NORTH SOUTH RAIL LINK FEASIBILITY REASSESSMENT

Context Review Technical Memorandum

January 18, 2018

1 Purpose of Document and Summary

This document identifies the major changes in the North South Rail Link's (NSRL) context since the Draft Environmental Impact Report (DEIR) was completed in 2003. It examines changes in engineering, technology, development, demographics and ridership that could have an effect on the NSRL's feasibility, and lays out Design Criteria, Study Objectives and Guiding Principles to shape the development of new alternatives and service plans for the NSRL.

The reassessment of the major components of the 2003 NSRL DEIR has revealed the following significant changes:

- Advances in tunneling technology since 2003 mean that Tunnel Boring Machines (TBMs) are now able to bore larger tunnel diameters and reduce the extent of mitigation needed to building foundations to avoid settlement damage
- FRA-compliant locomotives and electric multiple units are considered necessary for use across the network
- Modern signaling systems can allow for a greater number of trains to travel through the tunnel (subject to constraints on the rest of the commuter rail network)
- Flood resilience is an increased concern for NSRL portals and stations, and should be incorporated into any proposed design
- Significant development along the proposed NSRL alignment since 2003 has resulted in some conflicts which will need to be mitigated
- Commuter rail ridership has declined since 2009, and the most recent figures (National Transit Database from 2015) are only half of what was projected in the DEIR
- Population and employment in the region, while growing, are also progressing slower than DEIR forecasts

Full-page maps and figures are included at the end of the memo, as well as a list of definitions. The technical memo is organized as follows:

2 Summary of 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 component of the larger 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 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 Massachusetts Bay Transportation Authority (MBTA), FTA, the Massachusetts Highway Department, Amtrak and EOTC partnered on a Major Investment Study/Draft Environmental Impact Report (MIS/DEIR), released in June of 2003. The study identified a No-Build scenario as well as a Build Alternative with multiple variants, accounting for different numbers of tracks, locations of south portals, number of stations, and alignment of the southern section of tunnel. The following variants were evaluated for 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 context (planning, environmental and engineering) the DEIR established provides the base case against which this reassessment is being conducted. Other documents reviewed for this feasibility reassessment include:

- 1996 Schematic Design Report (Technical Report #3)
- 1997 Operations Study (Technical Report #5)
- 1997 Economic Briefing Paper (Technical Report #8)
- Other 1995-1997 Technical Memoranda
- Materials from the Central Artery Rail Link Task Force process
- Constructability Peer Review Report

The reassessment also takes account of contemporaneous planning and policy documents such as the MBTA's Focus40 planning process, the MBTA 2017–2021 Capital Investment Plan, the

Metropolitan Area Planning Council's (MAPC) Metro Future (30-year plan), the Boston Region Metropolitan Planning Organization's Long-Range Transportation Plan, and Go Boston 2030.

3 Technology and Regulatory Environment

This section examines changes in technology or regulation that could affect the construction and design of the NSRL. These various changes are discussed in more detail below.

3.1 Tunneling methods

3.1.1 TBM diameter

The majority of the tunnels would be constructed using Tunnel Boring Machines (TBMs), which have developed in both capability and technology over the last four decades. At the time the 1997 NSRL Technical Report No.3: Schematic Design Report was prepared, the Constructability Peer Review Committee report noted that "a tunnel boring machine of 41-foot diameter has not yet been constructed to date". While this was not strictly true, as maximum TBM diameters had reached 46'-6" by 1997, it was certainly the case that TBMs of this diameter were relatively new technology at the time. Since then, progressively larger TBM diameters have been used, up to the current maximum of 57'-6" in soft ground (both for the SR-99 Alaskan Way Tunnel in Seattle and the Tuen Mun to Chep Lak Kok connection in Hong Kong), and up to a maximum of 51'-3" in rock (Italian Motorway Pass A1). The maximum diameter of hard rock TBMs has lagged behind soft ground due to the higher forces required to excavate rock tunnels. However, as shown in Figure 3.1, a 41'-0" diameter TBM would now be well within the range of common practice for both soil and rock tunnels.

