Environmental and Economic Implications of Relocating Urban Highways Underground

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Abstract

The "Big Dig" was a massive infrastructure project in Boston that spanned 30 years and buried the city's main central highway artery underground. It is renowned amongst Bostonians for its exorbitant costs and drain on resources. The major argument for relocating I-93 underground was to relieve heavy traffic congestion clogging the downtown district, and was also driven by a poorly constructed highway with infrastructure instabilities that it was designed to replace. After relocation construction was completed, the cost of the project soared to over four times the original estimates, presumably discouraging other municipalities from similar major infrastructure projects. Although the primary desired outcome was reduced vehicular traffic, less tangible benefits do exist in the forms of increased property values, reduced emissions, the value of time saved for commuters that would otherwise be spent sitting in traffic, and green space creation. These benefits however are inherently difficult to compare directly with the dollar value attributed to the project's costs. However, using valuation techniques to place a dollar value on the benefits derived from the Big Dig shifts the paradigm for viewing such infrastructure projects. With tools for solid comparisons, other municipalities and cities could more accurately assess the overall costs and benefits of potentially constructing similar projects. Expanding the project focus to include the social, environmental, and economic pillars of sustainability assessment leads to a more accurate estimate of project value.

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Context

Traffic is the bane of commuter life, with the average American spending 42 hours a year sitting in traffic (INRIX, 2018). The evolution of the modern workforce, coupled with patterns of urban sprawl, has led to an influx of suburban workers commuting into urban areas for the workday. Some areas, such as the City of Boston, were built before the modern day automobile dictated wide roadways and multi-lane traffic patterns. In such scenarios, rapid population growth has exacerbated traffic congestion and hours of idle cars sitting on highways.

The City of Boston exemplifies an urban area historically overrun with increasing population and heavy congestion. As with any major city in the United States, over the years Boston has developed infrastructure to accommodate the growing population. A major elevated highway was constructed through the main downtown district of Boston as well as the waterfront region in the 1950s to deal with this issue (Commonwealth of Massachusetts, 2018).

According to the Commonwealth of Massachusetts, after construction in 1959 the main highway running through downtown Boston (the Central Artery) supported approximately 75,000 automobiles daily (2018). Ten hours of daily traffic cramped downtown streets, with projections increasing traffic levels to 16 hours per day by 2010 under a business-as-usual scenario. By the 1990s, daily automobile traffic had increased to roughly 200,000 cars per day. The costs associated with such congestion included high prices for fuel and an increased number of vehicular accident rates. Traffic congestion deterred population influx, slowing job growth and leading to loss of business productivity. These costs were estimated at $500 million annually, and were a huge drain on Boston’s economy and connectivity. In addition to heavy traffic congestion, the artery itself was poorly constructed, displaced families along its route, and had an accident rate four times higher than the national average (Commonwealth of Massachusetts, 2018).

In response to this economic detriment due to the traffic problem, Boston initiated a massive undertaking known as the Central Artery/Tunnel Project (CA/T). More colloquially known as the 'Big Dig,' the project is now renowned for its immense cost overruns and lengthy timeline. Essentially, Interstate 93 ran as an elevated highway (the Central Artery) through the main downtown area connecting the north and south regions of the eastern part of the state (Commonwealth of Massachusetts, 2018). The CA/T project was proposed in order to bury I-93 underground and to extend another highway, Interstate 90, beneath Boston Harbor so that it would connect the Massachusetts Turnpike, the state's main east/west highway, directly to Boston's Logan Airport. Furthermore, the Rose Fitzgerald Kennedy Greenway was planned to be constructed through downtown Boston where the elevated Interstate had previously run, and would serve as an open green space for recreational and business activities. (Commonwealth of Massachusetts, 2018).

The project was a huge undertaking, likened to some of the world's biggest infrastructure projects such as the Panama Canal and Europe's Channel Tunnel. Proposed in the 1970s, the project remained in planning stages throughout the 1980s in order to acquire funding, conduct impact statements and finalize design plans (Commonwealth of Massachusetts, 2018). Groundwork began in 1991 and wasn't fully completed until 2007 (Commonwealth of Massachusetts, 2018). Additionally, a complication of the design was that the project needed to undergo construction while allowing for a thriving and growing city to maintain operations.

Figure 1.1 Aerial view of downtown Boston before the Central Artery/Tunnel Project.

Adapted from The Boston Globe by D. L. Ryan, 2014, Retrieved from https://www.boston.com/news/national-news/2014/05/22/los-angeles-gets-ready-for-its-own-big-dig

Figure 1.2 Aerial view of downtown Boston after the Central Artery/Tunnel Project.

Adapted from City Parks by K. Blaha, 2013, Retrieved from https://cityparksblog.org/tag/big-dig/

After construction, Boston's artery burial resulted in a 62% reduction in vehicular hours on essentially the same highway that it replaced (Commonwealth of Massachusetts, 2018). This simple metric proves the project's efficacy as compared to its original goals, and represents environmental and social benefits in addition to the more obvious economic ones. The Greenway, seen above, promotes tourism and business activity while beautifying the city.

The CA/T project, while completed within the city limits of Boston, can be viewed as a case study and thereby has major implications for metropolises worldwide. Cities like Los Angeles, Moscow, New York City, Sao Paulo and San Francisco are some of the most congested areas in the world, and they currently incur enormous costs from automobiles sitting in traffic jams and lost business revenue connected to lost time (INRIX, 2018). For example, London's traffic congestion was calculated to cost the city as a whole an estimated $12.5 billion in 2017 (INRIX, 2018).

The Problem Evolves

The costs of traffic congestion, while less easily calculated than some traditional expenditures, are still being realized by municipalities and city officials. These economic costs were a major factor encouraging the construction of the CA/T project in Boston and should not be ignored. Beyond the economic aspect of streamlining traffic patterns, environmental impacts of the project are extensive. Perhaps inadvertently, environmental benefits from reduced congestion resulted from the CA/T project's mission. Some of these benefits have included avoided carbon emissions, improved ecosystem connectivity, reduced heat island effect, and groundwater filtration. Going a step further, social benefits have included the value of time not spent in traffic as well as the added enjoyment from activities on the Greenway above the tunnel.

