Highway Economic Requirements System (HERS) computer model. A full source citation is shown in

Table 2. After escalating to Year 2009 dollars, the cost of emissions varies from about $140 per metric ton of carbon monoxide to about $7,500 per metric ton of nitrous oxide.

Calculation:

Annual Emission Reduction x Air Pollution Damage Costs = Annual Benefit

Phase 1:	CO	=	2.8080 metric tons x $138 = $388
	NOx	=	0.5460 metric tons x $7,490 = $4,090
	VOC	=	0.6500 metric tons x $5,682 = $3,693

= ***$8,171 Annual Benefit***

Phase 2:	CO	=	3.8220 metric tons x $138 = $527
	NOx	=	0.7540 metric tons x $7,490 = $5,647
	VOC	=	0.8840 metric tons x $5,682 = $5,023

= ***$11,197 Annual Benefit***

Energy

Each work order report contained fuel consumption differences between existing, Phase 1, and Phase 2 conditions based on Synchro analysis output. When compared to existing conditions, fuel consumption at the study intersections under Phase 1 will be reduced by 4% during the a.m. peak hour, 6% during the mid-day peak hour and 10% during the p.m. peak hour. Phase 2 improvements will reduce fuel consumption by 8% during the a.m. peak hour, 7% during the mid-day peak hour and 12% during the p.m. peak hour relative to existing conditions. The difference in daily fuel consumption was calculated as the sum of values from the 3 peak hours. Based on recent Massachusetts data for the cost of gasoline ($2.64 per gallon), the associated cost of fuel savings was calculated.

Calculation:

Gallons of Fuel x Cost x 260 Days (work week) = Annual Fuel Savings

Phase 1:

155 Gallons x 260 x $2.64

= $106,392 Annual Benefit

Phase 2:

211 Gallons x 260 x $2.64

= $144,820 Annual Benefit

Costs

The cost of implementing the Phase 1 signal timing improvements in the Back Bay, $66,400, is the value of HSH's contract for Work Order #1. Phase 2 implementation costs, $228,400, include both Phase 1 engineering costs and $162,000 for traffic signal equipment implementation costs in 2009 dollars. It was determined that the retiming of signals should occur every five years, thus the retiming effort costs were annualized over a five year period. Using an assumed CPI rate of 3%, we determined the annual costs given the present value, or Capital Recovery Factor over a five year period. The annual costs for engineering services resulted were $14,502. Similarly, the costs related to traffic signal equipment/capital improvements were also annualized over a fifteen year period, the average life of such improvements. The annualized cost for these capital improvements were $13,600. What should be noted is that the costs associated with City of Boston staff time were not included as part of these annual costs.

Benefit-cost Ratios

Based on the methodology presented above, the resulting benefit-cost ratios for improving signal operations at the Back Bay intersections are presented in **Table 3** and **Table 4** for Phase 1 and Phase 2 implementation, respectively.

Data in **Table 3** show that Phase 1 timing improvements in the Back Bay will yield an annual benefit-cost ratio of 83:1.   On a daily basis, the improvements would yield benefits valued at $4,636.

The Phase 2 benefits, shown in **Table 4,** will increase over Phase 1 conditions, indicating the need for both retiming and rephasing improvements. However, the cost of implementing Phase 2 improvements will also increase, causing a lower, but still favorable annual benefit-cost ratio of 61:1. The daily benefits with Phase 2 improvements would be $6,607.

Additional, immeasurable benefits of the Phase 2 improvements include improved reliability of signal operations and the reduction of pedestrian delay time. The pedestrian delay reductions are due to the timing and phasing modifications made within the study area.

Table 3. Benefit-cost Ratios for Phase 1 – Signal Retiming Only

Performance Measure - Unit Measure	Value per unit measure (2009 dollars)	Daily Change (unit measure)	Daily Benefit (dollars)	Annual Change (unit measure)	Annual Benefit (dollars)
Delay					
Automobiles: Change in Intersection Delay - person hours	$16.09	-230	$3,701	-59,800	$962,182
Trucks: Change in Intersection Delay - vehicle hours	$106.24	-3	$319	-780	$82,867
Subtotal			**$4,020**		**$1,045,049**
Safety					
Change in Number of Crashes with Property Damage Only (PDO)	$3,165	-0.0165	$52	-4.2933	$13,588
Change in Number of Crashes with Injuries					
Minor	$18,771	-0.0066	$123	-1.7067	$32,036
Moderate	$392,755	0.0000	$0	0.0000	$0
Severe	$3,003,746	0.0000	$0	0.0000	$0
Fatality	$4,207,985	0.0000	$0	0.0000	$0
Subtotal			**$175**		**$45,624**
Emissions					
Change in Carbon Monoxide - metric tons	$138	-0.0108	$1	-2.8080	$388
Change in Nitrous Oxide - metric tons	$7,490	-0.0021	$16	-0.5460	$4,090
Change in VOC - metric tons	$5,682	-0.0025	$14	-0.6500	$3,693
Subtotal		-0.0154	**$31**		**$8,170**
Energy					
Change in Fuel Consumed - gallons	$2.64	-155	**$409**	-40,300	**$106,392**
Daily **Benefit** of Phase 1 recommendations			**$4,636**		
Number of Travel Days (workdays) per year					**260**

