Boston's Big Break

ADDRESSING THE MBTA COMMUTER RAIL SERVICE GAP IN DOWNTOWN BOSTON

Trent Joseph Chinnaswamy
THE FRANK BATTEN SCHOOL OF LEADERSHIP AND PUBLIC POLICY | CHARLOTTESVILLE, VA

Table of Contents

Acknowledgements

This document is the result of not only many hours and days of analysis but years spent commuting on the MBTA. Without the Commuter Rail, many of the opportunities that delivered me to where I am today would have been far out of reach. I would like to thank the many transit workers that made my education and love for the City of Boston possible.

This report is also the result of many hours of work completed against the odds of the current pandemic. I would like to thank Professor Wyckoff for his understanding and flexibility, Lucy Hopkins and Nick Flanagan for their endless support, and the Range for being a home and place of calm during tumultuous times. Policy is everywhere, lead from anywhere.

Disclaimer

The author conducted this study as part of the program of professional education at the Frank Batten School of Leadership and Public Policy, University of Virginia. This paper is submitted in partial fulfillment of the course requirements for the Master of Public Policy degree. The judgments and conclusions are solely those of the author, and are not necessarily endorsed by the Batten School, by the University of Virginia, or by any other entity.

List of Acronyms

MBTA- Massachusetts Bay Transportation Authority
NSRL- North-South Rail Link
FTA- Federal Transit Administration
MassDOT- Massachusetts Department of Transportation
GHG- Greenhouse Gases
FMCB- Fiscal Management and Control Board
SCR- South Coast Rail
GLX- Green Line Expansion
SSX- South Station Expansion
TBM- Tunnel Boring Machine
LIRR- Long Island Railroad
MTA- Metropolitan Transportation Administration
SEPTA- Southeastern Pennsylvania Transportation Authority

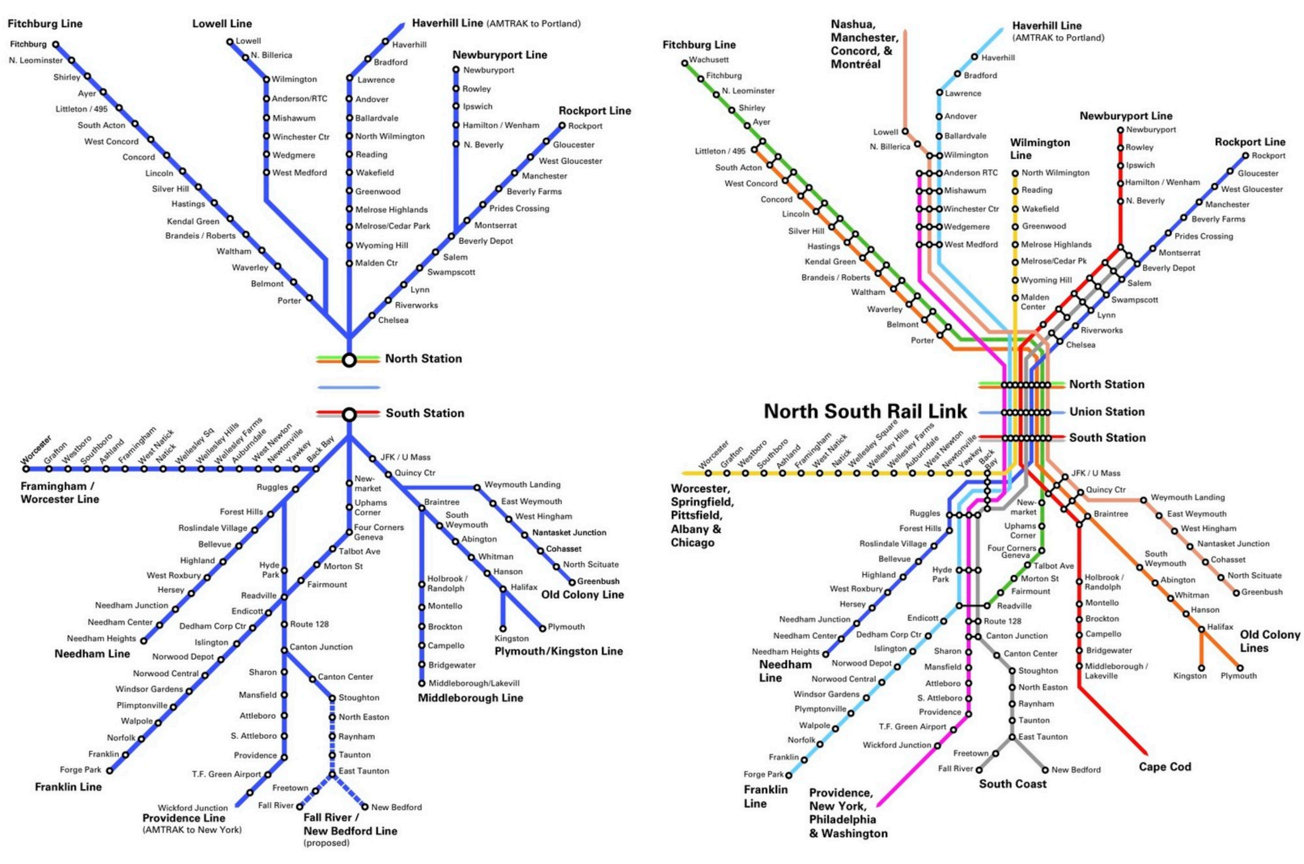
Executive Summary

Commuters looking to travel by regional rail into Boston, otherwise known as the Commuter Rail, can only travel as far as the stub-end terminals on the northern and southern side of the central business district. Between them is a one-mile gap that prevents commuters from travelling deeper into downtown or through the city. Boston and Massachusetts planners have proposed linking the two stations via tunnel for decades, and recent advocacy has brought this idea back into the forefront of planning considerations for the Commonwealth.

The Commuter Rail and MBTA are in dire need of massive investment in order to better serve residents and their core mission of linking the Boston metro area with an affordable public transit alternative. A rail link tunnel between North Station and South Station may provide greater accessibility and spur rapid growth in Boston, but the investment and maintenance required for such a tunnel are not feasible or worth their return. **This analysis concludes that the Massachusetts Department of Transit should no longer consider a North-South Rail Link tunnel and instead implement a Transit System Management alternative alongside further investigation into system capacity upgrades.**

The Transit System Management alternative is a bus shuttle connecting North Station and South Station and allowing travelers to commute between the stub-end terminals with only one transfer.

Figure 1: Current System Versus Proposed North-South Rail Link. Reprinted from Citizens for the North-South Rail Link, 2017



Scope

This report will provide a cost-benefit analysis of a North-South Rail Link connecting North and South Stations from the Massachusetts Department of Transportation's scope. All figures are in 2015 dollars. Costs and benefits accrued will only be incorporated if they directly affect Massachusetts Department of Transportation (MassDOT) funding, revenue, expenditures, or involve non-market values within the realm of MassDOT. These include travel time and externalities from transportation in the Commonwealth.