Despite city-wide efforts and public backing, the CA/T project was unfortunately extremely over budget and took many years to complete. To this day, the project's actual costs are debated. When the project's infrastructure and construction were completed in 2007, costs were estimated to be around $14.6 billion (Commonwealth of Massachusetts, 2018). Since then, costs of principal and inflation have escalated this number to over $20 billion, and in some scenarios as much as $24.3 billion is projected as construction loans will be incurred through 2038 (Moskowitz, 2012). The project's completion time also took longer than projections estimated, and this incurred further construction and hold up costs.

With many cities experiencing high volumes of traffic congestion and the associated environmental, social, and economic costs, a widely applicable tunnel solution would be hugely beneficial. Unfortunately, highway burial projects in other US cities have not been replicated often, presumably due to the CA/T's timetable downfalls and an overarching negative response to its perceived costs. Hypothesizing that monetary cost would overshadow other costs while benefits are ignored in the general mindset of the public, projects akin to the CA/T project should perhaps be revisited in other cities to achieve a more favorable outcome when benefits are presented in this new framework.

With more information about the project's beneficial effects on Boston's welfare, other municipalities could presumably benefit from their evaluation of similar projects. While the full benefits remain unknown, however, these implications are foregone. In terms of sustainability, the triple bottom line, consisting of environmental, social, and financial factors, is now emerging as a prevalent benchmark for business and profitable ventures (Indiana Business Review, 2011). With new accounting measures for assessing value, mere economic factors alone have been shown to not demonstrate the complete picture.

Across disciplines, holistic valuation methods are slowly replacing traditional cost evaluations. For example, Gross Domestic Product (GDP) is the traditional indicator of a nation's wealth, but may not be wholly accurate (Harris & Roach, 2013). Welfare accounting methods such as Green GDP or Genuine Progress Indicator (GPI) represent alternatives to GDP accounting and reflect Sustainability's triple bottom line (Harris & Roach, 2013). Social and environmental factors also hold actual effects on a nation's economy, potentially as valuable as simple economic factors. Incorporating the ideas of social capital and natural resources into welfare accounting results in a more accurate benchmark of the true cost and benefits than traditional GDP. With alternative forms of welfare accounting catching on at the global level, it is clear that widening the lens from traditional valuation methods to more inclusive policies is becoming more prevalent across the board.

Similarly, valuation methods for ecosystem services and project accounting could be better represented through a more holistic approach. Though widely relied upon, simple monetary cost accounting embodies just one facet of a project's true value. It is true that the CA/T project cost far more than originally budgeted, which by itself is a discouraging metric. But exacerbating this is the lack of tangible ways to account for a project's benefits, as well as the difficulties in comparing project benefits like green space and wider roadways to the monetary costs. The real challenge here lies in distinguishing the relationship between the number of cars idling on the highway and the billions of construction dollars required to reduce these numbers.

Response & Goals

Traditional accounting methods can be updated and improved by incorporating social and environmental costs and benefits. For example, such analysis could enable a broader and more accurate assessment of the CA/T project outcome. Beyond documenting project fiscal costs, a more complete economic assessment would also encompass the monetary equivalent value of social and environmental costs and benefits. Accordingly, this study is an attempt to accurately compare such disparate line items, valuation methods for ecosystem services, social capital, and environmental impacts and will assign numeric monetary values that can be compared across disciplines. This will be necessary in order to adapt the measurement to perform more comprehensive cost benefit analyses in the traditional manner so that other planners can use these figures to assess possible projects in their respective cities.

Figure 2 Traditional Accounting vs. Holistic Accounting

<table>
<tr><th colspan="2"></th><th>Traditional Accounting</th><th>Holistic Accounting</th></tr>
<tr><td rowspan="5">Economic</td><td>Capital</td><td>✓</td><td>✓</td></tr>
<tr><td>Labor</td><td>✓</td><td>✓</td></tr>
<tr><td>Loan Interest</td><td>✓</td><td>✓</td></tr>
<tr><td>Construction</td><td>✓</td><td>✓</td></tr>
<tr><td>Property Values</td><td></td><td>✓</td></tr>
<tr><td rowspan="2">Environment</td><td>Ecosystem Services</td><td></td><td>✓</td></tr>
<tr><td>Air Quality</td><td></td><td>✓</td></tr>
<tr><td rowspan="2">Social</td><td>Value of Time</td><td></td><td>✓</td></tr>
<tr><td>Recreation</td><td></td><td>✓</td></tr>
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The cost projections for the CA/T project, once they are completely paid off, are daunting. The goal of researching holistic accounting methods is not necessarily to “overcome” those costs, but to provide a view of the corresponding benefits in a more accurate way. This will enable more precise comparisons of the Big Dig's overall value to the City of Boston, as well as how other municipalities could similarly fare with their projects.

From an environmental economics standpoint, the value of the CA/T project itself would result from an assessment of the costs and benefits of highway reconstruction and its cascading effects. Included in this is a benefit evaluation of the creation of the Greenway, mainly a public park built on top of the former stretch of I-93 running through downtown Boston, which serves as a positive externality of the project. Since the Greenway was built as a direct result of the artery burial, it is a direct outcome of the project and therefore contributes to its overall worth. Open space valuation has been widely documented and previous case studies will be built upon for further inquiry into specifically the Rose Fitzgerald Kennedy Greenway's value. Further, the Greenway now serves as space for business pop-up activities and social outings. These sorts of events add value to the space that the elevated highway previously occupied and could not have been possible without the CA/T project's completion.

Ultimately, holistic accounting methods reflect a more accurate viewpoint of a project's worth. The CA/T project involves a multitude of aspects and avenues to evaluate, so a methodical approach to each factor's valuation would result in the most accurate reflection of the project's worth. Based upon these findings, the CA/T project may be painted in a new light. From this perspective, findings drawn here will enable recommendations for building similar highway tunnel projects as well as suggestions for relevant further research.

Methods

Evaluating the CA/T project's overall benefits involves setting boundaries to delineate relevant impacts affecting the project's worth. Many pertinent metrics were researched, and the appropriate variables were chosen based on their relevance and impact. Where decisions were made to include or omit certain factors, explanations are given to defend these positions below. The relevant metrics selected to be evaluated are as follows:

Table 1 Value Metrics and Associated Valuation Techniques

Metric	Valuation Technique
Construction/Materials/Labor	Existing Mass.gov DOT
Development	Hedonic Pricing Method
Emissions	EPA Cost of Carbon
Travel Time	Contingent Valuation
Rose Kennedy Greenway	Travel Cost Method, Existence Value

While some values such as construction materials and wages are tangible costs, other operations require alternative valuation techniques. Even within this murkier definition, services can further be classified into "use" and "non-use" values for evaluating indirect benefits. "Use values" refer to the direct benefits obtained by an end user, while "non-use values" are obtained through hypothetical benefits (Harris & Roach, 2013). For example, a consumer might place a non-use value on a public monument they will likely never visit, purely because they value its simple existence. For the purposes of this research, non-use benefits arise in the form of mere existence value: such as the value Bostonians attach to knowing the Greenway merely exists, as well as "bequest value": knowing air quality will be free of harmful pollutants for future generations (Harris & Roach, 2013).