Benefit Cost Estimation

Annual Benefit of recommendations *Based on 260 travel days (workdays) per year*				**$1,205,200**
	Engineering	Signal Equipment		
Annual Cost to develop recommendations *Includes consultant costs with a 5 year Capital Recovery Factor period and signal equipment over a 15 year Captial Recovery Factor period*	$ **14,502**	$ **-**		**$14,502**
Benefit-Cost Ratio				**83 :1**

Notes:
1 The costs that were assumed does not include BTD staff time.
2 Total cost spent in 2009: $ **66,400** $ **-**

Table 4. Benefit-cost Ratios for Phase 2 – Signal Retiming and Equipment

Performance Measure - Unit Measure	Value per unit measure (2009 dollars)	Daily Change (unit measure)	Daily Benefit (dollars)	Annual Change (unit measure)	Annual Benefit (dollars)
Delay					
Automobiles: Change in Intersection Delay - person hours	$16.09	-336	$5,406	-87,360	$1,405,622
Trucks: Change in Intersection Delay - vehicle hours	$106.24	-4	$425	-1,040	$110,490
Subtotal			**$5,831**		**$1,516,112**
Safety					
Change in Number of Crashes with Property Damage Only (PDO)	$3,165	-0.0165	$52	-4.2933	$13,588
Change in Number of Crashes with Injuries					
Minor	$18,771	-0.0066	$123	-1.7067	$32,036
Moderate	$392,755	0.0000	$0	0.0000	$0
Severe	$3,003,746	0.0000	$0	0.0000	$0
Fatality	$4,207,985	0.0000	$0	0.0000	$0
Subtotal			**$175**		**$45,624**
Emissions					
Change in Carbon Monoxide - metric tons	$138	-0.0147	$2	-3.8220	$527
Change in Nitrous Oxide - metric tons	$7,490	-0.0029	$22	-0.7540	$5,647
Change in VOC - metric tons	$5,682	-0.0034	$19	-0.8840	$5,023
Subtotal		-0.0210	**$43**		**$11,198**
Energy					
Change in Fuel Consumed - gallons	$2.64	-211	**$557**	-54,860	**$144,820**
Daily **Benefit** of Phase 2 recommendations			**$6,607**		
Number of Travel Days (workdays) per year					260

Benefit Cost Estimation

		Engineering	Signal Equipment	
Annual Benefit of recommendations *Based on 260 travel days (workdays) per year*				**$1,717,800**
Annual Cost to develop recommendations *Includes consultant costs with a 5 year Capital Recovery Factor period and signal equipment over a 15 year Captial Recovery Factor period*	$	14,502	$ 13,600	**$28,102**
Benefit-Cost Ratio				**61 :1**

Notes:

1 The costs that were assumed does not include BTD staff time.
2 Total cost spent in 2009: $ **66,400** $ **162,000**

Note that the ratios reflect estimated benefits for only the 3 weekday peak hours and do not account for benefits that would occur during off-peak hours, weekends, or holidays. While non-peak hour benefits have not been included, it should be noted that the resulting ratios would be higher.

The benefit-cost ratios show that the monetary investment in Back Bay signal improvements is recaptured many times over in terms of economic and social benefits.

Additionally, the benefit-cost data for other work order areas as shown in **Appendix A** indicate that travelers in all work order areas will experience a positive net benefit because of the Phase 1 retiming improvements.

Signal Retiming Costs in Other Cities

Agencies in many other cities have also examined the costs of improving signal timings, although fewer have quantified the associated benefit-cost ratio. **Table 5** shows the cost comparison from several other cities and Back Bay. It is worth noting that cost per location in the Back Bay is less than other cited studies.

Table 5. Signal Retiming Cost Comparison

Source	Location	Average Engineering Cost of Retiming One Traffic Signal	Study Date
National Traffic Signal Report Card	Nationally	$3,000 or less	2007
Millennia Mall Signal Retiming Project	Orlando, FL	$3,100	2005
Regional Signal Timing Program - 2005 Cycle Program Performance	Oakland, CA	$2,400	2007
Benefits of Retiming Traffic Signals: A Reference for Practitioners and Decision Makers	Various	$2,000 - $2,500	2005
Denver Regional Council of Governments Costs of Retiming Traffic Signals	Denver, CO	$1,800 - $2,000	2006
BTD Work Order #1 Back Bay	Boston, MA	***$1,110***	2007–09
BTD Average of all Work Orders	Boston, MA	***$1,935***	2007-09