3.1.2 TBM tunneling below groundwater pressure

TBM technology has also improved the ability to excavate tunnels under high groundwater pressures. As shown in Figure 3.2, tunnels have been excavated under steadily increasing external water pressures over the last several decades up to a current maximum of 14 bar (203 psi; equivalent to around 430ft of water depth). This is significantly in excess of what would be required for construction of the NSRL tunnels.

3.1.3 TBM settlement control

The amount of settlement that is 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 method of control has been demonstrated on multiple projects, including:

- Central Subway, San Francisco, where two new tunnels were excavated in soft ground 11 feet below and perpendicular to the existing BART tunnels, with minimum settlement and no interruption to train service.
- Crossrail, London, where in a location that became known as the "Eye of the Needle", the new tunnel was excavated over existing Northern line tunnels and under an escalator tunnel, with less than three feet of clearance above and 1.5 feet below, with no damage to existing tunnels.

This increased level of control is likely to reduce the extent of mitigation needed to building foundations to avoid settlement damage. This is discussed in Section 4 in more detail.

When the DEIR was prepared, one critical aspect that may not have been fully taken into account was that TBM technology is not very good at dealing with 'mixed face' locations where the ground changes from soil to rock. This is due to the large difference in the strength and stiffness of the ground between the soil and rock. Without mitigation measures, there is a tendency to over-excavate the overlying soil, leading to surface settlement, and in the worst case, the development of sinkholes. This issue has been documented in a number of technical papers, including Shirlaw, J.N. and Boone, S. Australian Tunnelling Conference 2005 - *The risk of very large settlements due to EPB tunnelling*. The problem can be avoided using ground improvement such as grouting to increase the strength and stiffness of the soil, but this requires access from the surface.

Sometimes, excavations for station structures can be located at these interfaces, and the TBM does not have to pass through this mix of soil and rock. Understanding where the interface locations occur along the alignment are important so that it can be verified that there is suitable access for ground improvement or so that station structures can be appropriately positioned. A preliminary evaluation of the elevation of the top of rock along the NSRL Dorchester Avenue alignment has been conducted and is shown in Figure 3.3. This shows that there are two locations where the alignment enters mixed face conditions along the TBM tunnel alignment. At the beginning of the TBM drives from the north portal, the tunnel would start in a mixed face condition which would continue for around 700 feet. This would best be mitigated by a combination of lowering the alignment by five to ten feet, extending the length of cut-and-cover, and/or by ground treatment. Just north of South Station there is a 1000- to 1500-foot length of mixed face tunneling, which would be best avoided by lowering the alignment by approximately 15 feet over this section.

3.2 Vehicles

The previous 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.

3.2.1 Dual-mode locomotives

A detailed memorandum has been prepared on the experience, applicability and cost of dual-mode locomotives (including fire and life-safety requirements) and this has been attached as an appendix.

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 5).

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.

In the near future, dual-mode locomotives may be unnecessary — fully electric battery vehicles, supplemented with some sections of electrified territory, will likely be available and viable. 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.

Battery technology has been examined for use in freight locomotives to reduce diesel fuel consumption. One study forecasts "up to a 25 percent reduction in diesel fuel consumption and [greenhouse gases]…and zero exhaust emissions for a significant portion of operations in and around railyards while in lower power settings."20 However, current battery technologies lack the energy density to fully power freight interstate line-haul locomotives over long distances and under extreme duty cycles.

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.

3.2.2 Rail vehicle static end strength

"49 CFR 238.203 - Static end strength" is the section of the federal regulations relating to static end strength (or buff strength, as it is generally referred to). This requires all passenger equipment to resist a static end load of 800,000 pounds without permanent deformation of the body structure. These requirements are unchanged since introduced in 1999.

Although waivers are available under certain circumstances to use rolling stock designed with crash energy management, these typically require temporal separation from freight trains, which is not implementable on the local network. Therefore, FRA-compliant locomotives and electric multiple units are considered necessary for use across the network.

The FRA has circulated a notice of proposed rulemaking (NPRM) to amend its regulations for passenger equipment safety standards (docket no. 4910-06-P). This would establish alternative crashworthiness and occupant protection performance requirements to those currently specified for Tier I passenger trainsets.

