Massachusetts Department of Transportation (MassDOT)

North South Rail Link Feasibility Reassessment

Final Report

January 2019

Cover Photo by Osman Rana

Massachusetts Department of Transportation (MassDOT)
North South Rail Link Feasibility Reassessment Final Report

Photo Source: Osman Rana

1. Introduction

Photo Source: Osman Rana

1. Introduction

The North South Rail Link (NSRL) project would connect the Massachusetts Bay Transportation Authority's (MBTA) northside and southside commuter rail networks into one regional system through the construction and operation of a rail tunnel through Downtown Boston. This tunnel would enable through-running of MBTA Commuter Rail and Amtrak trains, increasing system coverage, capacity, and ridership.

1.1 Study Purpose

The Massachusetts Department of Transportation (MassDOT) commissioned Arup to conduct this NSRL Feasibility Reassessment, which reexamines prior work on the concept and was scoped to do the following:

- Identify significant changes to the context within which the NSRL would be implemented, such as demographic shifts, new transportation technologies, and trends and changes to the regulatory and built environments.
- Review the technical viability of major elements of the NSRL that were proposed by previous studies (two- versus four-track tunnels, two versus three stations in the tunnel section, service plan alternatives, the location and construction of tunnel portals, tunnel alignments, and station and headhouse locations). Consider new alternatives and develop these to a level of detail to allow for an assessment of costs and benefits.
- Develop an order-of-magnitude cost estimate (including design, construction, and management costs), assuming the initial use of dual-mode locomotives to avoid full electrification of the commuter rail system. This cost estimate will be informed by recent experience in rail tunnel construction (both international and domestic) and industry best practices.
- Consider overall project benefits including ridership growth, increased system capacity, service reliability improvements, and economic development, and quantify the benefits and associated costs at a level appropriate to this stage in the project development process.

The results of this Feasibility Reassessment will help inform MassDOT's and state policymakers' decisions about any appropriate next steps with regard to the NSRL concept.

An NSRL Working Group composed of assembled technical experts, provided independent review of project findings from this Feasibility Reassessment. They have been engaged at various points in the process and have provided feedback on project deliverables, including this report. The members of this group who regularly attended meetings with the project team are as follows:

- Lynn Ahlgren
- Brad Bellows
- Barry Bluestone
- Robert Culver
- Evan Efstathiou
- Ed Mueller
- Clay Schofield

1.2 Previous Studies

While a rail tunnel between North and South Stations had been considered since 1909, the modern concept of the NSRL was first introduced in 1972 as part of the Boston Transportation Planning Review's Central Artery report. This masterplan proposed a two-track rail tunnel alongside the Central Artery road tunnel, but the rail connection was eventually eliminated in order to secure federal funding for the highway project.

In 1993, the secretary of the Massachusetts Executive Office of Transportation and Construction (EOTC) convened the Central Artery Rail Link Task Force to study the feasibility of the rail tunnel using the Central Artery alignment. In its final report, the EOTC-appointed task force recommended the construction of the rail tunnel with first two tracks, and then four in a further phase, and three downtown stations (North Station, South Station, and State Street).

A number of studies developed by organizations outside of state government followed, proposing that a more thorough examination of engineering and environmental impact be conducted. To satisfy these requests for further study, the MBTA, Federal Transit Administration, the Massachusetts Highway Department, Amtrak, and EOTC partnered on a major investment study / draft environmental impact report (DEIR), released in June of 2003. The study identified a No Build scenario, one focusing on enhancements to existing transit systems, and multiple variants of commuter rail tunnel build alternatives, accounting for different numbers of tracks, locations of south portals, numbers of stations, and alignments of the southern section of tunnel. All variants were evaluated in terms of financial feasibility, effectiveness, and equity measures:

- Two-track (Back Bay portal) / two-station
- Two-track (Back Bay portal) / three-station
- Two-track (South Bay portal) / two-station
- Two-track (South Bay portal) / three-station
- Four-track / two-station
- Four-track / three-station

The output of this evaluation was distributed to the relevant governmental agencies to inform decisions on future transportation investments. In addition to developing new alternatives, the current Feasibility Reassessment seeks to evaluate the 2003 rail concept in today's transportation context and provide updated estimates on anticipated benefits and costs.

1.3 Abbreviations

The following abbreviations are used throughout this report.

CTPS	Central Transportation Planning Staff
DEIR	Draft Environmental Impact Report
EOTC	Massachusetts Executive Office of Transportation and Construction
FTA	Federal Transit Administration
MAPC	Metropolitan Area Planning Council
MassDEP	Massachusetts Department of Environmental Protection
MassDOT	Massachusetts Department of Transportation
MBTA	Massachusetts Bay Transportation Authority
MPO	Metropolitan Planning Organization
NEC	Northeast Corridor
NSRL	North South Rail Link
SEM	Sequential Excavation Method
SSX	South Station Expansion
TAZ	Traffic Analysis Zones
TBM	Tunnel Boring Machine

2. Problem Statement

Photo Source: Osman Rana

2. Problem Statement

The NSRL has the potential to address several separate but interrelated needs in Boston's travel market.

2.1 A Growing Region

The Greater Boston area continues to add both jobs and people, straining its existing transportation network. A number of traffic indices rank the Boston metropolitan area, alongside Los Angeles, New York, San Francisco, and Washington DC, as among the most congested in the US,[1] and in the past 16 years, the City of Boston has experienced 8% population growth and 4% employment growth, while in the region's MBTA service area, population grew by 5% and employment by 10%, exacerbating capacity constraints in the transit system.[2] Similar to other growing regions, the Greater Boston economy has grown faster than its transportation infrastructure.

Traffic congestion

Crowds at MBTA Park Street Station

2.2 A Divided System

The MBTA's Commuter Rail network operates as essentially two separate systems, with five lines serving the areas north of the urban core and terminating at North Station, and the remaining nine lines serving areas south (and, to a lesser extent, west) of the urban core and terminating at South Station. This division creates two separate markets: lines running into South Station have easy access to the Back Bay, the Financial District and the Seaport District, while lines running into North Station arrive at the northern end of downtown, an area with lower employment density and fewer major destinations. This division creates disincentives for commuters from the northern suburbs to use transit to reach jobs in Downtown Boston and Back Bay, as many trips require a transfer from commuter rail to subway, adding about 10 minutes to their overall journey. Meanwhile, suburb-to-suburb trips between commuter-rail-accessible areas south and north of Boston's urban core require multiple transfers, and those trips are currently unlikely to be completed via public transit. This is supported by an analysis of 2010 journey-to-work data for this project, which shows the majority of trips from either the northside or southside MBTA Commuter Rail lines ending in a Downtown Boston destination.

2.3 Operational Issues

Operationally, this divided system creates inefficient terminals, limiting the number of trains that can enter and exit downtown during peak periods. Both North Station and South Station are stub-end terminals requiring trains to reverse direction to continue in both revenue and non-revenue service. Train schedules must allow adequate time for turning around and checking equipment, meaning trains occupy available tracks and platforms and thus reduce the overall number of trains that can serve the terminals at peak periods.

The division of the system also results in commuter rail fleet inefficiencies, as trains cannot easily move between the northern and southern portions of the commuter rail system. Storage and maintenance occurs within the separate portions of the system, in order to avoid these costly and slow train movements on the few and inadequate links between north and south.

The lack of direct connections between North Station trains and Back Bay or downtown core destinations contributes to overcrowding on the MBTA rapid transit system at peak times, as many North Station commuter rail passengers transfer to the Orange and Green Lines to complete their trips.

3. Background Information

Photo Source: Wikimedia Commons, User Das48

3. Background Information

The NSRL Feasibility Reassessment considers an economic and policy environment that has evolved and changed over the last 15 years. These changes range from demographic shifts — where and how people live and work — to physical changes including transformational modifications and improvements to the transportation system. To provide a disciplined assessment of the current potential for the NSRL, a set of guiding principles were developed for the study. Peer projects from around the world were investigated to understand best practices and value opportunities, and to provide thorough analysis and comparison.

3.1 Existing Conditions

Overview of the Region

Boston is the economic center of New England, and the central city of the 10th-largest metropolitan statistical area in the United States. Its concentration of highly skilled workers, high median household incomes, and strong healthcare, educational, and technology sectors all make Boston an important part of the larger Northeast Corridor (NEC) megaregion. [3]

A robust transportation system — comprising an interconnected highway network, intercity rail, and an international airport — provides key connections to the rest of the NEC and the country. However, local networks can be congested, due to growing demand, aging infrastructure and its attendant reliability issues, and transit capacity constraints at various points in the network. Additionally, indirect connections between locations can make journeys long and inconvenient.[4]

The urban core holds the majority of jobs, attracting hundreds of thousands of trips every day. However, while this area has seen the majority of growth in recent years, both jobs and people are spread widely throughout the region, leaving many trips dependent on private automobiles.

Overview of the Study Area

Although the NSRL's connections would improve transit trips for users throughout the region's transportation system, the project's construction impacts are concentrated on the central areas of Boston.