Appendix A. Additional Data

Annual Benefits – All Work Order Areas

Annual Benefits Summary for Each Work Order

Work Order #	Neighborhoods/Streets	Number of Signals	Delay (person hours)	Delay (Dollars)	Safety (Reduced Crashes)	Safety (Dollars)	Emissions (Metric Tons)	Emissions (Dollars)	Energy (Gallons)	Energy (Dollars)	Overall Benefit (Dollars)	B/C
			Annual Savings									
Work Order #1	**Back Bay (Phase 1 and 2)**	60	88,400	$1,516,112	6.0	$45,624	5.46	$11,198	54,860	$144,820	$1,717,754	**61:1**
Work Order #2	**Allston, Dorchester, East Boston and Roslindale**	29	108,940	$1,869,967	0.3	$4,010	7.90	$16,947	78,260	$206,960	$2,097,884	**45:1**
Work Order #3	**Jamaica Plain/Roxbury**	23	92,040	$1,574,560	0.0	$0	6.36	$12,985	63,180	$166,920	$1,754,465	**124:1**
Work Order #4	**Hyde Park Avenue**	11	26,780	$454,296	0.5	$8,347	1.95	$3,910	19,760	$52,260	$518,813	**84:1**
Work Order #5	**Brighton/Roxbury** *Cambridge Street, Washington Street, Market Street, Melnea Cass Blvd.*	21	19,500	$337,170	0.0	$0	7.07	$42,274	19,500	$51,480	$430,924	**52:1**
Work Order #6	**South End**	14	5,720	$92,040	0.0	$0	0.45	$919	4,420	$11,700	$104,659	**12:1**
Work Order #7	**Financial District** *Summer Street, Franklin Street, Congress Street, Pearl Street Devonshire Street/Kingston Street, High Street*	29	18,460	$320,438	0.3	$1,260	1.30	$2,671	12,740	$33,800	$358,168	**23:1**
Central Artery Work Order #1	**Central Artery** *Atlantic Avenue/Cross Street, Surface Road/Purchase Street Kneeland Street, Congress Street/Merrimac Street North Street, Summer Street, Congress Street (South Boston) D Street, Seaport Blvd., Albany Street, Frontage Road, North Washington Street/Rutherford Avenue*	90	65,260	$1,120,340	5.1	$42,254	3.98	$8,167	41,340	$109,200	$1,279,961	**27:1**
Total		277	425,100	$7,284,923	12.2	$101,495	34.47	$99,070	294,060	$777,140	$8,262,628	*

*		Engineering	Signal Equipment	
	Annual Benefit of recommendations			**$8,262,628**
All Work Orders	**Annual Cost** to develop recommendations	$ **117,052**	$ **57,134**	**$174,186**
	Includes consultant costs with a 5 year Capital Recovery Factor period			
	and signal equipment over a 15 year Captial Recovery Factor period		**Overall Benefit-Cost Ratio**	* **47 :1**

Notes:

1 The costs that were assumed does not include BTD staff time.

2 Total cost spent in 2009/2010 — $ **535,951** (Engineering); $ **681,789** (Signal Equipment)

Daily Benefits – All Work Order Areas

Daily Benefits Summary for Each Work Order

Work Order #	Neighborhoods/Streets	Number of Signals	Daily Savings: Delay (person hours)	Delay (Dollars)	Safety (Dollars)	Emissions (Metric Tons)	Emissions (Dollars)	Energy (Gallons)	Energy (Dollars)	Overall Benefit (Dollars)	B/C
Work Order #1	**Back Bay (Phase 1 and 2)**	60	340	$5,831	$175	0.0210	$43	211	$557	$6,607	**61:1**
Work Order #2	**Allston, Dorchester, East Boston and Roslindale**	29	419	$7,192	$15	0.0304	$65	301	$796	$8,069	**45:1**
Work Order #3	**Jamaica Plain/Roxbury**	23	354	$6,056	$0	0.0245	$50	243	$642	$6,748	**124:1**
Work Order #4	**Hyde Park Avenue**	11	103	$1,747	$32	0.0075	$15	76	$201	$1,995	**84:1**
Work Order #5	**Brighton/Roxbury** *Cambridge Street, Washington Street, Market Street, Melnea Cass Blvd.*	21	75	$1,297	$0	0.0272	$163	75	$198	$1,657	**52:1**
Work Order #6	**South End**	14	22	$354	$0	0.0017	$4	17	$45	$403	**12:1**
Work Order #7	**Financial District** *Summer Street, Franklin Street, Congress Street, Pearl Street Devonshire Street/Kingston Street, High Street*	29	71	$1,232	$5	0.0050	$10	49	$130	$1,378	**23:1**
Central Artery Work Order #1	**Central Artery** *Atlantic Avenue/Cross Street, Surface Road/Purchase Street Kneeland Street, Congress Street/Merrimac Street North Street, Summer Street, Congress Street (South Boston) D Street, Seaport Blvd., Albany Street, Frontage Road, North Washington Street/Rutherford Avenue*	90	251	$4,309	$163	0.0153	$31	159	$420	$4,923	**27:1**
Total		277	1,635	$28,019	$390	0.1326	$381	1,131	$2,989	$31,779	