Construction/Materials/Labor

As a relatively traditional accounting metric for infrastructure projects such as the Big Dig, overhead capital and labor have been estimated in escalating billions of dollars, depending on the year of evaluation. Costs grew immensely since the initial $2.6 billion estimation, and only approximations exist for what the actual final costs will be once the project is completely paid off (National Academic Press, 2003). In 2009, official final cost estimations rose to $14.78 billion, with subsequent years putting the number closer to $16 billion (Greiman & Warburton, 2009). More recently, projections have risen to $24.3 billion, once loans for its construction are completely paid off (Road Traffic Technology, 2012).

For the purposes of this research, an estimation of $24.3 billion will be used to represent the official costs of the Big Dig, under traditional accounting methods. The reasons for this are twofold: As the largest estimation for total costs, $24.3 billion enables a conservative means for comparison to benefits conferred. Also, this figure incorporates costs over a larger and more realistic time frame, which is more in line with the aims of this research. It is important to note that since total costs were estimated in 2012, all other costs and benefits will be converted into 2012 U.S. dollars.

Development

An important byproduct of the CA/T' project's completion was the opportunity for modest development along the path of the formerly raised highway. The resulting change in property values directly affected by the project serves as a gauge of the benefits and consequences associated with this opportunity. Tajima (2003) evaluated the change in property values along the central artery's corridor through the hedonic pricing method. Hedonic pricing is used to determine the price of a good, in this case a home, by way of statistical analysis in order to control for external factors (Harris & Roach, 2013). This model projected the total increase in property values from both demolition of the highway and construction of the Greenway to be $984 million, in 2000 dollars (Tajima, 2003). While the increase in property values would presumably continue for years to come, only the one-time annual value will be used in this study. Otherwise, too many independent variables could impact property values making it difficult to pinpoint the Greenway's sole contribution.

Avoided Emissions

To calculate the value of avoided emissions, the project's resulting decrease in daily traffic was used to obtain an equivalent benefit. Traffic data available directly before and after construction were used to calculate one-time annual benefits. Annual emissions would presumably follow this trend, but externalities such as population growth and business development could skew the volume of pollution and are therefore discounted. Because annual emissions reductions would presumably continue in the future, the valuation's classification as a conservative estimate is emphasized.

The EPA calculated the social cost of carbon and incorporated environmental, social and economic costs per metric ton of CO_2 (2016). This includes air quality valuation data, including health risks and effects of air pollution. Since costs will change over time, discount rates were attributed at 5%, 3%, and 2.5%. For this project, the 3% discount rate was used for data pertaining to the year 2010.

Table 2 The Social Cost of Carbon

Year	5% Average	**3% Average**	2.5% Average	High Impact (95th Pct at 3%)
2010	10	**31**	50	86
2015	11	**36**	56	105
2020	12	**42**	62	123
2025	14	**46**	68	138
2030	16	**50**	73	152
2035	18	**55**	78	168
2040	21	**60**	84	183
2045	23	**64**	89	197
2050	26	**69**	95	212

(Interagency Working Group on Social Cost of Greenhouse Gases, US Government, 2016).

The reduction in emissions as a result of the project was calculated using data from peak travel times in the morning and evening (2006). With increased traffic flow, fewer cars per hour were traveling on the highway. Morning peak travel volume was reduced by 1,010 average vehicles per hour, and evening peak travel was reduced by 2,183 vehicles per hour. (Economic Development Research Group, Inc., 2006). The EPA's social cost of carbon was then attributed to the reduction in vehicle hours on an annual basis.

Travel Time

Commuter willingness to pay for avoiding sitting in traffic has been estimated between $20-$40 per hour in urban environments where commuters tend to earn higher wages than the national average (Brownstone & Small, 2004). Since this is in line with Boston's demographic, this average value was used to estimate Boston consumer's willingness to pay. Using the travel time in minutes before and after the project, along with the average volume per hour, the added benefit calculation was based on the value of traveler time. The nature of this research provides benefit data via the revealed preference method, which indicates traveler willingness to pay

(Brownstone & Small, 2004). The use value placed on willingness to avoid sitting in traffic has been shown to be a reliable method for conveying traveler preferences (Brownstone & Small, 2004).

Rose Fitzgerald Kennedy Greenway

The Rose Fitzgerald Kennedy Greenway replaced the deconstructed elevated highway and has generated benefits for the downtown area. While the Greenway's effect on nearby property values has already been evaluated, the direct business and recreational values of the existence of the Greenway were considered relevant and necessitated evaluation. Every year since the Greenway's operational opening, the park has disclosed financial documents in the form of fiscal statements, tax documents and the Department of Transportation's allocation of funds (The Green Way, 2018). These annual fiscal statements outline the direct revenue generated by the Greenway, including leased space and nonprofit funds raised, less operating and capital expenses (The Green Way, 2018). The resulting net revenue represents the business generated by the Greenway through pop-up events and summer series, in-kind donations, and government support. Additionally, it incorporates the travel cost method for valuing Bostonian's willingness to pay for less tangible services like entertainment and recreation (Harris & Roach, 2013).

Goals & Outcomes

These individual sector valuations can be summed up to derive a final overall benefit value. The benefits, listed with line item components, are easily understood in a balance sheet format. Along with the caveat that this research supports Boston-specific circumstances surrounding the CA/T project, the final accounting of costs and benefits can provide insights for other cities and municipalities. Huge infrastructure undertakings require thorough inquiry, and with relatively few historical projects akin to something like the Big Dig, holistic cost accounting can be widely transferable and beneficial.

Results

Development

Hedonic pricing models estimate the price of real estate in downtown Boston, both before construction when properties abutted I-93, and after construction when houses and buildings lined the Greenway. This pricing method, controlling for external factors and implications, concludes that there was an increase in property value of $984 million, or $1,311,965,714 in 2012 dollars (Tajima, 2003) (US Inflation Calculator, 2018).