The project provides either a two- or four-track rail tunnel connecting North and South Stations, and entrance portals on both the north and south ends that connect to the wider commuter rail network. Tunnel alignment alternatives for this Feasibility Reassessment take account of the substantial development that has occurred along the Central Artery and in the surrounding neighborhoods that might have an impact on where tunnels can be located. Figures 1 and 2 illustrate these recent developments and the development that is planned within and along the indicative area encompassing potential tunnel alignments. This information was collected from the MassBuilds development database, administered by the Metropolitan Area Planning Council, which has been collecting data on constructed and planned developments throughout the Greater Boston area dating back to 2010.[5]

Rank	Metro Area	Population (Thousands)			Percent Change	
		2000	2016	Change	Total	Avg. Annual
1	Phoenix	3,252	4,662	1,410	43.3%	2.3%
2	Houston	4,878	6,973	2,095	42.9%	2.3%
3	Dallas	5,596	7,673	2,076	37.1%	2.0%
4	Atlanta	4,779	6,453	1,674	35.0%	1.9%
5	Seattle	3,776	4,685	909	24.1%	1.4%
6	Miami	5,476	6,725	1,249	22.8%	1.3%
7	DC	7,981	9,671	1,690	21.2%	1.2%
8	San Francisco	7,656	8,752	1,096	14.3%	0.8%
9	Los Angeles	16,374	18,688	2,314	14.1%	0.8%
10	Philadelphia	6,689	7,179	491	7.3%	0.4%
11	Boston	7,630	8,176	546	7.2%	0.4%
12	New York	22,241	23,689	1,448	6.5%	0.4%
13	Chicago	9,465	9,883	417	4.4%	0.3%

Table 1: Metro Area Rankings by Population Growth Rate

2000 – 2016

Source: US Census Bureau, Decennial Census 2000, American Community Survey 2016 1-Year Estimates

Rank	Metro Area	Population (Thousands)			Percent Change	
		2000	2016	Change	Total	Avg. Annual
1	Los Angeles	16,374	18,688	2,314	14.1%	0.8%
2	Houston	4,878	6,973	2,095	42.9%	2.3%
3	Dallas	5,596	7,673	2,076	37.1%	2.0%
4	DC	7,981	9,671	1,690	21.2%	1.2%
5	Atlanta	4,779	6,453	1,674	35.0%	1.9%
6	New York	22,241	23,689	1,448	6.5%	0.4%
7	Phoenix	3,252	4,662	1,410	43.3%	2.3%
8	Miami	5,476	6,725	1,249	22.8%	1.3%
9	San Francisco	7,656	8,752	1,096	14.3%	0.8%
10	Seattle	3,776	4,685	909	24.1%	1.4%
11	Boston	7,630	8,176	546	7.2%	0.4%
12	Philadelphia	6,689	7,179	491	7.3%	0.4%
13	Chicago	9,465	9,883	417	4.4%	0.3%

Table 2: Metro Area Rankings by Population Growth (Absolute)

2000 - 2016

Rank	Metro Area	Employment (Thousands)			Percent Change	
		2000	2016	Change	Total	Avg. Annual
1	Houston	2,272	2,947	675	29.7%	1.6%
2	Dallas	2,852	3,496	644	22.6%	1.3%
3	Phoenix	1,584	1,933	349	22.0%	1.3%
4	Miami	2,255	2,675	420	18.6%	1.1%
5	Seattle	1,864	2,195	331	17.7%	1.0%
6	Atlanta	2,413	2,765	352	14.6%	0.9%
7	DC	4,097	4,679	582	14.2%	0.8%
8	Los Angeles	6,794	7,619	825	12.1%	0.7%
9	New York	9,791	10,629	838	8.6%	0.5%
10	San Francisco	3,863	4,139	275	7.1%	0.4%
11	Boston	3,835	4,067	232	6.1%	0.4%
12	Philadelphia	3,069	3,182	113	3.7%	0.2%
13	Chicago	4,534	4,591	57	1.3%	0.1%

Table 3: Metro Area Rankings by Employment Growth Rate

2000 - 2016

Source: Bureau of Labor Statistics, Quarterly Census of Employment and Wages, Annual Averages

Rank	Metro Area	Employment (Thousands)			Percent Change	
		2000	2016	Change	Total	Avg. Annual
1	New York	9,791	10,629	838	8.6%	0.5%
2	Los Angeles	6,794	7,619	825	12.1%	0.7%
3	Houston	2,272	2,947	675	29.7%	1.6%
4	Dallas	2,852	3,496	644	22.6%	1.3%
5	DC	4,097	4,679	582	14.2%	0.8%
6	Miami	2,255	2,675	420	18.6%	1.1%
7	Atlanta	2,413	2,765	352	14.6%	0.9%
8	Phoenix	1,584	1,933	349	22.0%	1.3%
9	Seattle	1,864	2,195	331	17.7%	1.0%
10	San Francisco	3,863	4,139	275	7.1%	0.4%
11	Boston	3,835	4,067	232	6.1%	0.4%
12	Philadelphia	3,069	3,182	113	3.7%	0.2%
13	Chicago	4,534	4,591	57	1.3%	0.1%

Table 4: Metro Area Rankings by Employment Growth (Absolute)

2000 - 2016

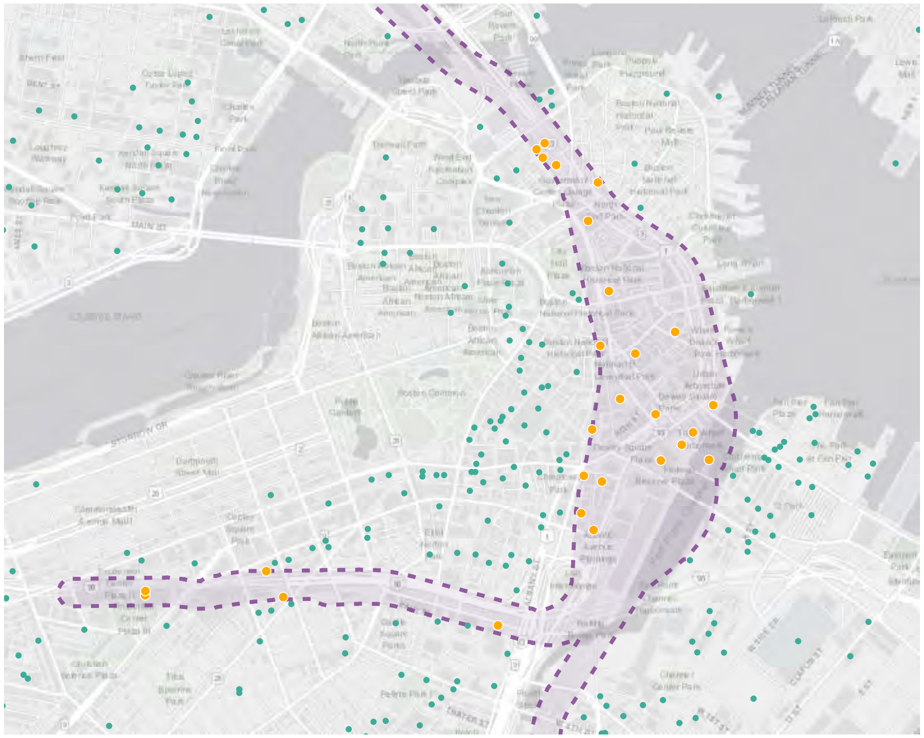

Figure 1: Properties Constructed or Renovated

2000 – 2017

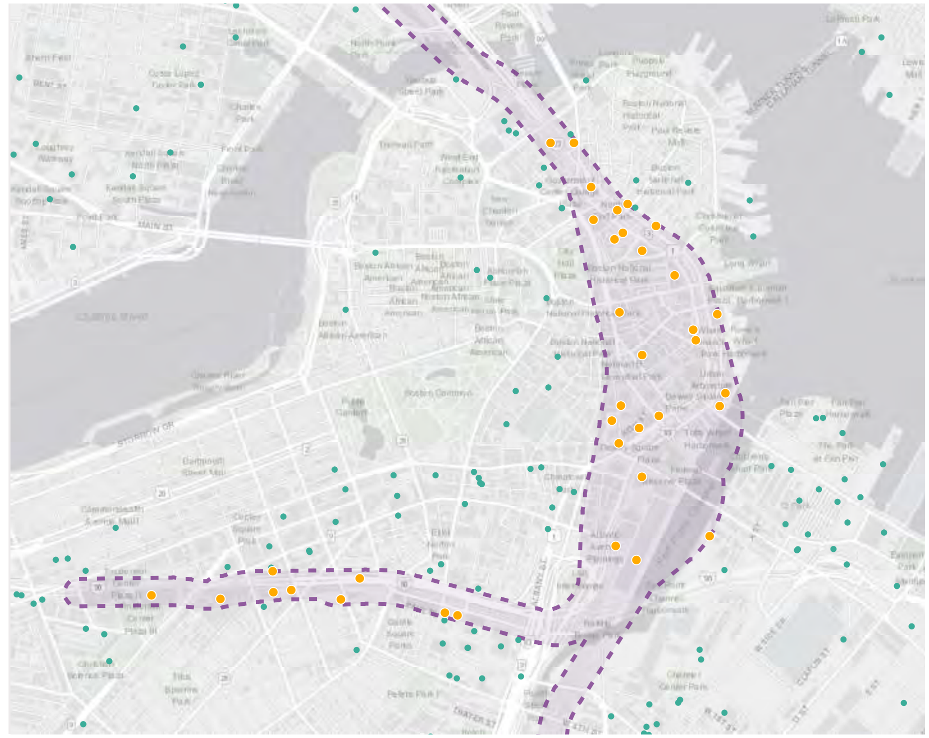

Figure 2: Planned Developments

2018+

All Developments 2000–2017 within 200 Feet of Alignment
All Developments
Indicative Alignment Area

All Developments 2018+ within 200 Feet of Alignment
All Developments
Indicative Alignment Area