Benefit-cost Ratios – All Work Order Areas

Benefit-Cost Ratio for Phase 1 - Signal Retiming Only
Work Order #1 - Back Bay

Performance Measure - Unit Measure	Value per unit measure (2009 dollars)	Daily Change (unit measure)	Daily Benefit (dollars)	Annual Change (unit measure)	Annual Benefit (dollars)
Delay					
Automobiles: Change in Intersection Delay - person hours	$16.09	-230	$3,701	-59,800	$962,182
Trucks: Change in Intersection Delay - vehicle hours	$106.24	-3	$319	-780	$82,867
Subtotal			**$4,020**		**$1,045,049**
Safety					
Change in Number of Crashes with Property Damage Only (PDO)	$3,165	-0.0165	$52	-4.2933	$13,588
Change in Number of Crashes with Injuries					
Minor	$18,771	-0.0066	$123	-1.7067	$32,036
Moderate	$392,755	0.0000	$0	0.0000	$0
Severe	$3,003,746	0.0000	$0	0.0000	$0
Fatality	$4,207,985	0.0000	$0	0.0000	$0
Subtotal			**$175**		**$45,624**
Emissions					
Change in Carbon Monoxide - metric tons	$138	-0.0108	$1	-2.8080	$388
Change in Nitrous Oxide - metric tons	$7,490	-0.0021	$16	-0.5460	$4,090
Change in VOC - metric tons	$5,682	-0.0025	$14	-0.6500	$3,693
Subtotal		-0.0154	**$31**		**$8,170**
Energy					
Change in Fuel Consumed - gallons	$2.64	-155	**$409**	-40,300	**$106,392**
Daily **Benefit** of Phase 1 recommendations			**$4,636**		
Number of Travel Days (workdays) per year					**260**

Benefit Cost Estimation

Annual Benefit of recommendations *Based on 260 travel days (workdays) per year*			**$1,205,200**
	Engineering	Signal Equipment	
Annual Cost to develop recommendations *Includes consultant costs with a 5 year Capital Recovery Factor period and signal equipment over a 15 year Captial Recovery Factor period*	**$ 14,502**	**$ -**	**$14,502**
Benefit-Cost Ratio			**83 :1**

Notes:

1 The costs that were assumed does not include BTD staff time.

2 Total cost spent in 2009: **$ 66,400** **$ -**

Benefit-Cost Ratio for Phase 2 - Signal Retiming and Equipment
Work Order #1 - Back Bay

Performance Measure - Unit Measure	Value per unit measure (2009 dollars)	Daily Change (unit measure)	Daily Benefit (dollars)	Annual Change (unit measure)	Annual Benefit (dollars)
Delay					
Automobiles: Change in Intersection Delay - person hours	$16.09	-336	$5,406	-87,360	$1,405,622
Trucks: Change in Intersection Delay - vehicle hours	$106.24	-4	$425	-1,040	$110,490
Subtotal			**$5,831**		**$1,516,112**
Safety					
Change in Number of Crashes with Property Damage Only (PDO)	$3,165	-0.0165	$52	-4.2933	$13,588
Change in Number of Crashes with Injuries					
Minor	$18,771	-0.0066	$123	-1.7067	$32,036
Moderate	$392,755	0.0000	$0	0.0000	$0
Severe	$3,003,746	0.0000	$0	0.0000	$0
Fatality	$4,207,985	0.0000	$0	0.0000	$0
Subtotal			**$175**		**$45,624**
Emissions					
Change in Carbon Monoxide - metric tons	$138	-0.0147	$2	-3.8220	$527
Change in Nitrous Oxide - metric tons	$7,490	-0.0029	$22	-0.7540	$5,647
Change in VOC - metric tons	$5,682	-0.0034	$19	-0.8840	$5,023
Subtotal		-0.0210	**$43**		**$11,198**
Energy					
Change in Fuel Consumed - gallons	$2.64	-211	**$557**	-54,860	**$144,820**
Daily **Benefit** of Phase 2 recommendations			**$6,607**		
Number of Travel Days (workdays) per year					260

Benefit Cost Estimation

	Engineering	Signal Equipment		
Annual Benefit of recommendations *Based on 260 travel days (workdays) per year*				**$1,717,800**
Annual Cost to develop recommendations *Includes consultant costs with a 5 year Capital Recovery Factor period and signal equipment over a 15 year Captial Recovery Factor period*	**$ 14,502**	**$ 13,600**		**$28,102**
Benefit-Cost Ratio			**61 :1**	

Notes:

1 The costs that were assumed does not include BTD staff time.
2 Total cost spent in 2009: **$ 66,400** **$ 162,000**

SUMMARY
Work Order #2 - Allston, Dorchester, East Boston, Roslindale
Benefit-Cost Ratio
Phase 1 - Signal Retiming Only