Background

In matters of transit, Boston is a city divided. Despite having the fourth largest geographic reach of any rail system in the United states, a one-mile gap between the city's Commuter Rail terminals, North and South Stations, prevents easy through-travel by rail. (Federal Transit Administration, 2009) Travelling between the terminals requires the use of two subway lines or a 30-minute walk, reducing accessibility for those fully reliant on public transit and diminishing incentives for those looking to avoid the region's congested roadways. In many cases, the time required to travel from the outlying cities into Boston is equivalent to the time required to travel the distance between the terminals.

The accessibility of transit has led to the growth of two different labor markets in the Boston region, as shown by figure 2. The business centers reached within 15 minutes by foot or transit from North and South Stations, respectively, have shockingly little overlap despite serving entirely different populations in the outlying suburbs and cities north and south of Boston. (Massachusetts Department of Transportation, 2018) Workers trying to work in the fastest growing business district, the Seaport, (BPDA Research Division, 2018) and the fastest growing community, Chelsea, (Baskin, 2019) have their housing choices cut in half by transit access. Residents trying to access both areas have driven up prices for the city's housing stock, causing rapid gentrification and displacement. (AbdelAlim, 2019)

Figure 2: Accessibility from North Station and South Station. Reprinted from 'North South Rail Link Feasibility Assessment', by MassDOT, 2018

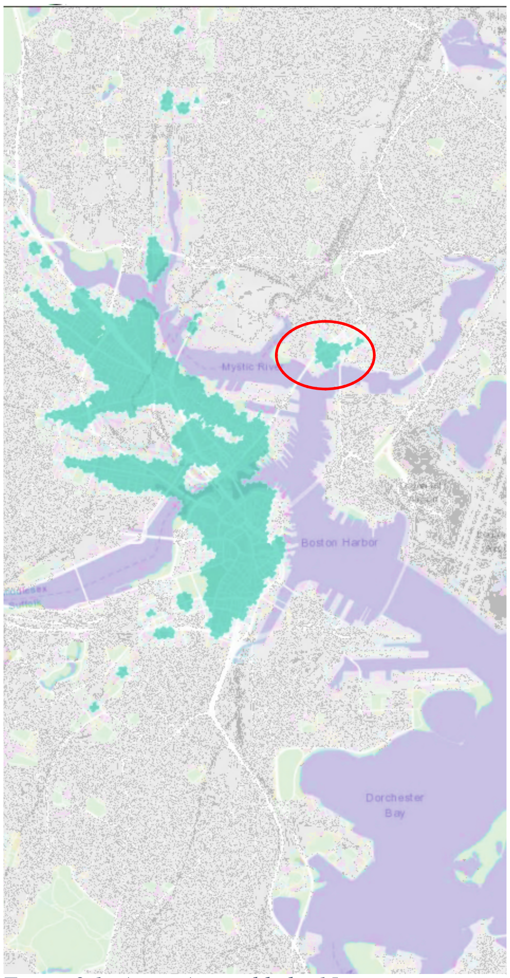


Figure 2.1: Areas Accessible by 15-minute walk/transit from North Station, Chelsea highlighted

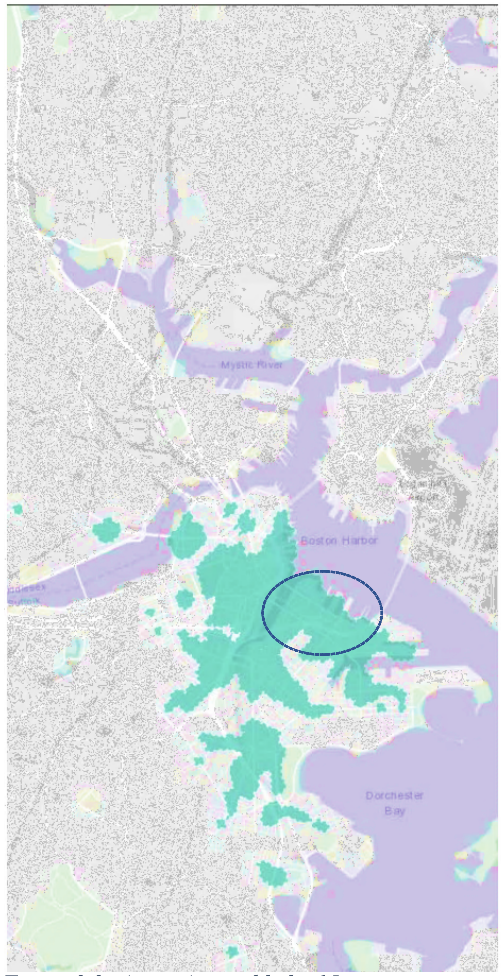


Figure 2.2: Areas Accessible by 15-minute walk/transit from South Station, Seaport District highlighted.

This gap also cuts off most of New England from the nation's most popular rail route, the Northeast Corridor, preventing economic links and encouraging travel by less efficient means. While this is a minor concern for Massachusetts, it has led to the growth of a wide coalition of support for a rail link across the region.

As the Seaport District and other parts of Boston have rapidly developed, more commuters are driving into downtown. Due to high real estate prices in the city, many developers have resorted to building along the Bay Area's ring roads, particularly Route 128. These trends have combined to make auto commutes longer no matter where residents live or work. This has tangible consequences for quality of life—23% of the area's workers have considered leaving the area to find a shorter commute. A majority of voters believe that without more frequent and reliable public transit, the region will near an economic breaking point due to traffic congestion. (The MassINC Polling Group, 2019) Current public transit is not efficient enough to incentivize commuting by rail—trips on the Commuter Rail in 2018 were the lowest in the millennium. (Sullivan G. , 2019)

Current transportation trends show the Commonwealth moving farther from its greenhouse gas (GHG) emissions targets. Although improvements in clean energy production and a decrease in manufacturing has helped the Commonwealth decrease total emissions, emissions from transportation are at their highest levels ever recorded. (Executive Office of Energy and Environmental Affairs, 2017) If they continue to increase or remain constant, it is highly unlikely the Commonwealth will meet its goal of a 25% GHG reduction from the 1990 baseline by 2020, or an 80% reduction by 2050. (Global Warming Solutions Act, 2008) These emissions are primarily created by roadway travel. A comparison done in North Carolina equated a 44-94% drop in carbon dioxide and carbon monoxide emissions per traveler switching from passenger car to commuter train. (Graver & Frey, 2016) In order to meet its stated goals, the Commonwealth needs to invest in moving residents out of cars and into rail coaches.

The gap in transit service between North and South Stations reduces the mobility of the region's workforce, disconnects New England from through service on Amtrak, and maintains incentives for residents to travel by less efficient means.

History

The concept for a tunnel between Boston's two transportation terminals is more than a century old. In the late 1800s, the numerous rail companies that operated one or two lines of track began to consolidate until only two remained—The Old Colony Line run by J.P. Morgan and Boston & Maine Railroad. In a compromise, the two firms drew an east-west line across the city to mark their operating territories. Next, each of the rail services consolidated their networks to have a main terminal hub in the city—North and South Stations. (Fowler Jr., 2000) Even then, future-thinking city planners floated the idea of a link. At this time, there was a direct elevated subway line connecting the terminals, but city planners saw a bifurcated transit system as too costly for freight and passengers. In 1912, the City of Boston, in conjunction with the Commonwealth Legislature and railroad companies, discussed the issue with the public. Soon, a world war and the Great Depression left the ideas tabled indefinitely. In the 1960s, the Massachusetts government acquired the Commonwealth's rail lines from bankruptcy and started to operate them as publicly subsidized transit under the Massachusetts Bay Transit Authority (MBTA).