Boston Metro Transit System

While the majority of the region's commuters drive to work, approximately 13% utilize the region's extensive transit system for work trips. This system is operated by the MBTA, an authority created by the General Court in 1964. It is one of the first combined regional transit system to be established in the United States.[6] The MBTA is overseen by two governing bodies: the MassDOT Board and the Fiscal and Management Control Board, the latter established in July of 2015 to monitor finances, management, and operations.[7] The MBTA operates as a division of MassDOT, under its Rail & Transit Division.[8]

The MBTA transports more than 1.3 million passengers daily via a variety of modes, making it the fifth-largest mass transit system in the United States. It operates 175 bus routes, two light rail lines (the Green Line and the Mattapan High Speed Line, an extension of the Red Line from Ashmont to Mattapan), three heavy-rail subway lines (the Red, Blue, and Orange Lines), and 14 commuter rail lines. The MBTA also provides ferry and paratransit services.[9]

The MBTA service area is comprised of 175 municipalities,[10] classified into the following three categories:

- **Core Service Area**
  The urban core. Includes Boston, Arlington, Belmont, Brookline, Cambridge, Chelsea, Everett, Malden, Medford, Melrose, Newton, Quincy, Revere, Somerville, Waltham, Watertown, and Winthrop.
- **Gateway Cities**
  Midsize post-industrial cities in the MBTA service area outside of the Core Service Area. Includes Brockton, Fitchburg, Framingham, Haverhill, Lawrence, Leominster, Lowell, Lynn, Salem, and Worcester.
- **Other MBTA Service Area**
  The rest of the municipalities comprising the MBTA assessment district.[11]

Figure 3 shows the geographies as they relate to the commuter rail network. These geographies have been used for the demographic analyses in Section 3.2 to help understand the geographic distribution of various trends.

MBTA signage

The MBTA Commuter Rail System

The MBTA's Commuter Rail system is comprised of 14 routes serving 138 stations over 388 route miles, all connecting to Downtown Boston.[12] The five routes running into North Station are Newburyport, Rockport, Haverhill, Lowell, and Fitchburg. The nine routes running into South Station are Framingham/Worcester, Needham, Franklin, Providence, Stoughton, Fairmount, Middleborough/Lakeville, Kingston/Plymouth, and Greenbush. Figure 4 illustrates the commuter rail system, as well as the rapid transit lines and the Silver Line.

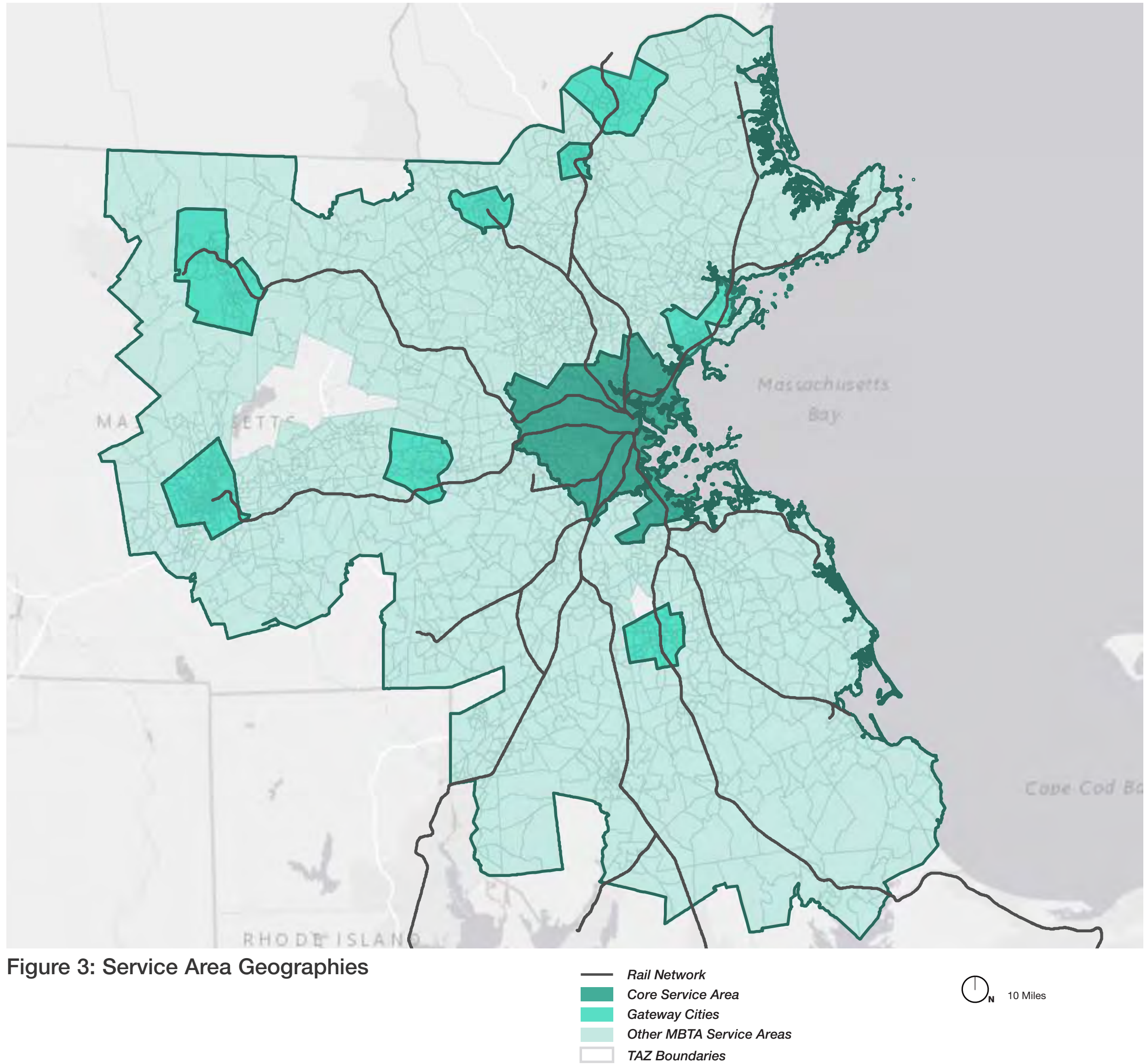

Figure 3: Service Area Geographies

Figure 4: Map of MBTA Commuter Rail System

Operations

The commuter rail system is operated and maintained by Keolis, a third-party contractor. Keolis is also responsible for the maintenance of the MBTA's approximately 90 diesel locomotives and more than 400 coaches, both single- and double-decker.[13]

While the span of service stretches from 3:30am to 1:40am on weekdays and 6:30am to 11:30pm on weekends, the most frequent service is provided for peak-period, peak-direction travel into and out of Downtown Boston. Midday and off-peak service is limited, making the commuter rail service most useful for those with regular work commuting patterns.

Lengthy sections of single-track and busy shared facilities — such as Reading Junction (the point where the Haverhill, Newburyport, and Rockport Lines merge), and the congested NEC network serving five commuter rail routes and Amtrak — create capacity and service constraints.

Maintenance facilities and yards are limited on either side of the network, and standard operating conditions such as restrictions on how closely trains can pass through signals and junctions can limit the throughput of more trains. In recent years, however, reliability has improved — in 2017, commuter rail had on-time performance of 93% and 99.6% of scheduled service was operated.[14]

Ridership

Average weekday ridership for MBTA commuter rail, taken from the National Transit Database, was 131,160 in 2012. The Boston Region Metropolitan Planning Organization (MPO)'s Central Transportation Planning Staff (CTPS) conducted a comprehensive survey of ridership by commuter rail line in 2012, which included manual passenger counts between January and June of that year. The survey collected detailed information that shows boardings and alightings for each route, as well as passenger loads on particular segments of the lines. Estimates were also made for station-to-station ridership and the proportion of interzone ridership. The results of this 2012 survey are summarized in Table 5.

A separate MBTA report on the state of the commuter rail system noted that '98% of commuter rail trains had a seat for every passenger', indicating that very few of these lines are experiencing trains that are running over capacity.[15]

MBTA Commuter Rail Maintenance Facility

	Commuter Rail Line	Daily Inbound Riders	Daily Outbound Riders	Total Daily Riders	Daily Inbound Trains	Daily Outbound Trains	Total Daily Trains
North Side Lines	Newburyport/Rockport	6,958	7,045	14,003	30	30	60
	Haverhill	3,489	3,502	6,991	24	24	48
	Lowell	4,988	4,639	9,627	31	27	58
	Fitchburg	3,955	3,969	7,924	17	17	34
South Side Lines	Worcester/Framingham	6,451	6,336	12,787	21	20	41
	Needham	2,724	3,090	5,814	16	16	32
	Franklin	4,959	5,121	10,080	19	18	37
	Providence/Stoughton	10,887	10,610	21,497	35	37	72
	Fairmount	376	413	789	17	15	32
	Middleborough/Lakeville	2,461	2,545	5,006	12	12	24
	Kingston/Plymouth	2,802	2,711	5,513	12	12	24
	Greenbush	2,191	2,162	4,353	12	12	24

Table 5: MBTA Commuter Rail Weekday Passenger Counts by Line

2012

These numbers show that ridership is skewed toward the lines leading to South Station, which carry about 66,000 passengers (63%) both inbound and outbound on a typical weekday, as compared to the lines running into North Station, which carry about 38,500 passengers (37%). This split is roughly in line with DEIR observations from 2003.[16]

Trends in ridership can be inferred by examining historical data, available from 2000 onwards. As illustrated in Figure 5, MBTA ridership has been declining since 2009, when it was at a high of almost 147,000. A number of factors may have had an impact on this approximate 15% decrease in commuter rail ridership. Possible explanations include four fare increases since 2003 (in 2005, 2008, 2012, and 2014), lower gas prices from 2008 to 2010 and then since 2014, the impacts of severe weather in the winter of 2015, and more people living in the urban core. In addition to this, the difficulty of accurately forecasting into the future is readily acknowledged amongst the planning community.