Performance Measure - Unit Measure	Source	Value per unit measure (2009 dollars)	Daily Change (unit measure)	Daily Benefit (dollars)	Annual Change (unit measure)	Annual Benefit (dollars)
Delay						
Automobiles: Change in Intersection Delay - person hours	(1)	$16.09	-414	$6,661	-107,640	$1,731,798
Trucks: Change in Intersection Delay - vehicle hours		$106.24	-5	$531	-1,300	$138,107
Subtotal				**$7,192**		**$1,869,905**
Safety [a)]						
Change in Number of Crashes with Property Damage Only (PDO)	(2, 3)	$3,165	-0.0006	$2	-0.1600	$506
Change in Number of Crashes with Injuries						
Minor	(2, 3)	$18,771	-0.0007	$13	-0.1867	$3,504
Moderate	(2, 3)	$392,755	0.0000	$0	0.0000	$0
Severe	(2, 3)	$3,003,746	0.0000	$0	0.0000	$0
Fatality	(2, 3)	$4,207,985	0.0000	$0	0.0000	$0
Subtotal				**$15**		**$4,010**
Emissions						
Change in Carbon Monoxide - metric tons	(4)	$138	-0.0209	$3	-5.4340	$750
Change in Nitrous Oxide - metric tons	(4)	$7,490	-0.0046	$34	-1.1960	$8,958
Change in VOC - metric tons	(4)	$5,682	-0.0049	$28	-1.2740	$7,239
Subtotal			-0.0304	**$65**		**$16,947**
Energy						
Change in Fuel Consumed - gallons	(5)	$2.64	-301	**$796**	-78,260	**$206,960**
Daily Benefit				**$8,069**		
Number of Travel Days (workdays) per year						260

Benefit Cost Estimation

Annual Benefit of recommendations *Based on 260 travel days (workdays) per year*			**$2,097,800**
	Engineering	Signal Equipment	
Annual Cost to develop recommendations *Includes consultant costs with a 5 year Capital Recovery Factor period and signal equipment over a 15 year Captial Recovery Factor period*	$ 13,344	$ 33,017	**$46,361**
Benefit-Cost Ratio			**45 :1**

Notes:

1 The costs that were assumed does not include BTD staff time.

2 Total cost spent in 2009: $ 61,099 $ 393,998

SUMMARY
Work Order #3 - Jamaica Plain/Roxbury
Benefit-Cost Ratio
Phase 1 - Signal Retiming Only

Performance Measure - Unit Measure	Source	Value per unit measure (2009 dollars)	Daily Change (unit measure)	Daily Benefit (dollars)	Annual Change (unit measure)	Annual Benefit (dollars)
Delay						
Automobiles: Change in Intersection Delay - person hours	(1)	$16.09	-350	$5,631	-91,000	$1,464,081
Trucks: Change in Intersection Delay - vehicle hours		$106.24	-4	$425	-1,040	$110,485
Subtotal				**$6,056**		**$1,574,566**
Safety [a)]						
Change in Number of Crashes with Property Damage Only (PDO)	(2, 3)	$3,165	0.0000	$0	0.0000	$0
Change in Number of Crashes with Injuries						
Minor	(2, 3)	$18,771	0.0000	$0	0.0000	$0
Moderate	(2, 3)	$392,755	0.0000	$0	0.0000	$0
Severe	(2, 3)	$3,003,746	0.0000	$0	0.0000	$0
Fatality	(2, 3)	$4,207,985	0.0000	$0	0.0000	$0
Subtotal				**$0**		**$0**
Emissions						
Change in Carbon Monoxide - metric tons	(4)	$138	-0.0172	$2	-4.4590	$615
Change in Nitrous Oxide - metric tons	(4)	$7,490	-0.0033	$25	-0.8684	$6,504
Change in VOC - metric tons	(4)	$5,682	-0.0040	$23	-1.0322	$5,865
Subtotal			-0.0245	**$50**		**$12,984**
Energy						
Change in Fuel Consumed - gallons	(5)	$2.64	-243	**$642**	-63,180	**$166,920**
Daily Benefit				**$6,748**		
Number of Travel Days (workdays) per year						260

Benefit Cost Estimation

		Engineering	Signal Equipment	
Annual Benefit of recommendations *Based on 260 travel days (workdays) per year*				**$1,754,500**
Annual Cost to develop recommendations *Includes consultant costs with a 5 year Capital Recovery Factor period* *and signal equipment over a 15 year Captial Recovery Factor period*	$	**9,675**	$ **4,441**	**$14,117**
Benefit-Cost Ratio				**124 :1**

Notes:

1 The costs that were assumed does not include BTD staff time.

2 Total cost spent in 2009: $ **44,300** $ **53,000**

SUMMARY
Work Order #4 - Hyde Park Avenue
Benefit-Cost Ratio
Phase 1 - Signal Retiming Only