The FRA published a report in 2011 – *Technical Criteria and Procedures for Evaluating the Crashworthiness and Occupant Protection Performance of Alternatively Designed Passenger Rail Equipment for Use in Tier I Service* – which established guidance for evaluation of waivers to the existing crashworthiness standards. This alternative criterion would be codified into the FRA regulations if adopted, removing the need for waivers, but not changing the undermining requirements for Tier I crashworthiness.

3.3 Fire and life-safety requirements

The National Fire Protection Association (NFPA) 130 guidance for fixed guideway transit and passenger rail systems has changed in numerous relevant areas since the 2003 DEIR, including:

- Technical revisions to the egress requirements and calculations for stations;
- [Expanded] Use of escalators in the means of egress;
- Power supply to tunnel ventilation systems;
- Elevators to be counted as contributing to the means of egress in stations;
- Technical revisions relating to escalators, doors, gates, and turnstile-type fare equipment;
- Enclosed stations are now required to be equipped with a fire alarm system, and enclosed stations and trainways (tunnels) are now required to be equipped with an emergency communication system; and
- Guidance on establishing noise levels in order to maintain a minimum level of speech intelligibility through the emergency communication system.

Table 3.1: 2017 NFPA 130 Egress Capacity and Travel Speed Changes Since 2003

Location	Capacity		Travel Speed	
	2003 DEIR	2017 NFPA 130	2003 DEIR	2017 NFPA 130
Corridors and ramps <4%	50 ppm per 22” wide exit lane	2.08 p/in.-min.	200 fpm	124 fpm 200 fpm (concourse)
Stopped escalators	35 ppm per 22” wide exit lane	1.41 p/in.-min.	50 fpm (vertical)	48 fpm (vertical)
Stairs down	40 ppm per 22” wide exit lane	1.41 p/in.-min.	60 fpm (vertical)	48 fpm (vertical)
36” wide doors and gates	30 ppm	60 ppm (single doors/gates)		
20” wide fare gates	50 ppm	50 ppm fare gates		
18” wide fare gates	35 ppm	25 ppm turnstiles		

** ppm – persons per minute*
***p/in.-min. – persons per inch per minute*
****fpm – feet per minute*

3.3.1 Emergency ventilation

Since the 2003 DEIR, technology has evolved to evaluate the design fires (heat release rate) for commuter rail vehicles using sophisticated Computational Fluid Dynamics (CFD) programs. This directly impacts the tunnel emergency ventilation capacities and design. These new tools can be used to maximize fan placement (efficiency) and verify/validate the existing 500 feet per minute design criteria. Therefore, it is recommended that the design fires and emergency ventilation be evaluated in the next project phase to explore any cost-benefit to the NSRL.

3.3.2 Evacuation routes

Due to improved emergency ventilation systems and fire detection systems since the 2003 DEIR, the industry is more accepting of longer evacuation routes and cross-passageways, and the availability of modern security cameras/systems allows for evacuation monitoring and situational awareness. Consequently, using a holistic fire/life-safety approach for the NSRL may develop a more cost-effective solution.

3.4 Signaling and communications

The DEIR noted that the NSRL tunnel would be able to accommodate 15 trains per hour, per direction. Modern signaling systems are capable of accommodating up 24 trains per hour (like Crossrail in London), which also helps to alleviate performance issues and improve service. While modern systems allow such a large number of trains to progress through the tunnel, further analysis on other constraints on the commuter rail network still needs to be completed before a baseline can be established for this reassessment.

A major change to the regulatory environment since the previous study was published in 2003 is the introduction of the Rail Safety Improvement Act of 2008 (RSIA). Among other things, this mandated that Positive Train Control (PTC) be implemented across a significant portion of the nation's rail industry by December 31, 2015 (subsequently extended to December 2018 with the potential for further extensions to December 2020 under certain circumstances). While the previous study assumed a modern signaling system for the new infrastructure, this legislation additionally requires improvements to the existing network.

The MBTA response to this initiative resulted in the award of a contract to deliver a complete PTC system on the entire commuter rail network. The contract includes design, integration, installation, testing, commissioning, training, and warranty. The current schedule requires hardware installation by December 2018, and a fully operating system in place by December 2020.