For a moment, a rail link tunnel seemed possible again in the early 1980s as The Central Artery/Tunnel Project, otherwise known as "the Big Dig", planned to bury the interstate highway system under Boston's central business district. Despite his own personal desires, Governor Dukakis was required to drop the rail link from the proposal in order to acquire a greater share of federal funding for auto tunnels. Since the end of his terms in 1991, Gov. Dukakis has been the foremost advocate for the reconsideration and implementation of a rail link between North and South Stations, even joining with his successor from the opposing party, Gov. Weld.

Under Governor Weld's administration, the Central Artery Rail Link Task Force spent a decade crafting a Draft Environmental Impact Report (DEIR). The report found modest but positive benefits from a tunnel by increasing rail ridership, decreasing car traffic, and speeding up commuting times. (Massachusetts Bay Transit Authority, 2003) Released in 2003 under the newly elected administration of Governor Romney, the report was buried under the wave of resentment against the increasingly delayed and expensive completion of the Big Dig.

In 2014, Governor Baker was elected on a platform of modernizing the Massachusetts Bay Transit Authority (MBTA) that oversees public transit in the Commonwealth. As ambitious and expensive projects such as South Coast Rail (SCR) and the Greenline Expansion (GLX) have been approved for initial construction, advocates for a rail link between North and South Stations were encouraged once again. Responding to public support, the Baker Administration acquired $10 million from the legislature for a feasibility reassessment of the North-South Rail Link (NSRL). Once again, there may be a chance to cross the invisible line drawn by railroad tycoons in the late 1800s.

The MBTA

The Commuter Rail has been in financial trouble for nearly a decade. Billions of dollars of capital investment, meant to modernize the train system, has been funneled into either paying interest on debts or funding everyday operational costs. (Governor's Special Panel to Review the MBTA, 2015) The system's aging diesel trains require an increasing amount of maintenance. From 2008 to 2013, the annual cost to run each vehicle increased by 73.5%, despite running nearly the same distance. (Sullivan & Stergios, 2015) While the Commonwealth and MBTA have borne the majority of this cost, ticket prices have regularly increased near their legal limit of seven percent every two years. For low-income residents in the cities surrounding Boston, commuting to work on the Commuter Rail is simply infeasible, as prices range from $7.00-12.25 each way. A daily commute from these regions into Boston can soak up 6-15% of the median American income, or nearly two hours of pay each day for minimum wage workers. (Haney, Corley, & Forman, 2019)

Even as travel on the MBTA has remained unreliable and becomes increasingly expensive, many residents rely on it out of necessity. 25% of those who ride the MBTA don't have access to a car or another form of transportation, leaving them unconnected to employment, healthcare, and ordinary services when delays or closures make travel inaccessible. (Flynn, 2017) Public transit is too crucial for the Commonwealth to let it fail.

Present State of Affairs

In the aftermath of the 2014-2015 winter storms which crippled the Commonwealth's transit system, Governor Charlie Baker made massive changes to the operational structure of the MBTA. Partnering with transit stakeholders and the state legislature, he temporarily replaced the Massachusetts Department of Transportation (MassDOT) Board with the Fiscal and Management Control Board to conduct a thorough analysis of the system's failures. Currently, the FMCB and the MassDOT Board of Directors jointly oversee all of the MBTA's contracting and planning. The Commuter Rail is currently operating under an eight-year contract by the French corporation Keolis, which is set to expire in 2022. MassDOT CEO Stephanie Pollack has publicly stated that this contract will not be extended. (Mohl, 2019)

In addition to more changes in organizational structure, the Governor and FMCB set out a two-stage capital investment plan on five- and twenty-year guidelines. Over 9 billion dollars have been raised, with more available if communities wish to approve more bonds. MassDOT created the "Rail Vision" project to reevaluate the Commonwealth's goals for the Commuter Rail, including the type of service and technology. (Massachusetts Bay Transit Authority, 2019) All of the Build Conditions under Rail Vision include a NSRL or the alternative South Station Expansion (SSX) in order to increase the number of headways possible from the at-capacity south terminal.

It has become clear that the Baker administration prefers the SSX over the NSRL from his past comments. He has also refused to meet with former Governors Weld and Dukakis to discuss the proposal. (Chesto, 2016) Research into a rail link tunnel has been championed by the former Governors, both U.S. Senators from Massachusetts, the Speaker of the Massachusetts House of Representatives, and 10 U.S. House Representatives from across New England. (McNichol, 2019)

Comparable Projects

The Philadelphia Center City Commuter Connection

By the end of the 1960s, Philadelphia's rail lines mirrored the history of those in Boston. Ownership of tracks was split to the West and North between the Pennsylvania and Philadelphia & Reading railroad companies. Each company's trains terminated at stub-end stations on the edge of downtown, 1.7 miles apart. Debt-ridden, rights to the rail lines were acquired by the state between 1963-1983 and converted into the Southeastern Pennsylvania Transportation Authority (SEPTA).

Even before full state acquisition, city planners were desperate to connect the two rail lines by tunnel in order to enhance development in the region. Proposals for federal funding were sent in 1964, immediately after the U.S. Congress created what is now known as the Federal Transit Administration (FTA). The proposal remained in Washington without answer until the federal agency revised its rules to allow for greater investment of funds into urban renewal projects. After eleven years, funding was approved, and construction began in 1978. The project was extremely controversial at the time, opposed by numerous community groups who attempted to stop development through the courts. Despite the backlash, Mayor Rizzo championed the project throughout his terms, 1972-1980. (Ujifusa, 2008)

Completed in 1984, the project cost 330 million dollars, 80% of which was paid by the federal government. The finished tunnel featured four tracks and a new station between the terminals capable of moving 80 trains through per hour at maximum capacity. Joining with other economic forces, the Center City Commuter Connection helped spur a new round of development in Philadelphia's downtown. Today, 650 trains pass through the tunnel per day, more than twice that of South station, which is at maximum capacity with three times as many tracks. (Kyriakodis, 2014) Through-travel also allows SEPTA to run far fewer expensive deadhead (non-revenue fleet reorganization) trips in the city center.

Philadelphia's Center City Commuter Connection is not a perfect comparison to the proposed NSRL, particularly in technology and context. At the time, SEPTA was already operating full-electric commuter rail service on a more frequent schedule than the MBTA's Commuter Rail. Construction on the tunnel was done in the disruptive "cut and cover" model first used to create subways in the 1890s. Builders would empty sections of the city, cut tunnels 30-70 feet deep, and then cover roadways with temporary planks. (Urban Mass Transit Administration, 1973) Additionally, this construction was done during the OPEC oil blockade, which refocused national attention on public transit as gasoline prices soared.