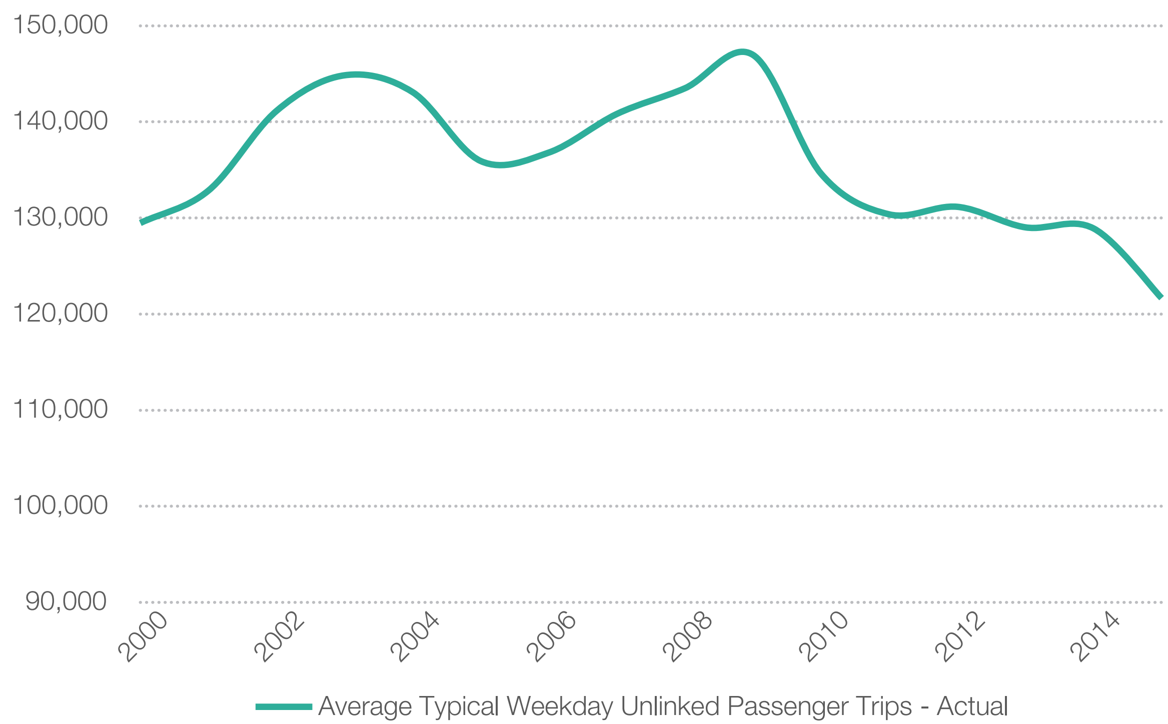

Figure 5: MBTA Commuter Rail Average Weekday Ridership

2000–2015 (Source: National Transit Database)

Amtrak

Amtrak currently runs four services into Boston terminals:

- Acela and NEC services running from Washington DC / Virginia to South Station (19 daily trains arriving and 20 departing)
- Lake Shore Limited service running out of South Station to Chicago via Springfield, Massachusetts (one daily train in either direction)
- Downeaster service from Maine to North Station (five daily trains in either direction).

Table 6 approximates ridership on the NEC/Acela and Downeaster services, using Amtrak's station counts showing average weekday ons and offs at Back Bay, South, and North Stations. This method was considered more accurate than full NEC ridership data, as these numbers include the full extent of routes running down to Washington DC and Virginia. Figures from 2012 are used to provide a direct comparison to the MBTA ridership discussed above.

Amtrak train at South Station

Photo Source: MTA / Flickr

Figure 6 shows historical average weekday ridership counts for Amtrak at Back Bay, South, and North Stations. Amtrak ridership figures, as opposed to commuter rail ridership, show steady growth at all Boston stations from 2001 to 2016, more than doubling over this period.

	Average Weekday Ridership (2012)
Amtrak Northeast Corridor incl. Acela (Back Bay and South Stations)	5,660
Amtrak Downeaster (North Station)	1,340
Total	**7,000**

Table 6: 2012 Weekday Ridership Data

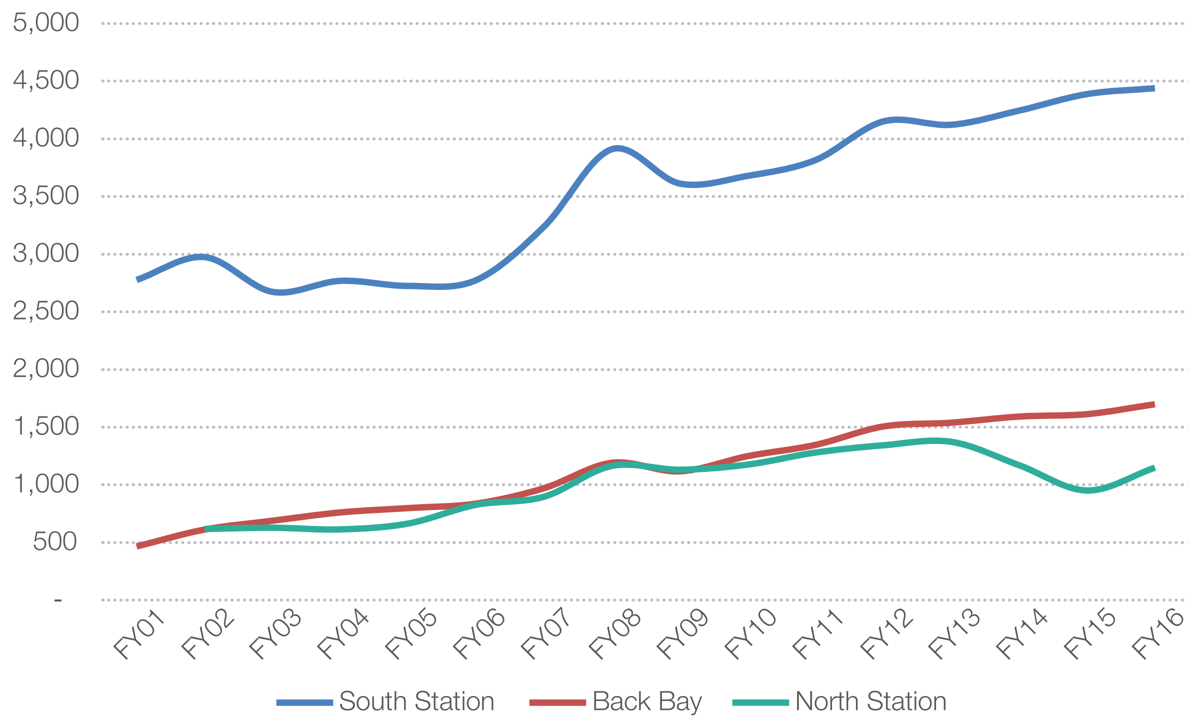

Figure 6: Amtrak Average Weekday Ridership

2001—2016 (Source: Amtrak)

3.2 Regional Demographics

Demographic changes in the MBTA service area are a key component of this Feasibility Reassessment. Projections used by CTPS and developed by the Metropolitan Area Planning Council serve as the basis for characterizing changes in regional growth, demographics, and development patterns in order to better understand the market for the NSRL. For all of the following analyses, population and employment data from 2000 (which was used in the 2003 report) were compared to 2016 figures used by CTPS. Regional demographic data includes population by age, households by type (by worker, by household income, and by auto availability), and employment categories (basic, retail, and service).

Population and household data came from the US Census, while employment data are from InfoUSA (a private data vendor). Vehicle ownership information was collected separately from the US Census for 2000 and 2015. These data, compared at a municipal level, informed the context review analysis for the NSRL project, and resulted in the maps and analysis provided over the next few pages.