Table 3.1 Change in Property Values Directly Affected by CA/T Construction

	Value, in Millions	
Highway Demolition	$732	
Park Development	$252	
Total	$984	
Total Value in 2012		$1,311,965,714

Avoided Emissions

The annual volume of vehicles traveling in the downtown area of the Interstate decreased by 14,374 per day (Economic Development Research Group, Inc., 2006). This equates to a cost savings of $659,054.88 when comparing annual data before and after project completion, as seen below.

Table 3.2 Total Traffic and Cost Comparison

	1994-1995	2003-2005
Vehicle Volume/Day	168,383	154,009
Daily Miles Driven*	1,313,387.4	1,201,270.2
Annual Miles Driven	479,386,401	438,463,623
CO_2 Emissions (grams)**	193,672,106,004	177,139,303,692
CO_2 Emissions (Metric tons)	193,672	177,139
Social cost of emissions***	$6,972,192	$6,377,004
Total Saved		$ 595,188
Converted to 2012 dollars		$659,054.88

*Daily miles driven based on the 7.8 mile stretch of highway (Economic Development Research Group, Inc., 2006)
**CO_2 Emissions in grams derived from EPA: 404 grams CO_2 per mile (EPA, 2018)
***Derived from EPA Social Cost of Carbon (Interagency Working Group on Social Cost of Greenhouse Gases, US Government, 2016)

The average volume of emissions totaled just after construction represents the one time annual reduction in emissions and cost savings for just one year, as compared to available data the year before construction began. Presumably, vehicular traffic reductions will continue in some manner for the foreseeable future as a result of less constricted roadways. However, changes in variables such as population levels and business growth can influence the number of cars on an Interstate, therefore invalidating any causal relationship between artery burial and emissions reductions. As it stands, the calculated savings of $659,054.88 represent the least possible cost savings factor derived from the social and environmental cost of carbon.

Travel Time

Using an average of $30/hour value attributed to travelers' willingness to avoid traffic congestion, the total value of reduced traffic time for the new infrastructure exceeds $25 million (Brownstone & Small, 2004). Similar to the calculated value of avoided emissions, these data only apply to a single year. Too many independent variables affecting travel times would confound values for subsequent years, resulting in another conservative estimate for the value of commuter time savings.

Table 3.3 Cost of Traveler Time Spent in Traffic, Before (1994-1995) and After (2003-2005) CA/T Project

	Northbound		Southbound	
	1994-1995	2003-2005	1994-1995	2003-2005
Travel Time AM (minutes)*	3.3	2.4	4.1	2.8
Travel Time PM (minutes)*	19.5	2.8	8.5	2.8
AM Average Volume/Hour*	5,982	5,115	4,580	4,437
PM Average Volume/Hour*	6,615	5,269	4,285	3,448
AM Traffic Time (minutes)	19,741	12,276	18,778	12,424
PM Traffic Time (minutes)	128,993	14,753	36,423	9,654
Daily Traffic Time (minutes)	148,733	27,029	55,201	22,078
Annual Traffic Time (minutes)	37,332,008	6,784,329	13,855,326	5,541,578
Cost to Travelers**	$18,666,004.05	$3,392,164.6	$6,927,662.75	$2,770,789
Total Cost Before CA/T				$ 25,593,666.80
Total Cost After CA/T				$ 6,162,953.60
Total Savings				$ 19,430,713.20
Converted to 2012 dollars				$ 25,906,940.57

*Travel time on the Interstate during peak hours (Economic Development Research Group, Inc., 2006)
**The average cost of commuting is $30/hour; $0.50/minute (Brownstone & Small, 2004)
Annual traffic time based on 251 annual days of peak traffic hours
Pre-construction traffic measured during 1994 and 1995 by MA Highway Department, Post-construction traffic counts were measured in 2004, and Southbound traffic was measured in 2005 when Southbound lanes opened

Rose Fitzgerald Kennedy Greenway

Operating activities of the Rose Fitzgerald Kennedy Greenway started in 2009, but were fully underway in 2010, so 2010 is the first full year of reported data (The Green Way, 2018). The net earned revenue for each full year since the Greenway's creation totals over $4 million.

Table 3.4 Revenue Generated - Rose Fitzgerald Kennedy Greenway

Year	Net Revenue*
2009	$ -
2010	$ 75,358.00
2011	$ 112,318.00
2012	$ 168,766.00
2013	$ 206,301.00
2014	$ 578,124.00
2015	$ 1,142,095.00
2016	$ 956,687.00
2017	$ 1,188,861.00
Total	$ 4,428,510.00
Converted to 2012 dollars**	$ 4,261,823.77

*Earned Revenue reported from Greenway operating activities and business ventures (The Green Way, 2018)
**Each year's revenue has been individually converted into 2012 dollars and summed

Total

Table 3.5

Value of Non-Traditional Benefits Resulting from the Central/Artery Tunnel Project	
Metric	**Value**
Development	$ 1,311,965,714.00
Emissions	$ 659,054.88
Travel Time	$ 25,906,940.57
Greenway	$ 4,261,823.77
Total	**$ 1,342,793,533.22**

Whenever possible, estimations were based on complete data representing as much time as possible in order to reflect an accurate portrayal of total value. However, when confounding variables and factors enter the situation, the least possible value or time frame was chosen in order to ensure accuracy and negate bias. Therefore the resulting total of $1.34 billion represents a conservative and low-end estimate over the period of time directly before and directly after project construction.

Further, while most investments ideally result in positive return on investments (ROI), the nature of an undertaking like the CA/T project cannot be evaluated in traditional dollars and cents. The calculated return from this construction was originally intended to be abstract in nature as opposed to holding a concrete ROI (Road Traffic Technology, 2012). While the ROI may not serve appropriately in this capacity, the return *of* investment is notable. This can be calculated by computing the added value amount as a simple percentage of the total amount invested (or projected to be invested) in the project. To avoid confusion with the traditional term of Return on Investment, this will be referred to in this paper as 'Beneficial Return'. Compared to the most recent estimate of $24.3 billion, the calculated value of non-traditional services represents a Beneficial Return approximately equal to 5.5% of the amount invested in construction.