PTC systems must be designed to prevent

- Train-to-train collisions;
- Overspeed derailments;
- Incursion into an established work zone; and
- Movement through a main line switch in the improper position.

Other functions are applicable within the requirements as specific conditions warrant. The PTC installation is likely to be complete before NSRL construction begins, and so will not have a significant impact on the project.

3.5 Traction power and catenary systems

It was previously assumed that the tracks in the tunnel would be electrified using an overhead catenary system (OCS), with the OCS treated as an extension of the electrification carried out under the Northeast Corridor Improvement Project. The electrification under the 2003 NSRL project concept would expand from the Back Bay portal to the Regional Transportation Center in Woburn.

Rigid bar catenary systems could be used to minimize the height required for the OCS and reduce the tunnel diameter. The clearance between the catenary and the tunnel roof can be as low as 400mm (1’4”). There is limited experience with such systems for extended sections of track both nationally and globally, so the long term reliability and maintenance implications are not well-understood.

Such systems claim maximum track speeds of up to 180mph (300kph) with a supply of 25,000 volts AC power.

3.6 Platform screen doors

The majority of new underground rail systems currently in construction utilize platform screen doors. These have a number of advantages, including improving the ventilation and climate control of the station (in both operational and emergency conditions), allowing for narrower platforms, reducing the risk of accidents, improving security by limiting access to the tracks, preventing litter on the tracks, and improving the overall ambience of the station.

The main disadvantage of platform screen doors is that all rolling stock in use needs to have the same door locations and spacing. If construction of the tunnel is tied to procurement of new multiple units or other specific rolling stock, then platform screen doors may be appropriate.

4 Engineering Assumptions

This section reviews engineering assumptions built into the original concept design, including assessments of the NSRL design concepts.

4.1 Tunnel diameters

The tunnel internal diameters used for the DEIR were 26 feet for a single-track tunnel (29 feet external), and 38 feet for a twin-track tunnel (41 feet external). Technical Report 3, Section 3.4.1 states that these diameters were developed as follows:

- MBTA minimum clearances for new construction on the Northeast Corridor (NEC)
- 8’-6” side clearance
- 19’-6” vertical clearance, extending 7’-0” either side of the centerline
- 2’-6” for catenary wire and supports

For this feasibility reassessment study, MBTA provided details of the train envelope used to procure and qualify the revenue equipment which operates in the MBTA commuter rail environment. This information is shown in Figure 4.1. This provides a slightly smaller train envelope that that described above, with a side clearance of just under six feet, and a vertical clearance of just under 16 feet. As described in Section 3.5, rigid catenaries are also likely to allow a small reduction in the space allocated for catenary wires and supports.

The DEIR tunnel diameters have also been compared with those developed to construction bid-level design for the Access to the Region’s Core Trans Hudson Express (THE) tunnels, completed in 2010. These tunnels would have also formed part of the NEC, conveying Amtrak trains and double-height New Jersey Transit trains, which have a very similar train envelope to the MBTA rolling stock. As shown in Figure 4.2, the single-track THE tunnels were designed to be 24’-6” internal diameter, which included an allowance for supplemental internal ventilation ducts for the long tunnels under the Hudson River (unlikely to be needed for NSRL). Based on this comparison, it can be concluded that the diameters included for the single-track tunnels in the DEIR are adequate, and probably slightly generous. The THE project did not include twin-track tunnels, but an arrangement has been developed in Figure 4.2 using the single-track tunnel design. This resulted in an internal diameter of 38’-0”, which is the same as the DEIR design. The arrangement in Figure 4.2 includes an internal wall to provide separation between the two tracks for ventilation and fire/life safety purposes, which does not appear to have been included in the DEIR configuration.

It would appear that the tunnel diameters used in the DEIR are still adequate, and that there is potential for a reduction in the diameter of the single-track tunnels.

4.2 Potential underpinning requirements

Where the proposed NSRL excavations for tunnels and stations are under or adjacent to existing structures, underpinning may be required. Tables 4.1 and 4.2 identify the surface structures and infrastructure elements identified as potentially impacted. The extent of modifications needed will range from nothing to underpinning or full replacement (from the DEIR Technical Report 3, 3-6 to 3-8). Most of these properties were identified in the DEIR but there are a few additional properties from new construction.