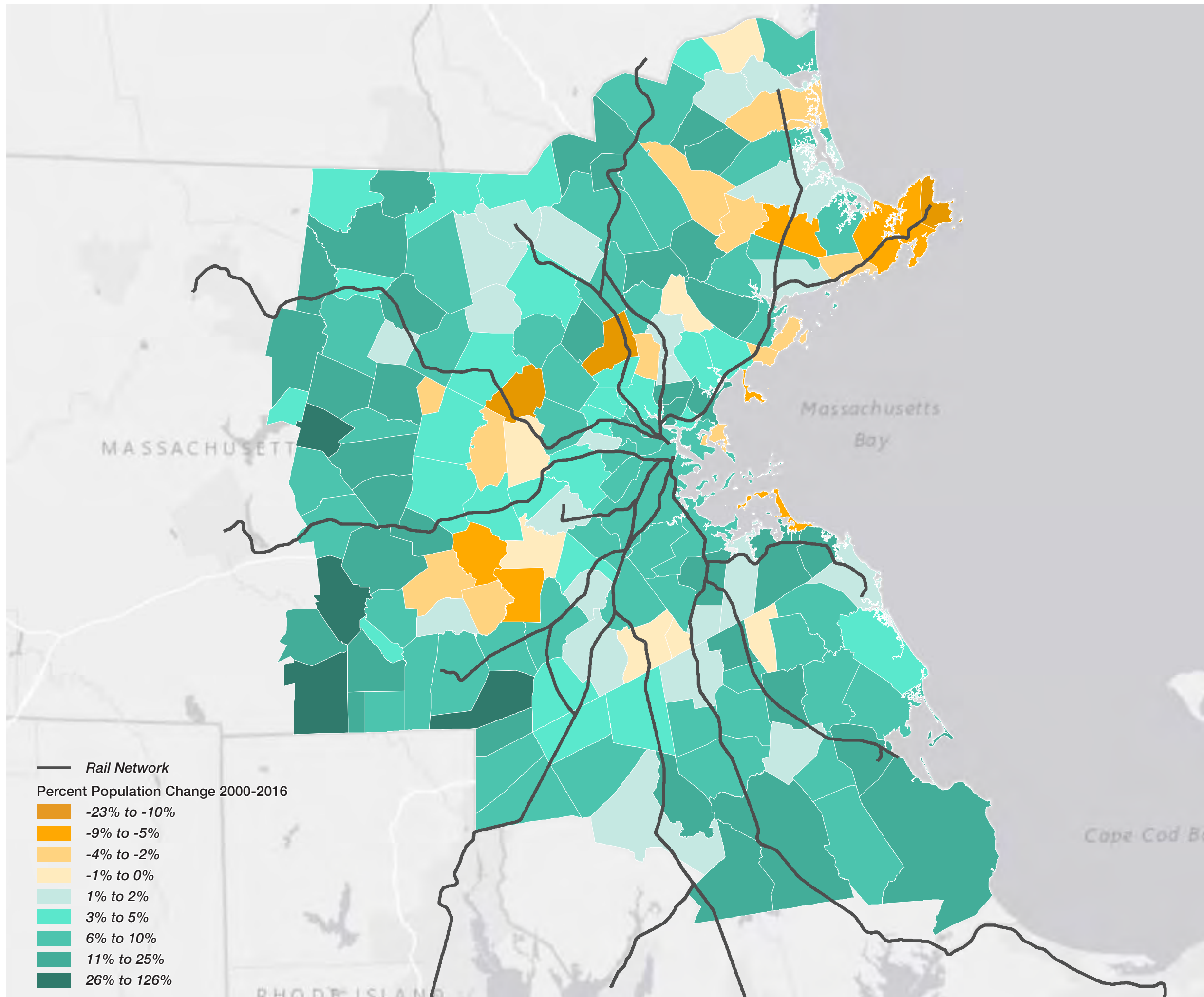

Figure 7: Population Change in the Study Area

2000—2016 – Percentage Change

The study area's population grew from 4.3 million in 2000 to 4.6 million in 2016, at an annual rate of approximately 0.4%.

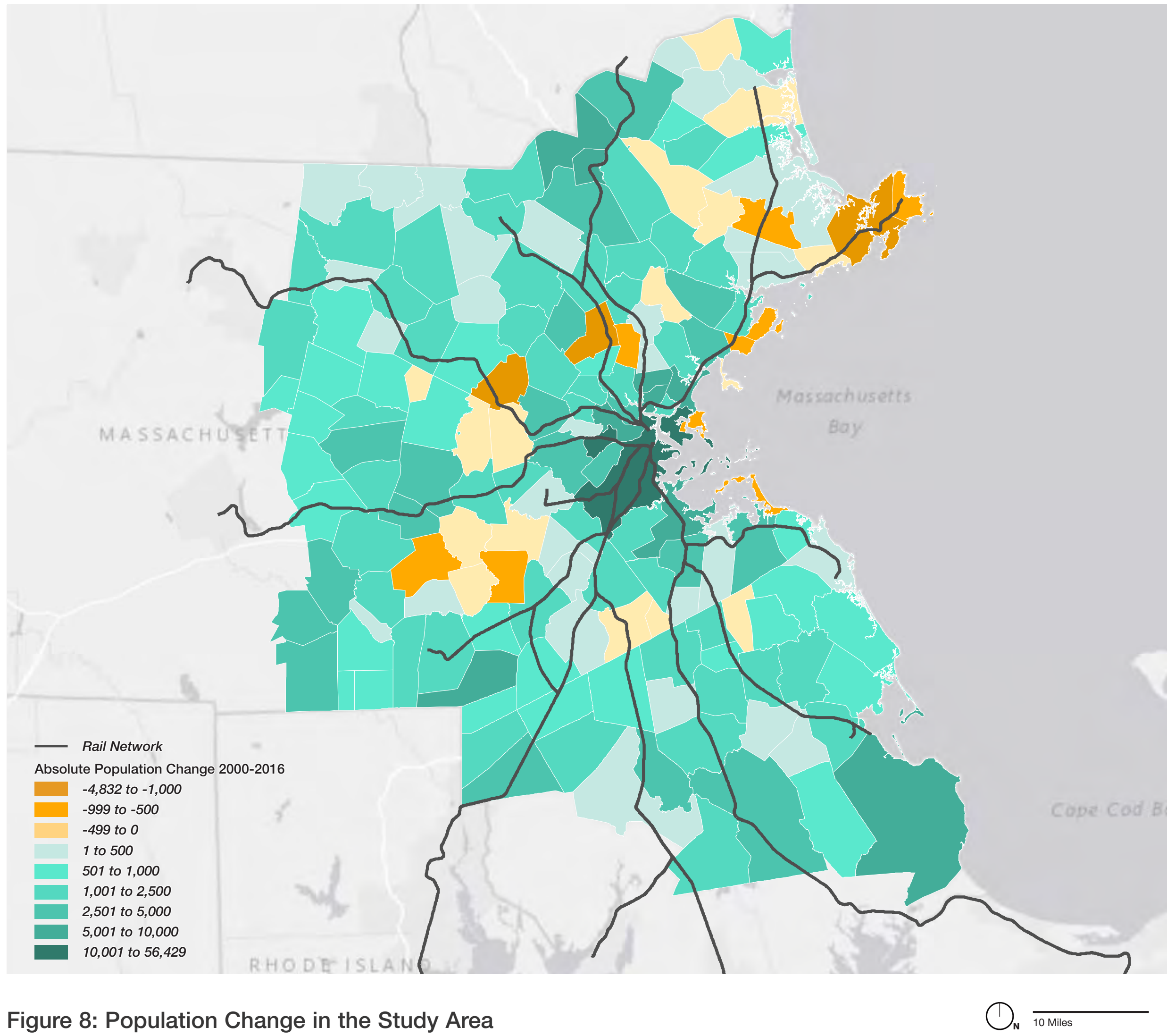

Figure 8: Population Change in the Study Area

2000—2016 – Absolute Change

Employment grew from 2.3 million in 2000 to 2.5 million in 2016, at an annual rate of approximately 0.5%. Figure 9 shows the distribution of this growth as a percentage.

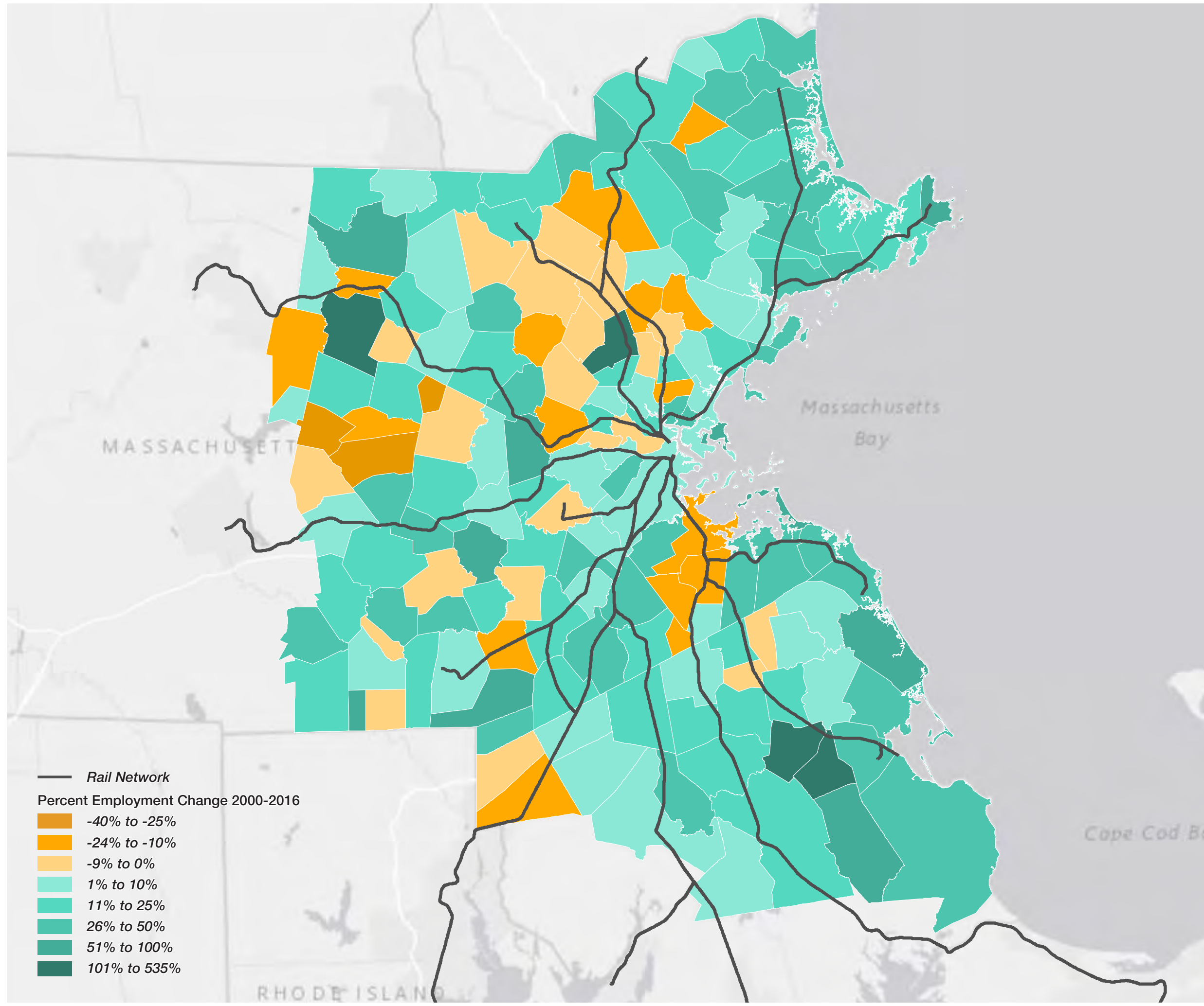

Figure 9: Employment Change in the Study Area

2000—2016 – Percentage Change

Figure 10 shows the distribution of this growth in absolute numbers.