Table 3.6 Return of Investment, Using Multiple Project Cost Estimations Over Time

Year	Estimate	2012 dollars	Beneficial Return, using $1,342,793,533.22 value
1982	$ 2,800,000,000	$ 6,661,794,818.65	20.2%
2007	$ 14,600,000,000	$ 16,166,875,982.68	8.3%
2012		$ 24,300,000,000.00	5.5%

However, comparing the total economic value to the original cost estimate from 1982 had those costs remained as projected, the Beneficial Return results in a 20% yield. The original cost estimate did not prove accurate as time progressed for a multitude of reasons. Exploring these failures may shed light on why this estimate is erroneous, how Boston could have kept the final cost closer to predictions, and how future endeavors of a similar nature can avoid the pitfalls of the CA/T project's escalating costs.

Discussion

Initial Predictions and Cost Escalation

The CA/T project is notorious for its escalating costs and roadblocks, leading to construction delays and therefore further expenses. A Boston University study explored the Big Dig's hazards and downfalls (2010). This study concludes one of the leading causes of cost escalation was incomplete information regarding subsurface conditions, including inadequate mapping of utility lines, groundwater drainage, soil quality, and unanticipated archaeological circumstances. Due to these unknown variables related to subsurface conditions, the project then required workers to relocate 29 miles of underground utility lines and sewage pipes. The study cites another leading cause of increasing costs and delays as disorganization in relation to project integration with its stakeholders and separating construction from design. Thousands of stakeholders needed to be more fully integrated into the process, and the issue was further exacerbated by contracting builders being separated from contracting designers. Where construction projects should have been integrated, a lack of communication between these parties led to project deficits. The project's 110 major contracts often involved processes too complex to easily integrate with other plans. Further, the government oversaw both the regulation and the ownership of the Big Dig, forcing some managers to report to a governmental entity, while others reported to design and construction managers (Appel Knowledge Services, 2010).

In a hurry to get the project underway, pieces of the construction project were often started before officially approved, leading to additional costs of reworking contracts to stay on schedule (Gelinas, 2007). The $14 billion price tag revealed in 2007 was actually derived over 5 years previously, but was initially kept quiet from the public and inevitably lead to more deceit and holdups (Gelinas, 2007). Ultimately, many of these pitfalls center on the state's lack of experience regarding large infrastructure cost projects. The government, instead of assuming responsibility, risk, and costs of construction failures, attempted to pay an outside contractor to absorb blame (Gelinas, 2007).

Numerous specific reasons can account for the CA/T project's inaccurate cost estimation, but 'the critical cause was a lack of experience and knowledge' with handling complex projects of this size and scope (Appel Knowledge Services, 2010). Seemingly obvious, a project of this magnitude requires intense planning and project organization. Had the Big Dig been preceded by similar projects, it could have modeled its organizational scheme off of prior successes and failures and presumably avoided steep cost escalations.

Within the context of applying the Big Dig's lessons to other cities and their infrastructure projects, much can be gleaned from the project's organizational breakdowns. The main proponent for the project, in this case the government, should have assumed all responsibility for oversight, expenses, and blame. More attention should have been paid to meticulously planning individual projects and multiple contract integration before construction began. A design-build schema would have better integrated the organizational structure with specific design projects so the general contractors on the ground could have had the tools necessary for success on the first attempt.

With these upgrades in the foreground, other municipalities would be better suited to handle an artery burial project with less likelihood of unforeseen costs and environmental detriment. If the Big Dig had implemented such foresight, perhaps the initial cost estimates would have rung true, or at least the final costs would not have escalated over 400%. And had this been the case, the infamy over the CA/T project's failures and expense would have at least been tempered by accurate reporting, and the benefits could have been better received. Future projects will have the Big Dig's successes and failures to map progress against, and can aim to avoid similar cost escalations through lessons learned.

Framing Costs in a Larger Context

The Beneficial Return calculated for each cost estimation simply reflects the valued benefits as a function of the dollars poured into the project. It does not consider all of the unknown costs associated with a business-as-usual scenario. For example, the emissions avoided valuation compares one calendar year's worth of vehicle emissions before construction with one calendar year following the project's completion. If the project had not been undertaken, however, emissions presumably would have risen over time as Boston's population increased leading to more commuter traffic and associated emissions. Traffic was projected to deteriorate further with estimations of 16 hours of crawling congestion per day (Commonwealth of Massachusetts, 2018). Compared to the emissions associated with this level of daily traffic, the added value of avoided emissions calculated would presumably have been higher.

In this business-as-usual scenario, it is impossible to know with certainty how exactly vehicle traffic would have grown and affected emissions. To ensure an unbiased and factual study, these costs have not been estimated or included in the estimation of overall project worth. It is important to note that had they been roughly estimated and taken into consideration, value added would have grown for the overall worth of the CA/T project. Evidently, this gives further credence to considering the $1.34 billion valuation as a conservative estimate.

Instead of benchmarking the Beneficial Return against traditional accounting methods like Return on Investment or profit margin, the Beneficial Return can be viewed simply as value added. Negative publicity surrounding the CA/T project focuses primarily on the expense ($2.8 billion, $14.6 billion, or $24.3 billion, depending on the year). That being said, shifting the focus to the incorporation of understanding the benefits reaped from the Big Dig is enlightening. With a daunting expense such as $24.3 billion, the intangible social and environmental benefits pale in comparison. But when those benefits are framed in economic terms, the benefits seemingly rise from 0 to $1.34 billion.

Environmental Impact

Calculations that value the non-traditional facets of the Big Dig in economic terms should not diminish the less tangible environmental impact achieved by reducing carbon dioxide equivalents. This study drew the boundaries at valuing the impact of reduced vehicle emissions and open green space created, but the environmental implications for reducing emissions and sequestering carbon go beyond this scope.

The planet's warming atmosphere is linked to climate change, and in Boston the implications of climate change and associated rising sea levels are severe (Massachusetts Office of Coastal Zone Management, 2013). Boston sea levels are rising at an average rate of 0.11 inches per year, leading to tidal inundation, eroded shorelines, increased storm flooding, soil contaminations, threatened property developments, and habitat destruction (Massachusetts Office of Coastal Zone Management, 2013).

Because of Boston's location on the water, significant emphasis has been placed specifically on keeping rising sea levels to a minimum. The City of Boston has developed mitigation measures to reduce rising sea level threats posed by climate change, and in this context factoring in the environmental benefits of reducing emissions cannot be overlooked. While these are global issues and do not adhere to manmade state and country boundaries, Boston is still focused on addressing issues that pose the largest threats. Perhaps unintentionally, curbing the amount of time commuters were sitting on I-93 has had significant impacts on the city and state's welfare.