Still, the Center City Commuter Connection provides a valuable historical model for effectively linking a city's rail system. Most importantly, it demonstrates a possible timeline and funding procurement method for the NSRL. At the time, the project was the largest transit investment ever made by the federal government, and it set the precedent used today for joint federal-state-locality transit investment.

New York City East Side Access

The most recent effort to link a city's terminals is occurring just a few hours south of Boston under the East River between Manhattan and Queens. Nearing completion, the East Side Access project will continue service on the Long Island Rail Road (LIRR) to Grand Central Station by way of an eight track-eight mile-tunnel. This project is intended to serve both strategic and accessibility concerns for New York City. In retro-analysis of both the September 11th terrorist attacks and flooding from Superstorm Sandy demonstrated the need for an additional route of entry and exit to Manhattan across the East River for emergencies. (Ain, 2001) Current routes on the LIRR are over capacity entering and leaving Penn Station at peak hours. Surveys of commuters found that many of the 269,000 daily riders on the LIRR work on the East Side near Grand Central Station. (Metropolitan Transportation Authority, 2001) Allowing them to ride directly there would save 40 minutes of travel time per person each way every compared to disembarking at Penn Station and back-commuting. (MTA, 2018)

This project has been under scrutiny for decades due to budget, timeline, and safety concerns. While initial projects intended for service to begin in 2009 for $4.3 Billion, (Hawkins & O'Kane, 2015) delays and other difficulties have moved the expected opening to late 2022/early 2023 for a total of $11.1 billion. (MTA, 2018) A structural collapse killed a construction worker in 2011, and a number of other workers have been injured on the job. (Kates, 2011) The project has become notorious for regular safety violation reports. (Grynbaum & Haughney, 2011) For many in Boston, these issues of cost and accident awake fears from the Big Dig, and provide enough reason to avoid even proposals for the NSRL.

Despite its many issues, this project also demonstrates the potential of new technology and infrastructure reducing time and costs. Unlike projects such as the Big Dig and the Center City Commuter Connection, much this project is not being excavated in the old "cut and cover" method. The East Side Access project is instead making use of recent advances in Tunnel Boring Machines (TBMs). These monstrous machines are capable of digging through any ground material at a previously impossible rate, all while building their own support tunnel around them. Excavated material is carried on beltways or through pipes back to the surface. With these machines, workers only need to excavate emergency and ventilation shafts with controlled explosives. For the caverns needed to construct stations, workers run the TBMs through an area multiple times, digging bores side by side or on top of one another. Using explosives, workers then break between bores, opening a massive space. Excavated tunnels and caverns are then sprayed with shotcrete (instant concrete capable of being forced through hoses at high pressure) and covered with plastic waterproofing. (MTA, 2018) This process can be repeated for more waterlogged ground.

The East Side Access project is also attempting to make use of the private-public partnerships that have made transit systems in Singapore and Hong Kong self-funding. The new LIRR concourse being built stories underneath Grand Central Station will feature 25,000 square feet of retail space, critically located beneath some of the world's most expensive real estate and with passing foot traffic of hundreds of thousands per day. (MTA, 2018) While including this space increases the overall complexity and cost of the project, rents from tenants will hopefully offset and surpass these costs to help provide much-needed revenue for the Metropolitan Transportation Authority (MTA).

Transformative Transit-Oriented Development

A NSRL will not just affect the City of Boston, but increase the accessibility of the entire region. This is critical for the Gateway Cities that have suffered despite Boston's rapid growth. These twenty-six mid-sized cities serve as the anchors of localized economies in Massachusetts, but have suffered from disinvestment and factory closures for decades. Their distance to Boston is both their greatest weakness and greatest opportunity for growth. When mid-level cities remain unconnected to high concentrations of development, this accelerates their decline. This is known as falling into the "agglomeration shadow." (Burger, Meijers, Hoogerbrugge, & Tressera, 2015) If two identical, competing businesses chose to locate in different locations—one in an agglomerated center and the other in an unconnected mid-level city, one could predict the dominance of the former over the latter simply by location. A connected, highly developed business center offers a large and skilled workforce, quality amenities for employees living in the area, and centers of research—either private businesses or universities. These components help the business provide a superior products or service, and customers are more likely to find and connect with firms in top-tier cities, increasing revenues. Without the same connections to workforce, inputs, and the market, the mid-level city competitor is bound to fall behind.

Measured on a macro scale, this is part of the reason why recent gains in the United States' GDP have been limited to only a few highly-developed counties. (Muro & Whiton, 2018)

Linking North and South Stations will enable greater regional travel through Massachusetts and decrease commute times for residents in the Gateway Cities to work in Boston. The effect of agglomeration is not measured by distance but the perceived and real time required to travel between points A and B. If the commute between is roughly one hour or less, the effects of a highly-developed business center can spread to mid-level cities surrounding. (Angel & Blei, 2016) This can allow mid-level cities to gain access to a richer workforce population and greater market access. At the same time, top-tier cities can access the cheap real estate and relatively cheap labor of mid-size cities. This effect is known as "borrowed size" and "borrowed performance" and its theoretical potential is enormous. In an ideal world, mid-level cities could use the talent, research, amenities, and greater connection of a top-tier city. Meanwhile, the core city could then settle more of its workforce outside of its borders, decreasing the cost of living within. In the long run, the core city could also benefit from the surrounding firms as they mature and spread their reach. (Meijers & Burger, 2015) These development effects have led over 30 regional mayors to approve the NSRL as an investment in their own communities. (McNichol, 2019)

Alternatives

In accordance with the Federal Transit Administration's funding evaluation process, four alternatives will be considered: status quo, transit system management (TSM), and two build alternatives. Under Rail Vision, a NSRL is only being considered alongside a full electrification of the Commuter Rail. For this analysis, it will be assumed that the MBTA has transferred to full use of Electrical Multiple Unit (EMU) cars, similar to the subway cars used on the Red, Blue, and Orange lines but with a larger passenger capacity.

1. Transit System Management (TSM)

The TSM alternative is a bus shuttle from North to South Stations operating along Atlantic Ave. Bus fare will be the standard for the MBTA of $1.70 per ride. 2 diesel-hybrid 40-foot buses will be acquired to operate the shuttle. 4 additional bus drivers will be hired at the standard MBTA salary. Service will operate from 5 AM to 1 AM with an average of 3 headways per hour, or 60 headways per day.

2. Minimum Build (2 Tracks, 2 Stations)

- NSRL Corridor length: 2.788 miles
- Number of tracks: 2
- Number of tunnels: 1

- Number of underground stations: 2
    - North Station
    - South Station
- Construction period: 1/1/2022-12/30/2027
- Revenue service start date: 1/1/2028

3. Maximum Build (4 Tracks, 3 Stations)

- NSRL Corridor length: 2.958 miles
- Number of tracks: 4
- Number of tunnels: 2
- Number of underground stations: 3
    - North Station
    - Union Station (located near the Aquarium station on the Blue Line)
    - South Station
- Construction period: 1/1/2022-12/30/2027
- Revenue service start date: 1/1/2028

Build Alternatives

Construction parameters have been adopted from the 2003 DEIR report on the NSRL. (Massachusetts Bay Transit Authority, 2003) Regardless of size or additional station, the proposed tunnel will have entrances at Back Bay Station, in between JFK/UMASS and South Stations, and across the Charles River from North Station. The tunnel would follow alongside the Central Artery Tunnels, I-95 and I-90. See Figure 3 for a map of this proposed route. The tunnels will be constructed using a Mixed Shield Tunnel Boring Machine. Electricity will be delivered to cars through an overhead (catenary) wiring system.