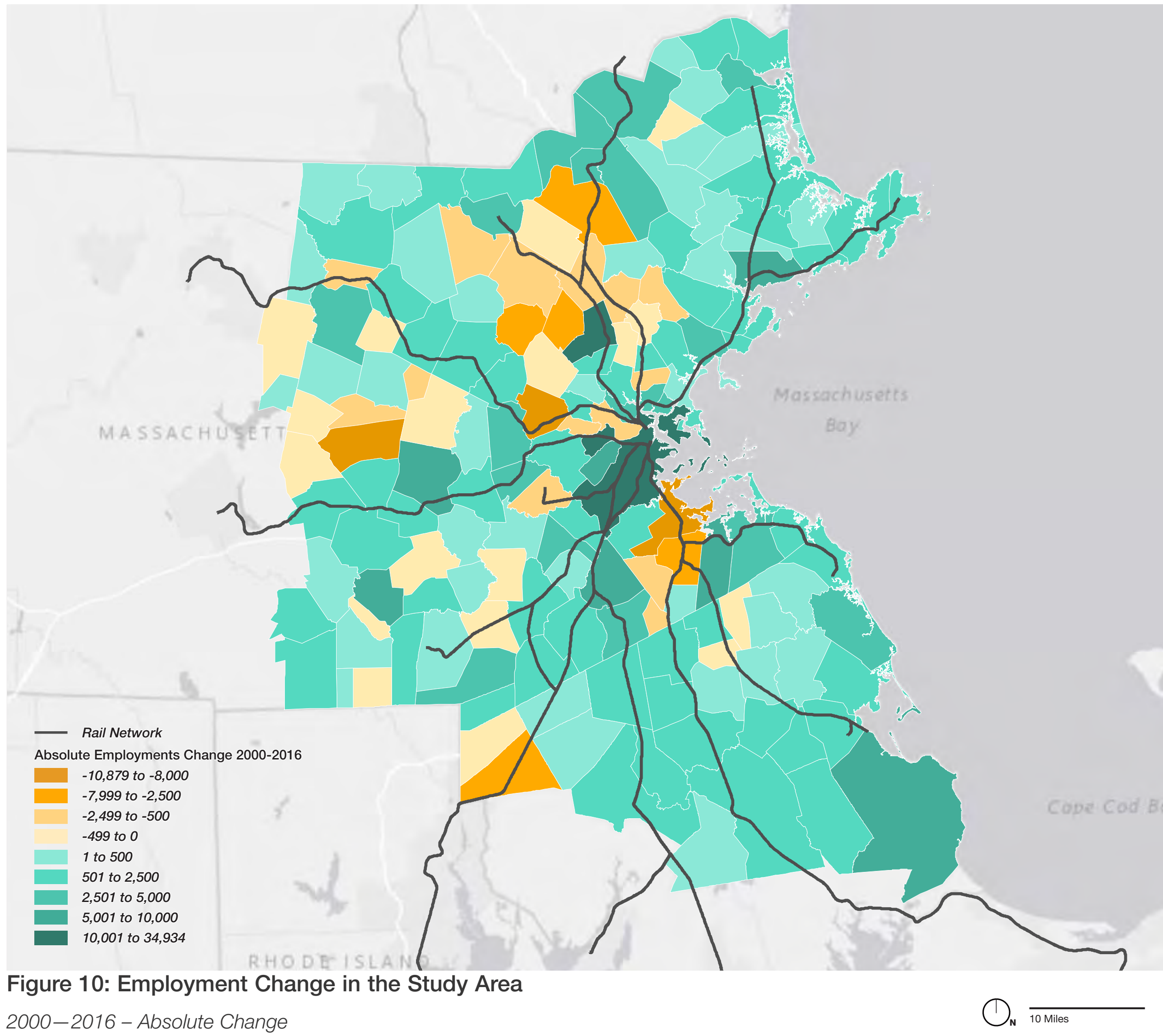

Figure 10: Employment Change in the Study Area

2000—2016 – Absolute Change

A closer look at growth in each of the geographies helps to shed light on the spatial distribution of population growth in the study area. Between 2000 and 2016, population growth concentrated in the Core Service Area, which grew at a faster rate (8%) than the Gateway Cities and the Other MBTA Service Area, each of which grew at approximately the same rate (5%). The few municipalities inside the study area but not designated within the categorized geographies saw a high growth rate, but account for a small portion of all residents.

Between 2000 and 2016, about 60% of employment growth in the study area occurred outside Core Service and Gateway Cities, indicating that growth is not tightly concentrated in one area. The rate of employment growth was lowest in the Core Service Area (which started with a large number of jobs), and the Gateway Cities greatly outpaced the other two geographic areas in the rate of its job growth. Figures 11 and 12 show the trend lines for each geography.

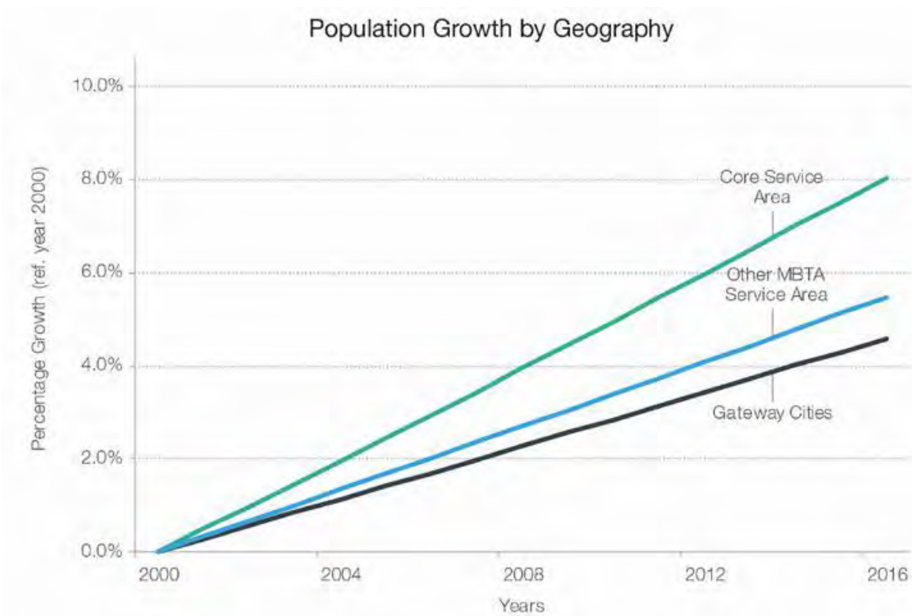

Figure 11: Population Change by Geography

2000—2016

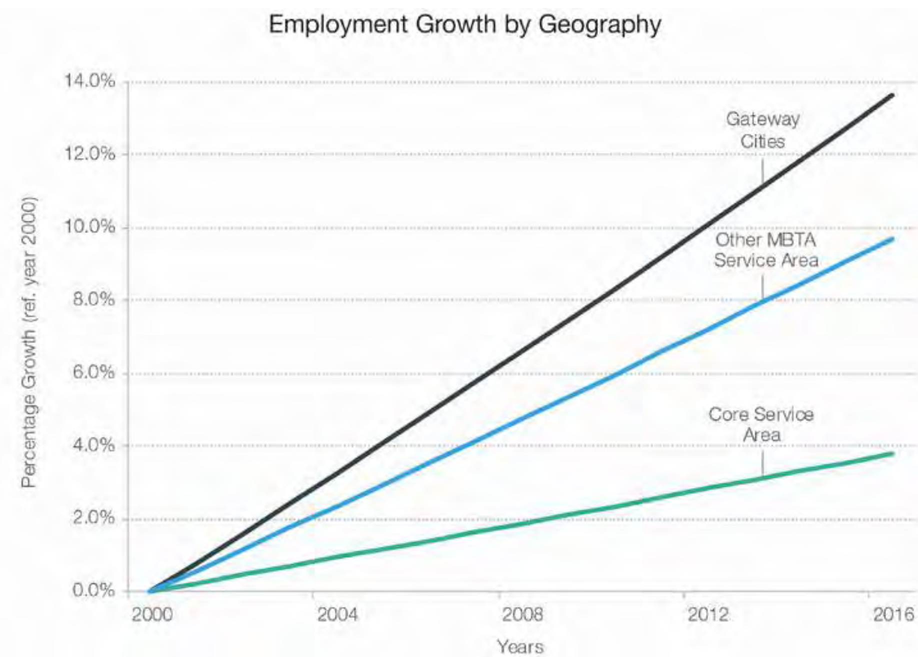

Figure 12: Employment Change by Geography

2000—2016

Auto Ownership and Land Use

Certain indicators, such as auto ownership by household and changes in land use, can be used to identify potential markets for transit.