The advances in TBM settlement control described in Section 3 mean that it is likely that less intrusive mitigation work, such as underpinning, would be needed now, compared with twenty years ago.

Table 4.1: Potentially Impacted Structures – Identified in DEIR

Structure / Infrastructure element	**Modifications needed**
Tremont Street Overpass	Impact depends on portal alignment
Shawmut Avenue, Washington Street, Harrison Avenue Overpasses	Full reconstruction
Herald Street	Street to be placed on deck
I-93 and ramps in the South Bay Interchange	Limited impacts
I-90 and ramps (Massachusetts Turnpike)	Underpinning on Central Artery/Tunnel (CA/T)
The Broadway Bridge	Potential settlement impacts on bridge
South Station Transportation Center	Significant underpinning to construct station on CA/T alignment
The South Station Headhouse	Significant underpinning to construct station on CA/T alignment
U.S. Post Office	Significant underpinning to construct station on CA/T alignment (unless demolished)
Stone and Webster Building (Summer Street)	Potential settlement impacts
Federal Reserve Bank Building	Significant underpinning to construct CA/T alignment
Fort Point Channel Seawall	Potential rebuild of seawall
Summer Street Bridge	Potential settlement impacts on bridge
Congress Street Bridge	Potential settlement impacts on bridge
MBTA Red Line Tunnel	Potential settlement impacts
MBTA Transitway Tunnel (Silver Line)	Limited impacts
Russia Wharf Building (Atlantic Wharf)	Potential settlement impacts
Central Artery/Tunnel (CA/T) Project	Significant underpinning to construct stations; limited tunneling impacts
CA/T Project Vent Building No. 3 (InterContinental Hotel)	Limited impacts
Boston Electric Company (BECO) Property (Atlantic Avenue)	TBM may encounter piles
Harbor Plaza Building (Old Sheraton Hotel)	Potential settlement of bell caissons
New Northern Avenue Bridge (Moakley Bridge)	Limited impacts
J. Hook Lobster Company	Further research required to evaluate impact
Coast Guard Building	Further research required to evaluate impact

Structure / Infrastructure element	Modifications needed
Rowes Wharf	Limited impacts
Orange Line/ Green Line SuperStation (North Station)	Limited impacts
TD Boston Garden/ North Station	Limited impacts
CA/T (I-93) Charles River Crossing (Zakim Bridge)	Potential settlement impacts on bridge
CA/T (I-93) Ramps North of the Charles River	Underpinning required
Storrow Drive Bridge over the Charles River	Limited impacts
The Charles River Dam	No impact
Boston Sand and Gravel	Assessed as design progresses
Orange Line Vent Building	Limited impacts
MBTA Bascule Bridges	Further research required to evaluate impact
Gilmore Bridge	Further research required to evaluate impact
Sites near Station Elements	Further research required to evaluate impact

New construction has resulted in some additional buildings above the alignment, as described in Table 4.2:

Table 4.2: Potential Additional Impacted Structures Since DEIR

Structure / Infrastructure element	Modifications needed
Beverly St area, Parcel 1B (MTA) Bullfinch Triangle (The Merano)	Potential settlement impacts on building, more research required to determine building foundations
110 Beverly St	Potential settlement impacts on building, more research required to determine building foundations
101 Canal St	Limited impacts
One Canal St	Potential settlement impacts on building, more research required to determine building foundations
InterContinental Boston, 510 Atlantic Ave	Potential settlement impacts on building, more research required to determine building foundations (Opened in 2006, it is included in this report because it was not completed by the time of the previous report)
110-112 Broad Street (The Boulevard)	Potential settlement impacts on building, more research required to determine building foundations
Atlantic Wharf, 280 Congress St	Limited impacts (Opened in 2011, construction began in 2007/2008, it is included in this report because it was not completed by the time of the previous report)
Lovejoy Wharf, 100 Lovejoy Wharf	Limited impacts
Boston Garden Expansion, 80 Causeway Street (Hub on Causeway)	More research required to determine building foundations