4. Status Quo

The status quo alternative will assume present trends from the past decade will continue. This includes the capital investments currently underway, but no other changes to service and technology on the Commuter Rail. Notably, this may include the future construction of the South Station Expansion Project (SSX). Too few details have been proposed for the SSX to reasonably compare it to the NSRL. For this analysis, endorsement of the status quo includes recommending further investigation into the SSX proposal.

Figure 3: Proposed Alignment of North-South Rail Link, reprinted from Citizens for the North South Rail Link, 2017

Criteria

Efficiency (Cost-Benefits Ratio)

This criterion will evaluate each alternative by its relative ratio of costs and benefits compared the status quo alternative. Given the limited scope of the analysis, those falling below a ratio of 1 are not immediately eliminated but will be weighted accordingly. This criterion will be measured quantitatively using a cost-benefit analysis and qualitatively given the quality of the underlying assumptions for each alternative. In accordance with MassDOT standard practice, all measures will be relative to the status quo alternative rather than in absolute values.

Feasibility

This criterion evaluates the probability of the alternative's implementation given the current political environment. This is combination of factors, primarily cost and public approval for each measure. This criterion is measured through public polling and surveys, statements of commitment from elected officials, and MassDOT's capacity to fund each alternative.

System Capacity

This criterion evaluates the peak capacity of the Commuter Rail system for each alternative. This is a major measure of the system's long-term growth potential and a minor measure of the system's ability to recover from a shock, such as a mechanical failure or natural disaster.

Evaluation

Transit System Management

Benefit-cost analysis for the TSM alternative was conducted using a financial spreadsheet model. Assumptions were originally taken from the 2003 MassDOT DEIR and updated to reflect the current technology and service of the MBTA. Three cost categories were used: capital acquisition, maintenance, personnel, and externalities from emissions. Two benefit categories were used: fare revenue and time savings. The net result was a benefit of $5,512,389 over the period of 2020-2040. At 2.01, this alternative had the only benefit-cost ratio over 1 and was significantly higher than the build alternatives.

This alternative is highly feasible. It requires no legislative or executive approval and has costs within the operating margins of the current MBTA system. Buses can use the existing bus connection stations at North and South Stations.

The TSM alternative makes no changes to the capacity of the Commuter Rail system. It is possible that the shuttle between North and South Station may alleviate congestion on the connecting subway lines, but the effect is assumed to be negligible given its estimated average daily ridership of 850 people.

Overall, this alternative provides extremely positive results with very limited reach. A shuttle will reduce the number of connections required for passengers traveling between the terminal stations, but it will not greatly affect the connectivity of the city or region. Downstream effects such as increased employment and mode shift from private automobile to public transit are negligible.

Build Alternatives

Methodology

Cost analysis for the NSRL build alternatives was conducted using a financial spreadsheet model based on line-item expenditures from past rail infrastructure projects. Costs are delineated by the Standard Cost Categories in the FTA Capital Cost Database and include categories such as tunnel boring, elevators and escalators, and station signage. The Database includes 54 federally-funded rail projects completed over the past five decades. Twelve projects were used to build the cost basis for this model, selected on recency, use of tunnels, and urban settings. The model adds a 16.4% increase to the federal data in order to adjust for Boston's construction costs.

In order to adjust these results to the particular complexity and technology of the NSRL, a linear regression was constructed from the total cost and details of extremely similar projects at or near completion in the United States and Western Europe. Data from 22 projects were selected based on recency, use of a TBM for tunnel construction, and relative complexity. Projects were adjusted for construction year and location to reflect the local Boston construction prices. Two variables significantly and positively associated with the total project cost. The OLS regression formula is as follows:

$$\textit{Total project cost} = \beta_0 + \beta_1\, \textit{usa} + \beta_2\, \textit{tunnel miles} + \varepsilon$$

The parameters of each build alternative were then entered into the resulting formula to estimate a mean cost and 95% confidence interval.

The costs from both the spreadsheet and regression models were then averaged to create a single cost estimate for each build alternative, listed in Table 1. This methodology is an adjusted version of the system used by researchers at the Harvard Kennedy School. (White, Rochet, Mathias, O'Gorman, & Bilmes, 2017)

Table 1: Summary of Mean Costs for Build Alternatives

	Minimum Build	Maximum Build
Linear Regression	2,431,830,000	3,854,323,000
Spreadsheet Model	4,593,052,000	9,512,731,000
Mean of means	3,512,441,000	6,683,527,000

The spreadsheet model consistently reported higher total costs compared to the linear regression. This is assumed to be a result of the Capital Cost Database's assumption of increasing marginal costs for every Capital Cost Category. The data included in the linear regression reports both increasing and decreasing marginal costs depending on the project which combine to a net linear function. Including the higher spreadsheet model figure is intended to build-in a contingency factor for cost overruns. The Capital Cost Database also provides a breakdown of cost share for the stages of construction, allowing each figure to be broken down and properly spread across the period of construction.

Maximum Build

This alternative has a net expected cost of $3,160,618,102 and the lowest benefit-cost ratio of the alternatives at 0.48. The total expected cost of this 4-track, 3 station build is nearly twice as costly as the minimum build alternative, but it is only expected to increase ridership by a little over thirty percent compared to the minimum build. Within that thirty percent, nearly half of the riders are current public transit commuters switching from subway to commuter rail. Depending on the route taken, these mode-shifted riders may be reducing net fare revenue across the system.

The greatest benefit of the maximum build alternative is the employment growth projections expected from a third commuter rail station in the Central Business district. Compared to the Status Quo, employment within quarter-mile of North and South Stations, respectively, would increase by 11% over the 20-year period. An increase of that size has not been seen in the area since the construction boom during the 1980s.

Although a number of influential state and federal officials have expressed support for a NRSL, the size of this project's construction costs substantially decrease its feasibility. Through intensive effort to gain support for bonds and new loans, the MBTA has raised $12 billion for its current capital improvements. (Massachusetts Bay Transportation Authority, 2019) Raising over $6 billion more will is highly improbable without the support of the Governor.

This alternative does provide the highest peak capacity for the Commuter System with an expected 67,000 passengers per hour. This is more than 1.5 times the Status Quo capacity but only about 16% more capacity compared to the minimum build. Still, this increased range would allow the MBTA move the Commuter Rail to a more frequent, subway-like service model.

Minimum Build

This alternative has a net expected cost of $1,078,968,502 and a benefit-cost ratio of 0.66. The primary driver of cost is the tunnel construction, which will break down to over $600 million per mile. While less tunneling and construction are required for this alternative compared the maximum build, the lengths of construction are identical due to the operating speed of the TBM involved.