Census data show low household vehicle ownership in the region, and this indicator has remained fairly constant since the DEIR examined data from 2000. The proportion of zero-vehicle households throughout the study area did not change significantly over the period; however, the proportion of households with access to one or two cars deceased slightly, while those with access to three or four (or more) cars increased slightly. Overall, the average rate of household vehicle ownership increased by 2.3% (or about four additional cars per hundred households) for the region as a whole. It is unlikely that this trend will have a major impact on travel throughout the study area.

Figure 13 shows the geographic distribution of vehicles per household in 2015 — unsurprisingly, the areas in the MBTA Core Service Area, well served by transit, have the lowest number of household vehicles, while the greatest numbers are seen in areas farther out from the city center. However, numbers remain low in some of these far-flung municipalities, especially the built-up Gateway Cities. Auto ownership is lower where household incomes are lower, a finding that aligns with a 2011 Brookings Institution study that found the majority of zero-vehicle households in the U.S. are located in cities and are lower-income households. This is equally applicable to the Boston-Cambridge-Quincy, MA-NH statistical area, with 58.1% of zero-vehicle households qualifying as low-income.[17]

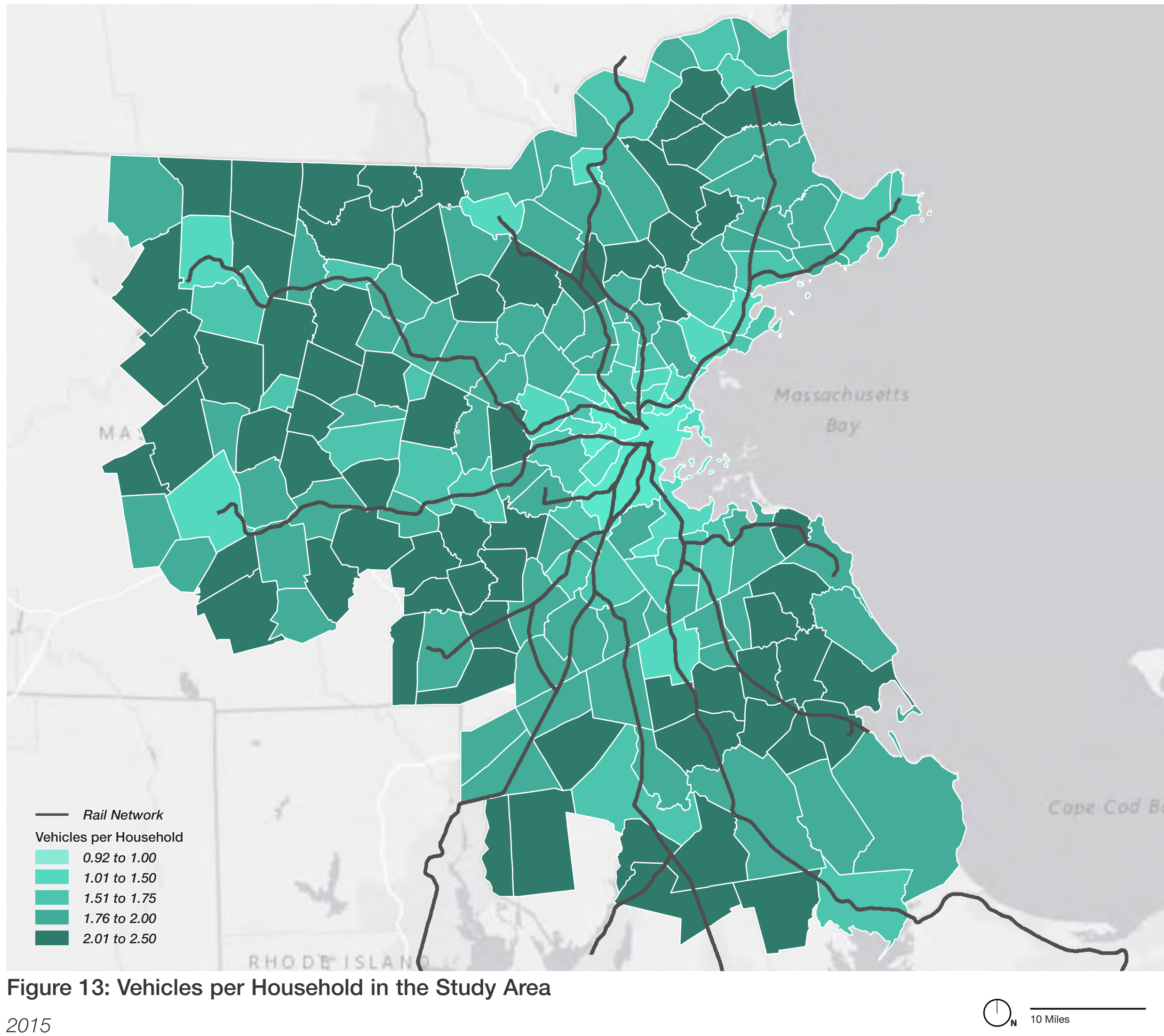

Figure 13: Vehicles per Household in the Study Area

2015

Assembly Row, an example of local transit-oriented development
Photo Source: Todd Van Hoosear / Flickr

Data from the MassBuilds development database were analyzed to determine the growth of transit-oriented development along commuter rail lines.[18] The data were obtained from MassBuilds in May 2017 and contain information on the number of residential units and commercial square footage in various stages of development within a half mile of 187 individual MBTA stations.

Since 2010, 9,627 new housing units and 6.5 million square feet of new commercial space either have been completed or are under construction within a half mile of a commuter rail station. Projects in the planning stages within a half mile of commuter rail stations accounted for an additional 11,923 housing units and 14.2 million square feet of commercial space.[19] Longer-term projects designated as projected are planned to account for 9,909 housing units and 12 million square feet of commercial space.

Of the total number of projects (completed, under construction, and planned) around the MBTA commuter rail stations included in the dataset:

- those around South Station accounted for 18% of housing units and 27% of commercial square footage,
- those around North Station accounted for 10% of housing units and 9% of commercial square footage, and
- those around Back Bay accounted for 8% of housing units and 10% of commercial square footage.

3.3 Guiding Principles

For the purposes of this Feasibility Reassessment, a set of Guiding Principles was developed. These principles provide the framework for creating the service plans for the different service alternatives, and they are the standards by which these alternatives will be evaluated.

Primary Principles

These address the major problems the NSRL is intended to solve:

- Design a system to enable service patterns that support the MBTA Focus40 goals and objectives
- Increase the capacity of the MBTA's commuter rail network to bring commuters into Downtown Boston and Back Bay during peak commuting hours.
- Improve the transit accessibility to employment opportunities in Boston's urban core, particularly for residents on the north side of the Boston metropolitan area.
- Relieve congestion on the MBTA's rapid transit network (in particular on the Orange Line) by directly connecting commuters with their final destination.
- Improve the MBTA's ability to efficiently maintain its rail fleet.

Secondary Principles

These are additional problems the NSRL can help address, but are not the primary motivation for advancing the project concept:

- Reduce the physical footprint of rail layover facilities (both at the downtown terminals and elsewhere in the urban core), freeing these locations up for higher and better use.
- Reduce the emissions associated with the commuter rail system in the urban core through the electrification of portions of the network.

3.4 Best Practices and Emerging Trends

Since the 2003 DEIR (the most recent assessment of the NSRL), advances in tunneling technology and practice have helped make large tunneling projects easier and less expensive. The information gathered in the following pages provides an indication of how far the state of the practice has come since 2003 and offers valuable lessons for the NSRL project.

Tunnel for the 7 Line Extension in New York to the 34th Street / Hudson Yards Station

Photo Source: MTA / Flickr

Peer Project Summary

Fifteen peer projects were examined to understand the details of projects similar to the NSRL. These projects — a mix of urban subway and suburban-metro services and infrastructure from around the world — each included substantial subway and underground station construction and as such were deemed representative projects for the NSRL:

- Barcelona, Spain (Line 9/10)
- Leipzig, Germany (City Tunnel)
- London, United Kingdom (Crossrail, Thameslink)
- Los Angeles, United States (Regional Connector, Gold Eastside Extension, Purple Westside Extension)
- Malmo, Sweden (City Tunnel)
- Melbourne, Australia (Metro Tunnel)
- New York City, United States (East Side Access, 7 Line Extension, Second Avenue Subway)
- San Francisco, United States (Central Subway Phase 2)
- Sydney, Australia (Sydney Metro)
- Zurich, Switzerland (Durchmesserlinie)

Cost information was not available for most projects outside of North America, and not at all for concession (public-private partnership) projects, where cost details are confidential. As a result, the cost analysis herein is limited.

However, the review resulted in some insights into the method of construction for and the scope of similar projects. The size and length of the subway projects ranged from just 1.5 miles to 19 miles, but about one-third of the projects were less than 2.5 miles. Of the projects with underground stations, the majority were cut-and-cover rather than mined (except the 46 stations of the Barcelona Line 9/10).

Costs per mile vary widely across the projects. Some of the major outliers were as follows:

- The San Francisco Central Subway project, a 1.4-mile-long light rail subway with three stations, with total per track mile tunnel costs of $112m per mile — about double the other examples
- The 7 Line Extension in New York to the 34th Street/Hudson Yards station, with a total cost of $2.4bn for a 1.5-mile extension and one new station
- The Barcelona Line 9/10, 13 miles of bored tunnel plus stations and an additional 2.5 surface/elevated miles, for a total cost of US$8.4bn — half the per track mile cost of either of the other outlier projects

Costs per track- and tunnel-mile on the other projects ranged from about $36m (New York's Second Avenue Subway) to about $65m each for LA's Regional Connector and Purple Line Extension 2. The cost per volume (per cubic foot) ranged from about $23 for the Second Avenue Subway to about $45 for the LA projects.