Further, this study evaluated the economic contributions of open green space as a proxy for the Greenway's value added by way of revenue generated on the Greenway and the impact of the project on property values. However, additional benefits would reward the City's environmental quality through carbon sequestration, reduced heat island effect, groundwater treatment and land connectivity. Other benefits linked to creating the open green space on the Greenway include increased job satisfaction and worker productivity, decreased air conditioning costs, and revived business districts, employment and tourism (Project Evergreen, 2018). Ostensibly, valuation techniques applied to the multitude of green space benefits would result in added monetary values annually.

The United States has one of the highest levels of carbon dioxide emissions in the world, second only to China (Union of Concerned Scientists, 2018). In 2015, the U.S. emitted 4,997.50 million metric tons of carbon dioxide attributed to fuel combustion, which makes up 15% of the world's total (Union of Concerned Scientists, 2018). With the U.S.'s high percentage of emissions relative to other countries, along with the Regional Greenhouse Gas Initiative calling for reduced emissions, projects that largely affect emission levels should take precedence in U.S. municipalities (The Regional Greenhouse Gas Initiative, 2018).

Climate change poses global threats to coastal cities like Boston as well as landlocked regions. Either way, the environmental impact of reducing traffic and vehicular emissions can garner impactful benefits in addition to social and economic implications. Every aspect of Sustainability's triple bottom line is integral to considerations involving highway artery burial. While the major proponents for large projects like the CA/T project are realistically economically-driven, environmentalists may take note of such undertakings and support artery burials as well for environmental reasons.

Conclusion

The implications of valuing social and environmental services are largely based on perspective. Through a traditional lens regarding federal and state funding, the CA/T project was an enormous expense and drain on public resources. Despite monetary benefits applicable to less tangible goods, the 400% escalation in costs can be viewed as an outright failure.

Altering the evaluation paradigm, however, concludes a more tempered perspective of the project and holds important implications for similar infrastructure undertakings. The initial goals of this research included possible cost benefit analyses, but these end results proved this kind of breakdown unrealistic. With the costs exorbitantly outweighing the benefits, the focus of the study shifted to simply evaluating benefits and framing the concept differently. Fortunately, this kind of research can be advantageous to a project where the costs are concrete but the benefits are traditionally intangible. With public perception largely viewing the benefits of the

Big Dig at no palpable value, the $1.34 billion price tag is seemingly impressive. Essentially, because the project did not calculate inherent benefits linked to monetary values, using an alternative approach to value those benefits gives the project something to work with where nothing existed before.

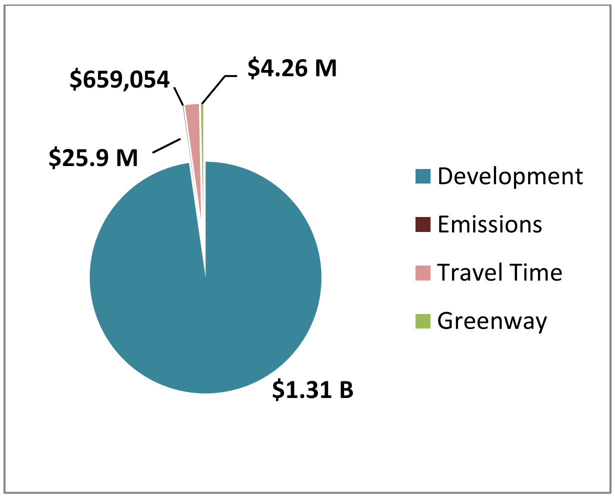
With a Beneficial Return of 5.5%, the Big Dig at least derived some notable positive outcomes, despite the disappointing cost to benefit ratio. However, if the lessons learned from the Big Dig's cost escalation are used to avoid such pitfalls in the future, the Beneficial Return would presumably increase. Indeed, had the Big Dig authority figures known how to circumvent avoidable snares through more oversight and organization, the costs could have remained near the original estimate. In this scenario, the derived Beneficial Return of 20% is noteworthy.

Reiterating the conservative nature of this study's final value attributed to the CA/T project's services, a 20% return factor poses the project as a more attractive case study. Barring difficulties transferring the CA/T project's operational tactics to other cities, project replication should model similar success rates at the 20% Beneficial Return threshold. In this sense, the 20% Beneficial Return could be used as a benchmark for endeavors of a similar size and scope.

An important conclusion to draw from this project is the likeness between the project's original economic proposal and the final valuation generated by holistic accounting. Framing all the costs and benefits back into economic terms brings the project full circle and allows for easy comparison between what the project was attempting to accomplish and the actual results. Comparing intangible benefits such as avoided traffic time to economic costs like materials and labor is not easily feasible, but through simple valuation techniques it can be made more viable.

Important to note is the amount that each metric contributed to overall total value. While the social and environmental byproduct benefits were almost certainly not a factor considered during the CA/T project's conception, studying what part the varying impacts each metric played is notable.

Figure 3 Breakdown of $1.34 Billion Benefit Components



The proxy value for the Rose Fitzgerald Kennedy Greenway itself is relatively small, but the Greenway's impact on abutting property values is prominent. The contribution that increased housing prices had on the overall value of the project dwarfs the contribution of the other factors combined. Inherently, homes and businesses facing a finely manicured greenway will generate more interest and drive real estate prices more than buildings that were facing a noisy elevated highway. While it is difficult to tease out the difference between the negative impacts of the elevated industrial highway on property values compared to the positive influence of the Greenway, the overall value added remains the same. In today's society, it is imperative to plan for large scale transportation methods for major metropolitan areas, but the effects that such arteries' appearances have on property values may be overlooked.

Recommendations

Many lessons can be ascertained by the results of this study. With the effects of social media and the ability for widespread conceptions to take hold, negative publicity surrounding a project like the Big Dig can hold a lot of weight. Because the CA/T project pioneered this kind of infrastructural scheme, it naturally can act as a case study for benchmarking other projects. At this point, other cities have not adopted similar highway burial projects, despite heavy congestion clogging roadways, detracting from business profitability, and increasing air pollution. Assuming the reason for lackluster project duplication elsewhere at least partially derives from the Big Dig's excessive expenses, the results of this study could influence large municipalities to reconsider these non-actions. While the monetary benefits may not outweigh the costs, it is still important to view the Big Dig through this renewed scope.

An important theme that operates parallel to this research is the linkage between economic incentives and environmental initiatives. Historically, environmental ventures have tended to be costly, leading to a dichotomy between environmental initiatives and the economic bottom line. But as sustainability and environmental awareness have grown in recent years, along with technological advances, environmental initiatives no longer necessarily automatically equate to a higher price tag.