Performance Measure - Unit Measure	Source	Value per unit measure (2009 dollars)	Daily Change (unit measure)	Daily Benefit (dollars)	Annual Change (unit measure)	Annual Benefit (dollars)
Delay						
Automobiles: Change in Intersection Delay - person hours	(1)	$16.09	-102	$1,641	-26,520	$426,675
Trucks: Change in Intersection Delay - vehicle hours		$106.24	-1	$106	-260	$27,621
Subtotal				**$1,747**		**$454,296**
Safety [a)]						
Change in Number of Crashes with Property Damage Only (PDO)	(2, 3)	$3,165	-0.0004	$1	-0.1067	$338
Change in Number of Crashes with Injuries						
Minor	(2, 3)	$18,771	-0.0016	$31	-0.4267	$8,009
Moderate	(2, 3)	$392,755	0.0000	$0	0.0000	$0
Severe	(2, 3)	$3,003,746	0.0000	$0	0.0000	$0
Fatality	(2, 3)	$4,207,985	0.0000	$0	0.0000	$0
Subtotal				**$32**		**$8,347**
Emissions						
Change in Carbon Monoxide - metric tons	(4)	$138	-0.0053	$1	-1.3780	$190
Change in Nitrous Oxide - metric tons	(4)	$7,490	-0.0010	$7	-0.2600	$1,947
Change in VOC - metric tons	(4)	$5,682	-0.0012	$7	-0.3120	$1,773
Subtotal			-0.0075	**$15**		**$3,910**
Energy						
Change in Fuel Consumed - gallons	(5)	$2.64	-76	**$201**	-19,760	**$52,260**
Daily Benefit				**$1,995**		
Number of Travel Days (workdays) per year						260

Benefit Cost Estimation

		Engineering	Signal Equipment	
Annual Benefit of recommendations *Based on 260 travel days (workdays) per year*				**$518,800**
Annual Cost to develop recommendations *Includes consultant costs with a 5 year Capital Recovery Factor period and signal equipment over a 15 year Captial Recovery Factor period*		$ 6,181	$ -	**$6,181**
Benefit-Cost Ratio				**84 :1**

Notes:

1 The costs that were assumed does not include BTD staff time.

2 Total cost spent in 2009: $ 28,300 $ -

SUMMARY
Work Order #5 Cambridge Street, Washington Street, Market Street, Melnea Cass Blvd
Benefit-Cost Ratio
Phase 1 - Signal Retiming Only

Performance Measure - Unit Measure	Source	Value per unit measure (2009 dollars)	Daily Change (unit measure)	Daily Benefit (dollars)	Annual Change (unit measure)	Annual Benefit (dollars)
Delay						
Automobiles: Change in Intersection Delay - person hours	(1)	$16.09	-74	$1,191	-19,240	$309,549
Trucks: Change in Intersection Delay - vehicle hours		$106.24	-1	$106	-260	$27,621
Subtotal				**$1,297**		**$337,170**
Safety [a)]						
Change in Number of Crashes with Property Damage Only (PDO)	(2, 3)	$3,165	0.0000	$0	0.0000	$0
Change in Number of Crashes with Injuries						
Minor	(2, 3)	$18,771	0.0000	$0	0.0000	$0
Moderate	(2, 3)	$392,755	0.0000	$0	0.0000	$0
Severe	(2, 3)	$3,003,746	0.0000	$0	0.0000	$0
Fatality	(2, 3)	$4,207,985	0.0000	$0	0.0000	$0
Subtotal				**$0**		**$0**
Emissions						
Change in Carbon Monoxide - metric tons	(4)	$138	-0.0053	$1	-1.3780	$190
Change in Nitrous Oxide - metric tons	(4)	$7,490	-0.0207	$155	-5.3820	$40,311
Change in VOC - metric tons	(4)	$5,682	-0.0012	$7	-0.3120	$1,773
Subtotal			-0.0272	**$163**		**$42,274**
Energy						
Change in Fuel Consumed - gallons	(5)	$2.64	-75	**$198**	-19,500	**$51,480**
Daily Benefit				**$1,657**		
Number of Travel Days (workdays) per year						260

Benefit Cost Estimation

		Engineering	Signal Equipment	
Annual Benefit of recommendations *Based on 260 travel days (workdays) per year*				**$430,900**
Annual Cost to develop recommendations *Includes consultant costs with a 5 year Capital Recovery Factor period and signal equipment over a 15 year Captial Recovery Factor period*		**$ 8,256**	**$ -**	**$8,256**
Benefit-Cost Ratio				**52 :1**

Notes:
1 The costs that were assumed does not include BTD staff time.
2 Total cost spent in 2009: **$ 37,800** **$ -**

SUMMARY
Work Order #6 - South End
Benefit-Cost Ratio
Phase 1 - Signal Retiming Only