The greatest benefit of this alternative is the expected mode shift of commuters traveling by commuter rail instead of private automobile. Over 50,000 drivers are expected to ride by rail instead of highway daily under this alternative, reducing over $30 million in damage from GHG and other pollution emitted from automobiles. Additionally, this alternative provides nearly as much time savings daily per rider as the maximum build, accumulating nearly $125 million in equivalent wages annually.

This alternative is more feasible than the maximum build alternative but still improbable given the current political environment. The $3.5 billion needed to construct a single-tunnel NSRL would require significant federal funding, private partnerships, or both. Neither are likely given the FTA's investments in ongoing projects and opportunities for private firms to invest in the currently transit-rich areas of Kendall Square and Back Bay.

This alternative will increase peak hourly commuter capacity by 34%, easily alleviating South Station of its max-capacity status. The extra capacity could be used to expand regional rail service and provide subway-like service to the near-suburbs, such as Needham.

Status Quo

This alternative will allow present trends on the Commuter Rail continue. Future capital upgrades such as advanced signaling and fleet improvements may decrease costs relative to these projections, but there is little political momentum to make such piecemeal improvements to the Commuter Rail.

There is still capacity for slightly increased service running out of North Station. Demand for this increase is negligible given the current destinations available. In order to increase passenger capacity from South Station, the MBTA would have to invest in greater numbers of bi-level coaches, which slow down service and further congest the terminal station.

Recommendation

Table 2: Policy Matrix

Alternative	Maximum Build	Minimum Build	TSM
Present Value Cost	6,024,240,894.42	3,180,307,929.10	5,452,508.64
Present Value Benefits	2,863,622,791.87	2,101,339,427.07	10,964,898.15
Net Present Value	-3,160,618,102.55	-1,078,968,502.02	5,512,389.52
Benefit-Cost Ratio	0.48	0.66	2.01
Peak Hour System Capacity	67,000	59,000	44,000
Feasibility (1-10)	1	3	10

Given its high feasibility and benefit-cost ratio, we recommend the TSM alternative in addition to letting status quo trends continue. This alternative does not address many of the issues currently present: capacity remains constant, Amtrak is not able to connect the New England to the Chicago Line and Northeast Corridor, and the labor markets around North Station and South Station will have a limited connection.

In order to satisfy the remaining transit needs in Boston, it is also recommended that MassDOT invest into greater studies on a few medium-size projects. Primary is the SSX plan, which has great potential for a new private-public-partnership model that may increase the feasibility of capacity upgrades in the future. Additionally, those supporting the NSRL currently ought to shift support to the many projects which Governor Baker has championed, such as South Coast Rail and extensions to a few of the subway lines.

The North South Rail Link is a massive project that has remained in the public consciousness of Massachusetts for over a century. The historical rift in the public transit system caused by the competition of railway giants in the late 1800s will likely be causing problems for another century. In an old city such as Boston, however, residents are used to accommodating their lives around such conditions. Otherwise no one would be able to stand the winters.

Appendix

Capital Cost Basis Projects

Requirements:

1. Involves tunneling
2. Completed in the last 20 years
3. Occurred in a heavily-populated area
4. Involves infrastructure for Commuter Rail, Heavy Rail, or major improvements for Light Rail or Bus Rapid Transit.

Projects:

- Atlanta MARTA - Line Dunwoody Extension
- Boston MBTA - South Boston Piers - Busway
- Los Angeles- East Side Extension
- Los Angeles - Red line Segment 2A and 2B
- Los Angeles - Red line Segment 3
- Philadelphia SEPTA - Frankford Rehabilitation
- Pittsburgh - Light Rail Stage II
- Pittsburgh - North Shore LRT Connector
- San Diego - Mission Valley East
- San Francisco BART SFO Extension
- Washington, D.C. - Glenmont Outer (B)
- Washington, D.C. - Greenbelt Mid (E)

Linear Regression Cost Analysis Base Projects

Requirements:

1. Involves use of a Tunnel-Boring Machine

2. Tunnel is between 1km and 10km
3. Completed in the last 20 years
4. Construction occurred under a major urban center or site of similar complexity, such as a nature preserve or body of water.
5. Construction occurred in the United States or Western Europe.

Projects:

- Stockholm- Citybanan
- Malmo- Citytunneln
- Amsterdam- Noord-Zuidlijn Line
- Zurich- Weinberg Tunnel & Durchmesserlinie
- Gothenburg- West Link
- Berlin- Tiergarten Spreebogen tunnel
- Turin- Metro Line 1 Phase 1
- Turin- Metro Line 1 Phase 2
- Rotterdam/Amsterdam- Groene Hart Tunnel
- Antwerp- North-South Junction
- Leipzig- S-Bahn CityTunnel
- Madrid- Túneles de la Risa 2 West
- Madrid- Túneles de la Risa 3 East
- Barcelona- Provença
- Seattle- Highway 99
- Seattle- Ulink
- San Francisco- Central Subway
- Los Angeles- Regional Connector
- Miami- Port of Miami Tunnel
- New York City- East Side Access
- New York City-Second Avenue- Phase 1
- New York City- No. 7 Line Extension

Figure 5:Construction Cost Index for American Cities. Source: Metro Denver EDC, 2019

City	Materials	Installation	Composite
Atlanta, GA	99.0	75.6	89.0
Baltimore, MD	101.2	85.0	94.2
Boston, MA	99.4	133.3	113.9
Buffalo, NY	103.0	110.0	106.0
Chicago, IL	101.7	146.1	120.7
Cincinnati, OH	96.9	80.7	89.9
Cleveland, OH	98.7	92.2	95.9
Columbus, OH	97.4	83.2	91.3
Dallas, TX	99.1	67.7	85.6
Denver, CO	**101.8**	**74.4**	**90.0**
Detroit, MI	100.2	103.0	101.4
Houston, TX	100.7	67.9	86.6
Indianapolis, IN	98.7	83.0	92.0
Kansas City, MO	98.1	103.6	100.5
Los Angeles, CA	98.7	130.4	112.3
Memphis, TN	97.3	71.1	86.1
Miami, FL	95.8	67.4	83.7
Milwaukee, WI	99.6	105.9	102.3
Minneapolis, MN	99.7	116.5	106.9
Nashville, TN	98.4	71.1	86.7
New York, NY	99.0	176.2	132.1
Philadelphia, PA	100.1	135.3	115.2
Phoenix, AZ	100.0	73.0	88.4
Pittsburgh, PA	99.9	102.2	100.9
St. Louis, MO	99.6	105.8	102.3
San Antonio, TX	99.3	63.5	83.9
San Diego, CA	99.6	120.8	108.7
San Francisco, CA	106.3	158.1	128.5
Seattle, WA	106.0	107.4	106.6
Washington, D.C.	101.0	87.7	95.3
National Average	100.0	100.0	100.0