The byproduct results of the CA/T project attest to this. The reduction in vehicle emissions, along with the carbon sequestered from the construction of the Greenway, contribute to environmental remediation, although this was presumably not a component in the original project plans. It stands to reason that environmental advocates might benefit from considering alternate routes to project completion. Different stakeholders can hold contrary motives for projects across the board, aside from and in addition to projects like the Big Dig. Stakeholders may be interested in profit margins, with little concern for a project's eco-conscience. In this scenario, it would behoove an environmentalist to value the project's untraditional benefits in economic terms. This can take a paradigm shift to get stakeholders on the same page, but it may convince different parties to desire similar goals despite different intentions.

In one sense, this paradigm shift introduces a new pathway not only to valuing environmental goods and services, but also to underlining the reasons a project should be granted funding in the first place. In another sense, however, evaluating the overall costs and benefits during project proposal is extremely traditional. The change is merely incorporating a more holistic accounting of costs and benefits, rather than a giant paradigm shift. Again, public perception of value plays a large role.

In terms of pushing projects through and securing backing or funding, it seems evident to keep the triple bottom line at the forefront. Traditional accounting techniques for a project's worth may not cover the entire value derived from a project. Including social and environmental pillars along with economic profits can make an undertaking seem more attractive, and presentation methods for project benefits can be aided by the use of untraditional techniques. Assigning a monetary value to environmental goods and services should be just as valid as specifying financial costs.

Notes for Construction Replication

If another government entity, whether federal, state, or city, decides to embark on a highway relocation project like the Big Dig, lessons learned from Boston could influence recommendations for new construction. First and foremost, the components of the intense cost escalations need to be addressed and mitigated. Operations should be streamlined during the planning stages, instead of waiting until construction is underway. With countless workers on jobsites, time is money and the cost of the project only increases as construction time is delayed. Also, project planners need to be upfront about project costs even if they are starting to exceed original estimations. Hiding unknown variables would likely lead to further time delays and frustration.

It seems like a major lesson learned from the CA/T project centers around ownership of project oversight and liability. With so many moving parts including contractors, designers, builders, and engineers, one entity would have plenty to coordinate and oversee. Adding in more managing entities overseeing operations could lead to miscommunications and could further exacerbate costs. Avoiding this pitfall, which the Big Dig fell victim to, would streamline construction and keep costs to a minimum.

The CA/T project also struggled to coordinate timing. Future projects, once complete oversight and organization has been implemented, should time individual construction projects across the board. With a project of this scope and size, many contractors and construction workers are likely to be involved. By enforcing strict start dates that follow official approval, as opposed to rash start times, would lead to a more favorable outcome than what transpired during the Big Dig.

Beyond aiming similar construction and infrastructure projects for a Beneficial Return of 20%, a realistic timeline and cost structure should be outlined. If the proper funding is amassed before construction commences, fewer roadblocks will pose threats to the project’s completion time. Fewer time delays, cost escalations, organizational failures, and unrealistic expectations will set the stage for a more successful undertaking.

Limitations and further research

There are many unknown variables associated with inferring benefits in business-as-usual scenarios that differ from historical events. This research has incorporated the unknown nature related to how the I-93 burial affected multiple years of emissions related data, as reiterated in the Methods and Discussion sections above. More unknown variables to consider, however, also reside in the assumption of the business-as-usual scenario. Population increases, fuel prices, consumer trends, public perception, and business development are just a few examples of unknown variables and how they might have affected the Big Dig's subsequent years of traveler data. Further research conducted in future studies might consider these factors for controlling case study data and adding credence to the causal relationship between increased highway lanes and emissions from idling cars.

Another limitation to this research is the abundance of services that could be valued and monetized for a more holistic account. It could be argued that factors such as noise pollution, land connectivity, heat island effect, wildlife disruption, food chain effects, and urban population influx all hold some extent of the costs or benefits that contribute to the CA/T project's value. From this standpoint, future studies could explore valuation methods for these variables as well. This kind of thinking is akin to the attributes that make up Scope I, II, and III emissions (World Resources Institute, 2004). Scope I and II emissions have concrete definitions, but Scope III emissions incorporate supply chain players, specifically in relation to solid waste disposal (World Resources Institute, 2004). While this boundary has been drawn as clearly as possible, it still leaves a fair amount of boundary delineation up to the reporting agency. Similarly, evaluating the total economic value of a project like the Big Dig requires boundaries to be drawn where deemed most sensible. Life cycle analyses pose similar challenges which can also be circumvented by clearly stating boundaries with logical explanations. While in many cases the cascading effects of downstream supply chain management may seem endless, effectively stated boundaries lead to the most useful results. Future studies would do well to keep this at the forefront, while attempting to incorporate as many relevant variables as deemed fit.