Station costs are another large expense, with total costs ranging from $230m to more than $1.3bn (Second Avenue Subway). The unit costs (costs per linear foot of station) ranged from $285,000 for LA's Regional Connector to $722,000 for the Second Avenue Subway. The LA Purple Line stations ranged from $340,000 to about $485,000 per linear foot.

The Second Avenue Subway had low tunneling costs and high station costs, and the LA Regional Connector had low station costs and midrange to high tunneling costs. No project reviewed had both low tunnel and station costs.

Peer Group Session

MassDOT, as part of the NSRL Feasibility Reassessment study and process, convened a peer group on October 19, 2017, to consider the work to date at the 10-week point of the study. Attendees were asked to provide guidance for the project and identify best practices from their cities.

Members of the peer group were as follows:

- Becca Nagorsky, Rapid Transit Project Planning, Planning and Policy Division, Metrolinx, Toronto
- Jeanet Owens, Program Management/Regional Rail, Los Angeles Metro
- Matt Preedy, Director of Construction Management, Sound Transit, Seattle
- Ron Hopkins, Assistant General Manager of Operations, Southeastern Pennsylvania Transportation Authority, Philadelphia
- Edward La Guardia, Michael Baker International, formerly Chief Engineer, Southeastern Pennsylvania Transportation Authority, Philadelphia

These agency staff were joined by three construction industry executives:

- Jack Brockway, President, Herrenknecht Tunneling Systems USA, Inc.
- Jim Marquardt, Senior Vice President, J.F. Shea Construction, Inc.
- Norbert Fuegenschuh, Executive President, BeMo Tunneling USA

Prior to an afternoon briefing session, MassDOT conducted an orientation walk from South Station to North Station, considering the various alignments and explaining potential constraints and conflicts. Agency attendees then presented on their respective projects, and the industry experts shared insights on best practices. The day wrapped up with a progress update from the NSRL project team and a presentation on purpose and need from the NSRL Working Group.

Key conclusions from the day included the following:

- Maintain a focus on developing strategic network goals against which to evaluate proposed system elements.
- Identify benefits to all system users, rather than focusing on just a few.
- Take the eventuality of risks seriously, including significant contingencies (50 to 60%), and spread the responsibility for the risk to match the significant unknowns of the project.
- Put in place project delivery methods that help anticipate project costs and risks.
- Understand the balance between operational efficiency and ease of use for passengers.
- Structure operations to minimize unintended effects (such as longer routes having less recovery time and a subsequent increase in delays, or new stations adding journey time to those farther out on the system).
- Ensure the outlying infrastructure (beyond the limits of the major project) can support the full potential of the major investment.
- Engage early with contractors in order to get feedback on the project.
- Maintain momentum for the project, and build a coalition of influential supporters for the project.

Tunnel Boring Machines

The majority of the tunnels would be constructed using tunnel boring machines (TBMs), which have developed in both capability and technology over the last three decades, resulting in the ability to develop larger-diameter TBMs, as illustrated in Figure 14. Since the 1997 NSRL Technical Report No.3: Schematic Design Report was prepared, TBMs of over 41ft in diameter have been used in major tunneling projects, up to the current maximums of 57ft 6in in soft ground (both for the State Route 99 Alaskan Way Tunnel in Seattle and the Tuen Mun to Chep Lak Kok connection in Hong Kong) and 51ft 3in in rock (Italian Motorway Pass A1).

TBM technology has also improved the ability to excavate tunnels under high groundwater pressures, and the amount of settlement caused by TBM tunneling has steadily reduced over the last two decades, due to the increased sophistication of TBM control systems and rapid development of chemical conditioners to control the excavated material. This increased level of control is likely to reduce the extent of mitigation needed to building foundations to avoid settlement damage.

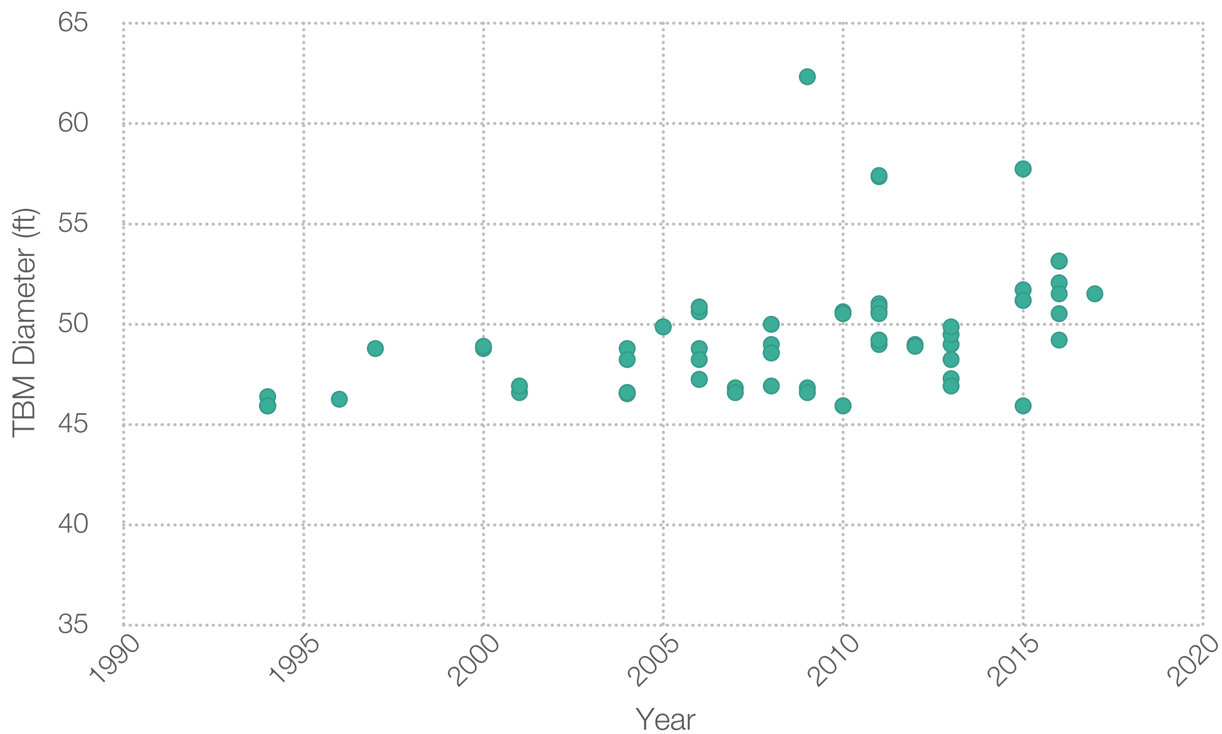

Figure 14: Increase in TBM Diameters

1990–2017
Source: https://www.tunneltalk.com/Discussion-Forum-Mega-TBMs.php

Motive Power

The 2003 study recommended the use of dual-mode locomotives, allowing electric operations within the tunnel and any other electrified areas, and diesel mode where electrification is not available. This would allow the existing MBTA coach fleet to be utilized through the tunnel.

Recent examples of dual-mode locomotives (specifically in North America, the ALP-45DP) have shown that they can offer performance in diesel and electric mode similar to that of single-mode diesel locomotives and electric locomotives, respectively. While capital costs can generally be expected to be greater for a dual-mode locomotive than for an equivalent diesel locomotive, dual-mode locomotives generally have maintenance costs comparable to single-mode diesel locomotives and significantly lower operating costs when operating in electric mode than when operating in diesel mode (see Table 7).

In terms of operations, some current dual-mode locomotives can change modes (between diesel operation and electric operation) while in motion, while others must be stopped to complete the change. Stationary mode changes, when required, typically take less than two minutes to complete and can be completed during station stops — the mode change itself can have little impact on overall run time.

One development that could ultimately make dual-mode locomotives unnecessary in the future is that of fully electric battery vehicles, supplemented with some sections of electrified territory. Batteries and ultracapacitors, which have begun to be tested by railroads in North America and worldwide, have potential to lower the emissions of rail systems. While still in the early stages, these technologies are expected to continue to improve considerably in the coming years, bringing down prices and improving their economic feasibility.

Item	Cost per Locomotive Mile (2017 dollars)	Cost per Locomotive Mile, Compared to Diesel Operations
Diesel Propulsion	$8.12	-78%
Electric Propulsion	$1.80	
Diesel Locomotive Maintenance	$5.66	0%
Diesel/Electric Dual-Mode Maintenance	$5.66	

Table 7: Locomotive Operating and Maintenance Costs by Type [20]

Given that limitation, battery tender railcars appear to be a promising technology in the mid-term. These cars could be placed in trainsets immediately behind a locomotive to power it through environmentally sensitive areas. In addition to having zero onboard emissions, the battery-tender-car concept would also have the specific advantage of being compatible with existing electric locomotives.

Battery component costs are forecast to decrease by two-thirds between 2012 and 2030, which is expected to minimize the differences in cost between conventional diesel locomotives and near-zero or zero-emission locomotives. However, battery tender technology remains in the conceptual stage, and additional research will be needed to assess its feasibility for the NSRL project.

Bombardier ALP-45DP locomotive

Source: Wikimedia / Fan Railer