Performance Measure - Unit Measure	Source	Value per unit measure (2009 dollars)	Daily Change (unit measure)	Daily Benefit (dollars)	Annual Change (unit measure)	Annual Benefit (dollars)
Delay						
Automobiles: Change in Intersection Delay - person hours	(1)	$16.09	-22	$354	-5,720	$92,028
Trucks: Change in Intersection Delay - vehicle hours		$106.24	0	$0	0	$0
Subtotal				**$354**		**$92,028**
Safety [a)]						
Change in Number of Crashes with Property Damage Only (PDO)	(2, 3)	$3,165	0.0000	$0	0.0000	$0
Change in Number of Crashes with Injuries						
Minor	(2, 3)	$18,771	0.0000	$0	0.0000	$0
Moderate	(2, 3)	$392,755	0.0000	$0	0.0000	$0
Severe	(2, 3)	$3,003,746	0.0000	$0	0.0000	$0
Fatality	(2, 3)	$4,207,985	0.0000	$0	0.0000	$0
Subtotal				**$0**		**$0**
Emissions						
Change in Carbon Monoxide - metric tons	(4)	$138	-0.0012	$0	-0.3120	$43
Change in Nitrous Oxide - metric tons	(4)	$7,490	-0.0002	$2	-0.0598	$448
Change in VOC - metric tons	(4)	$5,682	-0.0003	$2	-0.0754	$428
Subtotal			-0.0017	**$4**		**$919**
Energy						
Change in Fuel Consumed - gallons	(5)	$2.64	-17	**$45**	-4,420	**$11,700**
Daily Benefit				**$403**		
Number of Travel Days (workdays) per year						260

Benefit Cost Estimation

		Engineering		Signal Equipment	
Annual Benefit of recommendations *Based on 260 travel days (workdays) per year*					**$104,600**
Annual Cost to develop recommendations *Includes consultant costs with a 5 year Capital Recovery Factor period and signal equipment over a 15 year Captial Recovery Factor period*	**$**	**8,605**	**$**	**-**	**$8,605**
Benefit-Cost Ratio					**12 :1**

Notes:

1 The costs that were assumed does not include BTD staff time.

2 Total cost spent in 2009: **$ 39,400 $ -**

SUMMARY
Work Order #7 - Financial District
Benefit-Cost Ratio
Phase 2 Signal Retiming & Equipment

Performance Measure - Unit Measure	Source	Value per unit measure (2009 dollars)	Daily Change (unit measure)	Daily Benefit (dollars)	Annual Change (unit measure)	Annual Benefit (dollars)
Delay						
Automobiles: Change in Intersection Delay - person hours	(1)	$16.09	-70	$1,126	-18,200	$292,816
Trucks: Change in Intersection Delay - vehicle hours		$106.24	-1	$106	-260	$27,621
Subtotal				**$1,232**		**$320,438**
Safety [a)]						
Change in Number of Crashes with Property Damage Only (PDO)	(2, 3)	$3,165	-0.0009	$3	-0.2400	$760
Change in Number of Crashes with Injuries						
Minor	(2, 3)	$18,771	-0.0001	$2	-0.0267	$501
Moderate	(2, 3)	$392,755	0.0000	$0	0.0000	$0
Severe	(2, 3)	$3,003,746	0.0000	$0	0.0000	$0
Fatality	(2, 3)	$4,207,985	0.0000	$0	0.0000	$0
Subtotal				**$5**		**$1,260**
Emissions						
Change in Carbon Monoxide - metric tons	(4)	$138	-0.0035	$0	-0.9100	$126
Change in Nitrous Oxide - metric tons	(4)	$7,490	-0.0007	$5	-0.1820	$1,363
Change in VOC - metric tons	(4)	$5,682	-0.0008	$5	-0.2080	$1,182
Subtotal			-0.0050	**$10**		**$2,671**
Energy						
Change in Fuel Consumed - gallons	(5)	$2.64	-49	**$130**	-12,740	**$33,800**
Daily Benefit				**$1,378**		
Number of Travel Days (workdays) per year						260

Benefit Cost Estimation

		Engineering	Signal Equipment	
Annual Benefit of recommendations *Based on 260 travel days (workdays) per year*				**$358,200**
Annual Cost to develop recommendations *Includes consultant costs with a 5 year Capital Recovery Factor period and signal equipment over a 15 year Captial Recovery Factor period*		$ **10,680**	$ **4,609**	**$15,289**
Benefit-Cost Ratio				**23 :1**

Notes:

1 The costs that were assumed does not include BTD staff time.
2 Total cost spent in 2009: $ **48,900** $ **55,000**

SUMMARY
Central Artery Work Order #1
Benefit-Cost Ratio
Phase 1 - Signal Retiming Only