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APPENDICES

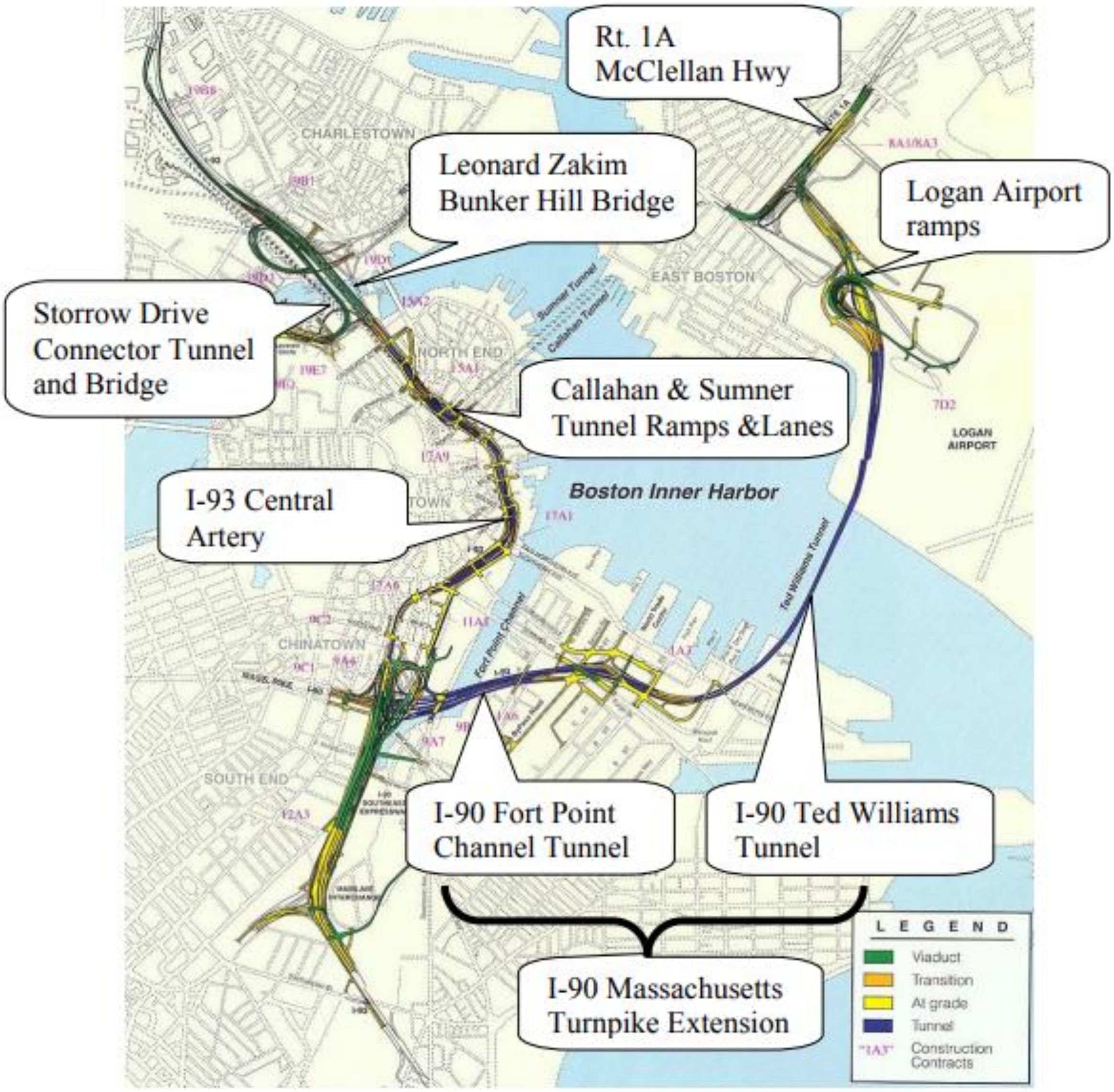
APPENDIX A: CA/T Project Effects on Property Values

Hedonic Regressions: Highway Variables Before and After the Big Dig

	Model I		Model II	
Variables	Coefficient	Standard Error	Coefficient	Standard Error
ln(area)	0.979	0.009*	0.973	0.009*
ln(rooms)	0.068	0.009*	0.073	0.009*
ln(bath rooms)	0.102	0.010*	0.104	0.010*
Dummy = 1 if:				
Owner-occupied	0.039	0.005*	0.039	0.005*
with parking	0.136	0.006*	0.136	0.006*
with a fire place	0.091	0.006*	0.091	0.006*
ln(building age)	−0.063	0.005*	−0.064	0.005*
ln(residential units)	−0.053	0.003*	−0.054	0.003*
ln (Distance) from:				
large park	−0.085	0.004*	−0.085	0.004*
small park	−0.046	0.005*	−0.043	0.005*
Charles River	−0.165	0.005*	−0.165	0.005*
harbor	−0.031	0.009*	−0.051	0.009*
highway (before the Big Dig)	0.064	0.006*		
highway (after the Big Dig)			0.080	0.007*
Subway	−0.103	0.008*	−0.098	0.008*
Dummy = 1 if zip code is:				
02108	0.228	0.014*	0.223	0.014*
02109	0.108	0.023*	0.027	0.024
02110	0.478	0.029*	0.314	0.031*
02111	0.082	0.018*	0.080	0.018*
02113	−0.136	0.021*	−0.186	0.020*
02114	−0.004	0.014	−0.008	0.014
02115	−0.035	0.013*	−0.014	0.014
02116	0.187	0.011*	0.201	0.012*
Constant	7.959	0.144*	7.987	0.142*
Adjusted R-squared	0.823		0.823	
Number of observations	16,044		16,044	

Note. Summary statistics of highway after the Big Dig: mean = 685.64, std. dev. = 290.57, min = 60, and max = 1300.
The dependent variable is natural log of the assessed value of condominium unit (in dollars).
The omitted zip code is "02118."
*$p < .01$.
Source: City of Boston, Property Assessing Data, 2000.

APPENDIX B: Central Artery/Tunnel Project Infrastructure



(Economic Development Research Group, Inc., 2006)

APPENDIX C: Traffic Patterns Before and After CA/T Project

Measures of Highway Use and Speed/Time Performance	Pre-Construction 1994-1995 [A]	Post-Construction 2003-2005 [B]	Absolute Change	Percent Change
	Old Elevated Route	*New Underground Route*		
(A) Total Daily Traffic				
Northbound (1.7 miles)				
Average Volume/Day	96,656	83,671	-12,985	-13.4%
Southbound (1.7 miles)				
Average Volume/Day	71,727	70,339	-1,388	-1.9%
Total Northbound + Southbound				
Average Volume/Day	168,383	154,009	-14,374	-8.5%
(B) Peak Hour Traffic**				
Northbound (1.7 miles)				
AM Peak Hour (7-8 am)				
Travel Time (minutes)	3.3	2.4	-0.9	-26.2%
Average Volume/Hour	5,982	5,115	-867	-14.5%
PM Peak Hour (3-4 pm)				
Travel Time (minutes)	19.5	2.8	-16.7	-85.6%
Average Volume/Hour	6,615	5,269	-1,346	-20.4%
Southbound (1.7 miles)				
AM Peak Hour (7-8 am)				
Travel Time (minutes)	4.1	2.8*	-1.3	-31.7%
Average Volume/Hour	4,580	4,437	-143	-3.1%
PM Peak Hour (3-4 pm)				
Travel Time (minutes)	8.5	2.8	-5.7	-67.1%
Average Volume/Hour	4,285	3,448	-837	-19.5%

[A] *Pre-construction traffic counts and travel times were measured during 1994 and 1995 by staff of the Massachusetts Highway Department (MHD) and published by the Central Transportation Planning Staff (CTPS).*

[B] *Post construction traffic counts were measured by a combination of MHD and Central Artery/Tunnel Project (CA/T) staff during 2004; the travel times were measured by CA/T staff during 2004 except for southbound times which were not measured until 2005 when all southbound lanes were opened.*
** denotes consultant estimate.*

(Economic Development Research Group, Inc., 2006)