Figure 6: Construction Costs for European Nations. Source: Eurostat, 2020

GEO/Year	EU (28)	Euro Area (19)	Belgium	Germany	Spain	France	Italy	Netherlands	Sweden	Switzerland
1999	70.6	74.3	.	.	67.4	76.4	72.3	.	65.3	83.6
2000	73.4	77	83.1	83.6	70.3	79	74.4	79.6	67.8	86.9
2001	75.8	78.7	83.6	84.1	72.2	81.1	76.1	83	70.9	89.6
2002	78.4	80.5	85.1	84.9	73.4	82.8	79.1	85.5	73.3	89.3
2003	80.5	82.1	85.4	85.9	75	84.4	81.5	86.7	75.8	87.8
2004	83.7	85.1	87.5	88.1	78.5	87.9	84.9	87.3	78.8	88.3
2005	86.6	87.6	90	89.5	82.2	89.9	88.2	88.5	81.9	90.3
2006	90.3	91.1	94.4	91.5	87.8	93.1	90.7	91.3	86	92.7
2007	94	94.6	98.7	94.4	92.2	96	94	95	91.2	96.3
2008	98.1	98.2	101.1	97.6	96.5	99	97.6	99.4	95.7	100
2009	98.6	98.2	100	97.9	97.5	97.7	98.5	99.7	97.6	100.1
2010	100	100	100	100	100	100	100	100	100	100
2011	103	103.3	103.9	103.6	103.8	103.7	103	101.9	103	102
2012	104.7	104.8	105.9	105.8	103.5	105.2	105.4	103.7	105.7	102.3
2013	105.3	105.1	106.1	106.6	105.8	104.5	106.1	103.9	107.4	102.4
2014	106.2	105.4	107.4	107.7	104	104.3	105.9	104.9	108.3	102.8
2015	106.9	105.6	109.1	109.2	102.6	103.6	106.4	106.8	110.8	102.3
2016	107.9	106	110.8	110.5	101.2	103.9	106.7	109	113.2	.
2017	.	.	.	.	.	.	.	111.9	.	.

Regression Output

```
. reg cost_real_2010 US_dummy length_mi

      Source |       SS           df       MS      Number of obs   =        22
-------------+----------------------------------   F(2, 19)        =      7.84
       Model |  2.3296e+19         2  1.1648e+19   Prob > F        =    0.0033
    Residual |  2.8229e+19        19  1.4858e+18   R-squared       =    0.4521
-------------+----------------------------------   Adj R-squared   =    0.3945
       Total |  5.1525e+19        21  2.4536e+18   Root MSE        =    1.2e+09

------------------------------------------------------------------------------
cost_re~2010 |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
    US_dummy |   1.76e+09   5.61e+08     3.14   0.005     5.90e+08    2.94e+09
   length_mi |   4.83e+08   1.53e+08     3.16   0.005     1.63e+08    8.03e+08
       _cons |  -6.35e+08   6.34e+08    -1.00   0.329    -1.96e+09    6.92e+08
------------------------------------------------------------------------------
```

Works Cited

AbdelAlim, A. A. (2019). *Gentrification in Black Boston.* Boston.

AECOM. (2020). *Second Avenue Subway - Phase 1*. Retrieved from Projects: https://aecom.com/projects/second-avenue-subway/

Ain, S. (2001, December 23). Pushing to Speed Up East Side Rail Link. *New York Times*.

Angel, S., & Blei, A. M. (2016). The Productivity of American Cities: How Densification, Relocation, and Greater Mobility Sustain the Productive Advantage of Larger U.S. Metropolitan Labour Markets. *Cities*, 36-51.

Baskin, K. (2019, February 26). These Five Cities Around Boston Are Getting Big, Fast. *Boston*.

Basler & Hofmann. (2020). *Zurich cross-city link: Löwenstrasse railway station and Weinberg tunnel*. Retrieved from Projects: https://www.baslerhofmann.ch/en/projects/en-projekte-detailansicht/projekt/durchmesserlinie-zuerich-bahnhof-loewenstrasse-und-weinbergtunnel.html

BPDA Research Division. (2018). *Boston's Economy 2018.* Boston: Boston Planning and Development Agency.

Brinklow, A. (2017, September 20). The Central Subway: San Francisco's new line to Chinatown. *Curbed San Francisco*.

Burger, M. J., Meijers, E. J., Hoogerbrugge, M. M., & Tressera, M. J. (2015). Borrowed Size, Agglomeration Shadows and Cultural Amenities in North-West Europe. *European Planning Studies*, 1090-1109.

Chesto, J. (2016, June 9). *Baker's clear he's no fan of North-South Rail Link*. Retrieved from The Boston Globe: https://www.bostonglobe.com/business/2016/06/09/governor-rush-back-north-south-rail-link/UV3vZNM50P9HI7OqJih65L/story.html?event=event12

Duran electrónica. (2020). *SOL Railway Tunnel (Atocha-Charmatin), Madrid*. Retrieved from News and Projects: https://www.duranelectronica.com/english/sol-railway-tunnel-atocha-chamartin-madrid/

Eriksson, M. (2016). *West Link, Gothenburg*. Retrieved from Tunnel: http://swedenunderground.com/tunnel/west-link-gothenburg/

Eurostat. (2020, April 13). *Eurostat Data Explorer*. Retrieved from Construction cost (or producer prices), new residential buildings - annual data: https://appsso.eurostat.ec.europa.eu/nui/submitViewTableAction.do

Executive Office of Energy and Environmental Affairs. (2017). *Massachusetts Annaual Greenhouse Gas Emissions Inventory.* Boston: Massachusetts Department of Environmental Protection.

Federal Transit Administration. (2009). *Rail Modernization Study 2009.* United States Department of Transportation.

Florida DOT. (2011). *Tunnel Info*. Retrieved from Port of Miami Tunnel: http://www.portofmiamitunnel.com/employment/

Flynn, S. (2017). *Boston Under Snow: Resilience Lessons for the Nation.* Boston: Northeastern University Center for Resilience Studies.

Flyvbjerg, B., Bruzelius, N., & van Wee, B. (2008). Comparison of Capital Costs per Route-Kilometre in Urban Rail. *European Journal of Transport and Infrastructure Research*, 17-30.

Fowler Jr., W. M. (2000, May 21). City Speak: History, greed have blocked north-south rail link in Boston. *The Boston Globe*.

García, P. (2018, July 5). Security flaws delay the five AVE openings planned for 2018. *The Independent*.

Global Warming Solutions Act, M.G.L. c. 21N, §§ 3(c), 3(d), & 7 (2008).

Governor's Special Panel to Review the MBTA. (2015). *Back on Track: An Action Plan to Transform the MBTA.* Boston: Office of the Governor.

Graver, B., & Frey, H. (2016, October 26). Highway Vehicle Emissions Avoided by Diesel Passenger Rail Service Based on Real World Data. *Urban Rail Transit, 2*, pp. 153-171.

Grynbaum, M. M., & Haughney, C. (2011, November 18). A Now-Rare Tunnel Accident Claims a Worker's Life. *The New York Times*.

Haney, E., Corley, T., & Forman, B. (2019). *Prioritizing Equitable Growth Throug Fare Policy.* Boston: Massachusetts Institute for a New Commonwealth.

Hawkins, A. J., & O'Kane, S. (2015, November 5). *Inside New York City's East Side Access, the Biggest Transportation Project in America*. Retrieved from The Verge: https://www.theverge.com/2015/11/5/9677300/manhattan-train-tunnel-project-grand-central-lirr-access

Hodges, D., & Forman, B. (2018). *The Promise and Potential of Transformative Transit-Oriented Development in Gateway Cities.* Boston: The Massachusetts Institute for a New Commonwealth.