Performance Measure - Unit Measure	Source	Value per unit measure (2009 dollars)	Daily Change (unit measure)	Daily Benefit (dollars)	Annual Change (unit measure)	Annual Benefit (dollars)
Delay						
Automobiles: Change in Intersection Delay - person hours	(1)	$16.09	-248	$3,990	-64,480	$1,037,406
Trucks: Change in Intersection Delay - vehicle hours		$106.24	-3	$319	-780	$82,864
Subtotal				**$4,309**		**$1,120,270**
Safety [a)]						
Change in Number of Crashes with Property Damage Only (PDO)	(2, 3)	$3,165	-0.0130	$41	-3.3867	$10,719
Change in Number of Crashes with Injuries						
Minor	(2, 3)	$18,771	-0.0065	$121	-1.6800	$31,535
Moderate	(2, 3)	$392,755	0.0000	$0	0.0000	$0
Severe	(2, 3)	$3,003,746	0.0000	$0	0.0000	$0
Fatality	(2, 3)	$4,207,985	0.0000	$0	0.0000	$0
Subtotal				**$163**		**$42,254**
Emissions						
Change in Carbon Monoxide - metric tons	(4)	$138	-0.0107	$1	-2.7820	$384
Change in Nitrous Oxide - metric tons	(4)	$7,490	-0.0021	$16	-0.5460	$4,090
Change in VOC - metric tons	(4)	$5,682	-0.0025	$14	-0.6500	$3,693
Subtotal			-0.0153	**$31**		**$8,167**
Energy						
Change in Fuel Consumed - gallons	(5)	$2.64	-159	**$420**	-41,340	**$109,200**
Daily Benefit				**$4,923**		
Number of Travel Days (workdays) per year						260

Benefit Cost Estimation

		Engineering	Signal Equipment	
Annual Benefit of recommendations *Based on 260 travel days (workdays) per year*				**$1,279,900**
Annual Cost to develop recommendations *Includes consultant costs with a 5 year Capital Recovery Factor period and signal equipment over a 15 year Captial Recovery Factor period*		**$ 45,810**	**$ 1,467**	**$47,276**
Benefit-Cost Ratio				**27 :1**

Notes:

1 The costs that were assumed does not include BTD staff time.
2 Total cost spent in 2009: **$ 209,751** **$ 17,500**

Source	Measure
(1)	**DELAY** Automobiles: Cost per person hour of $15.47 is from 2009 Mobility Report, Exhibit A-1. Convert value from Year 2007 to Year 2009 by CPI of 1.04. $15.47 x 1.04 = $ 16.09 Convert vehicle delay (from Synchro) into person delay by assuming 1.25 persons per vehicle, also from Exhibit A-1. Trucks: Cost per vehicle hour of $102.15 is from 2009 Mobility Report, Exhibit A-1. Convert value from Year 2007 to Year 2009 by CPI of 1.04. $102.15 x 1.04 = $ 106.24
(2,3)	**SAFETY** For Safety measures, Convert Table A1 from values NHTSA report - from Year 2000 values to Year 2009 values by CPI value of 1.25.
(4)	**EMISSIONS** For Emission measures, Convert Table E5 from HERS report - from Year 2000 values to Year 2009 values by 1.25.
(5)	**ENERGY** Cost of Fuel (year 2009 dollars) per gallon is $2.64

Safety (Source 2,3):

	2000 $ value per crash from Table A1	CPI Factor	2009 $ value per crash
PDO Crash	$ 2,532	1.25	$ 3,165
Minor	$ 15,017	1.25	$ 18,771
Moderate	$ 314,204	1.25	$ 392,755
Severe	$ 2,402,997	1.25	$ 3,003,746
Fatality	$ 3,366,388	1.25	$ 4,207,985

Crash reduction Factor of 0.08 is taken from "Desktop Reference for Crash Rate Reduction".
Note that 0.08 is the conservative estimate given the range of 0.08 to 0.18 shown in Table A1 for Crash Type =All and Crash Severity = All.

Emissions (Source 4):

	2000 $ value per ton from Table E5	Urban/Rural Factor from Table E5	CPI Factor	Convert from ton to metric ton	2009 $ value per metric ton
Carbon Monoxide	$ 100	1.0	1.25	1.102	$ 138
Nitrous Oxide	$ 3,625	1.5	1.25	1.102	$ 7,490
VOC	$ 2,750	1.5	1.25	1.102	$ 5,682

(1) “2009 Mobility Report” Texas Transportation Institute, July 2009. Appendix A
Exhibit A1 - "National Congestion Constants for 2009 Urban Mobility Report"
Value converted from Year 2007 to Year 2009 by CPI of 1.04.

(2) “The Economic Impact of Motor Vehicle Crashes 2000”, by USDOT/National Highway Traffic Safety Administration (NHTSA); 2002.
Table A1 - "Summary of Unit Costs, 2000" for Injury and Non-Injury Related Costs
Value converted from Year 2000 to Year 2009 by CPI of 1.25.

(3) “Desktop Reference for Crash Reduction Factors", Report no. FHWA-SA-08-0111 by USDOT/Federal Highway Administration, September 2008.
Page 9, For Improve Signal Timing with Crash Type = All and Crash Severity = All.

(4) HERS-ST 2.0 (Highway Economic Requirements System – State Version) Technical Report US DOT/Federal Highway Administration. 2002.
Table E5 - "Air Pollution Damage Costs and Adjustment Factors Used in HERS"
Value converted from Year 2000 to Year 2009 by CPI of 1.25.

(5) Energy Information Administration website, http://www.eia.doe.gov/oil_gas/petroleum/data_publications/wrgp/mogas_home_page.html.
Data for Massachusetts. Viewed December 2009.

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