Jiang, Y., & Herten, A. (2019, January). SR 99 Tunnel in Seattle. *Structure Magazine*.

Kates, B. (2011, November 18). *Son Dies in LIRR Tunnel Collapse Despite Father's Efforts to Save Him*. Retrieved from New York Daily News: https://www.nydailynews.com/new-york/son-dies-lirr-tunnel-collapse-father-efforts-save-article-1.979611

Koers, H., Kropp, U., & Röder, T. (2011). Minimising Risks through complex Groundwater Management for the Amsterdam North/South Line. *Tunnel*, 24-31.

Kyriakodis, H. (2014, November 7). *Hidden City*. Retrieved from Singe Most Transformative Investment? The Commuter Rail Tunnel, Now Turning 30: https://hiddencityphila.org/2014/11/single-most-transformative-investment-the-commuter-rail-tunnel-now-turning-30/

Massachusetts Bay Transit Authority. (2003). *Major Investment Study: Draft Environmental Impact Report.* Boston: USDT-FTA.

Massachusetts Bay Transit Authority. (2019, October 18). *Rail Vision*. Retrieved from Massachusetts Bay Transit Authority: Projects: https://www.mbta.com/projects/rail-vision

Massachusetts Bay Transportation Authority. (2019, June 7). *Capital Investment Plan*. Retrieved from MBTA Financials: https://www.mbta.com/financials/capital-investment-plan

Massachusetts Department of Transportation. (2018). *North South Rail Link Feasibility Reassessment.* Boston: MassDOT.

McNichol, D. (2019, January 31). *3 Reasons Why We Should Build the North-South Rail Link*. Retrieved from WBUR: https://www.wbur.org/cognoscenti/2019/01/31/north-south-rail-link-boston-dan-mcnichol

Meijers, E. J., & Burger, M. J. (2015). Stretching the Concept of 'Borrowed Size'. *Urban Studies*.

Metro. (2020, April 10). *Purple Line Extension - Section 1*. Retrieved from Projects: https://www.metro.net/projects/purple-section1/

Metro Denver EDC. (2018, September 24). *U.S. Construction Cost Index by Select City 2018.* Retrieved from Statista: https://www.statista.com/statistics/916435/us-construction-market-cost-index-by-city/

Metropolitan Transportation Authority. (2001). *East Side Access: Purpose and Need.* New York: MTA.
Metzger, A. (2019, September 25). *Poll: Most Biotech Workers Angry About Commutes*. Retrieved from Commonwealth Magazine: https://commonwealthmagazine.org/transportation/poll-most-biotech-workers-angry-about-commutes/
Mohl, B. (2019, April 4). *Pollack Hedging on Next Commuter Rail Contract*. Retrieved from Commonwealth Magazine: https://commonwealthmagazine.org/transportation/pollack-hedging-on-next-commuter-rail-contract/
MTA. (2018). *MTA Capital Program*. Retrieved from East Side Access: http://web.mta.info/capital/esa_alt.html
MTA. (2018). *MTA Capital Projects*. Retrieved from East Side Access Project Elements: http://web.mta.info/capital/esa_alt.html?tab=elements
Muro, M., & Whiton, J. (2018). *Geographic Gaps are Widening While U.S. Economic Growth Increases.* Washington, D.C.: Brookings.
Newmark, Z. (2017, April 6). FIRST FULL SPEED, FULL LENGTH TEST OF NEW AMSTERDAM SUBWAY ENDS SUCCESSFULLY. *NL Times*.
Port of Miami Tunnel Project. (2010, June 3). *Comparable Tunneling Projects Fact Sheet.* Retrieved from POMT Public Affairs: http://portofmiamitunnel.com/system/js/back/ckfinder/userfiles/files/10-0601%20Comparable%20Tunneling%20Projects-%20FINAL.pdf
Railway Gazette. (2008, February 8). Barcelona tunnel contract let. *Railway Gazette*.
Railway Technology. (2008). *Antwerpen Centraal and North South Junction*. Retrieved from Projects: https://www.railway-technology.com/projects/antwerpen/
Railway Technology. (2011). *Torino Metro Line 1*. Retrieved from Projects: https://www.railway-technology.com/projects/torino-metro/
Railway Technology. (2015). *Zurich Durchmesserlinie project*. Retrieved from Projects: https://www.railway-technology.com/projects/zurich_capacity/
Railway Technology. (2016). *West Link Rail project*. Retrieved from Projects: railway-technology.com/projects/west-link-rail-project-vastlanken/
Railway Technology. (2017). *Stockholm City Line*. Retrieved from Projects: https://www.railway-technology.com/projects/stockholmcityline/
Rosenthal, B. M. (2017, December 28). The Most Expensive Mile of Subway Track on Earth. *The New York Times*.
RTVE. (2008, September 7). *The new 'laughter tunnel' connects MAdrid from north to south through the Cercanías*. Retrieved from Madrid: https://www.rtve.es/noticias/20080709/nuevo-tunel-risa-une-madrid-sur-norte-traves-del-cercanias/113489.shtml
Saxon State Ministry of Economics, Labor and Transport. (2019). *Tunnel Info*. Retrieved from Citytunnel Leipzig: https://www.citytunnel.sachsen.de/tunnelroehre-3967.html
SFMTA. (2020, February). *San Francisco's T Third light rail extension to downtown*. Retrieved from Central Subway Project: https://www.sfmta.com/projects/central-subway-project
Sound Transit. (2015, September 14). *Northgate Station*. Retrieved from System Expansion: https://www.soundtransit.org/system-expansion/northgate-station/documents

Sullivan, G. (2019, Febraury 22). *Drop in MBTA Commuter Rail RIdership Continues*. Retrieved from Pioneer Institute: https://pioneerinstitute.org/better_government/drop-in-mbta-commuter-rail-ridership-continues/#_ednref1

Sullivan, S., & Stergios, J. (2015). *The MBTA Commuter Rail's Cost Structure is Off the Rails.* Boston: The Pioneer Institute.

The MassINC Polling Group. (2019). *Gridlock: Stopped in Traffic, Delayed on Transit.* Boston: The Massachusetts Institute for a New Commonwealth.

Ujifusa, S. (2008, February 12). *PBS: WHYY*. Retrieved from From Our Reprise COllection: Making the Center City Commuter Connection: https://whyy.org/articles/2712/

Urban Mass Transit Administration. (1973). *Draft Environmental Statement: Center City Commuter Rail Connection.* Philadelphia: U.S. Department of Transportation .

Vantuono, W. C. (2017, January 27). Tutor Perini/O&G JV Lands LACMTA Purple Line contract. *Railway Age*.

White, L., Rochet, J.-L., Mathias, P., O'Gorman, K., & Bilmes, L. (2017). *Connecting the Northeast: A Cost Estimate for the North South Rail Link.* Cambridge: Harvard Kennedy School.

WSP USA. (2020). *East Side Access*. Retrieved from Projects: https://www.wsp.com/en-US/projects/east-side-access