4.3 Flood protection options

After Hurricane Sandy in 2012 and accompanying growing awareness of extreme weather and future climate change risks in the Boston area, the MBTA recognizes the need to incorporate resilience in infrastructure design. Boston is a coastal city requiring attention to 100- and 500-year floods (each with a 1% and 0.2% annual chance of occurring, respectively). The South Bay Portals (Dorchester Branch and Old Colony Lines) are both currently within the 500-year floodplain according to FEMA's current flood maps. As sea level rises, the coastal floodplains will expand, as evidenced by the Boston Harbor Flood Risk Model (BH-FRM), which was developed by the Woods Hole Group and in use by the City of Boston, City of Cambridge, MassDOT's Highway Division, and the MBTA. The Back Bay and North Portals will be in flood zones by no later than the 2070s.

Flood protection for the impacted portals of the NSRL can be provided by either setting the elevation of all entrances into the tunnel system (portals, station entrances, vent shafts, etc.) above the predicted flood elevation, or by providing flood doors at the entrances. Figures 4.3 and 4.4 show the FEMA flood maps for the CA/T, North Station and South Station areas. With ongoing sea level rise, and the more significant storm surges from extreme weather events, it would be typical to design to at least the 1 in 500-year levels, as projected through at least the 2070s. Based on these criteria, flooding of the NSRL can be avoided by providing flood prevention measures as shown in Table 4.3. It should be noted that in the "boat" sections of the portals, anti-buoyancy measures such as tension piles or additional structural weight may be needed to avoid flotation in the event of high water levels outside the structure.

The stations along the proposed route also require flood resilience consideration. South Station is not currently in a floodplain, but as sea level increases, Dorchester Avenue is projected to be in the 1-year floodplain by the 2070s. One possible way to resist flooding is to raise the station entrances by having passengers go up a few stairs or a short ramp before going down into the station. Similar measures are also suggested at the proposed Central and North Stations, because these stations fall near the 100-year floodplain (but not directly in it). Table 4.3 shows the flood prevention requirements proposed for each station and portal.

Table 4.3: Flood Protection Measures

Portal	Within flood plain?	Resiliency measures to avoid flooding
Back Bay Portal	10-year by 2070s	By 2070s, 500-year flood depths at street level could exceed 10 feet. Portal protection (flood gate) would prevent any tunnel flooding.
South Bay: Dorchester Portal	1-year by 2070s	500-year flood depth by 2070s up to 2.5 ft. in vicinity of both South Bay Portals. Portal protection (flood gate) would prevent any tunnel flooding.
South Bay: Old Colony Portal	1-year by 2070s	
North Portal: Eastern Portal	20-year by 2030s 1-year by 2070s	500-year flood depth by 2070s up to 4 ft. Portal protection (flood gate over entrance) would prevent any tunnel flooding
North Portal: Western Portal	10-year by 2070s	500-year flood depth by 2070s up to 2.5 ft. Portal protection (flood gate over entrance) would prevent any tunnel flooding
Station		
South Station	100-year by 2070s	By 2070s, 100-year flood depth could be 1 ft. 500-year flood depth projected to be 2 ft. Flood-proofing first floor of building (including sealing all walls and installing flood gates at doors) is an option.
Central Station	Currently in 100-year	Current 500-year flood depth is 1.5 ft. Flood depth projected to be over 10 ft. by 2070s. Flood-proofing station entrance(s) is an option.
North Station	10-year by 2070s	By 2070s, 500-year flood depth is projected to be 3 ft. More frequent flooding could be 1-2 ft. Flood-proofing first floor of building (including sealing all walls and installing flood gates at doors) is an option.

4.4 Mined station construction

While South Station is planned to be constructed as a cut-and-cover station, the North and Central Stations are required to be mined, due to the lack of surface access. Various options were considered for the mined North and Central four-platform stations in the DEIR (see Figure 4.5).

The preferred option consisted of a station with a 160-foot-wide span formed within an enclosure of interlocking small-diameter tunnels. The reference for this project was the Mount Baker tunnel in Washington, which is a near-circular tunnel with a span of 65 feet. The proposed NSRL stations were shown with an oval single vault with a much larger span. This approach would be without precedent and is considered unlikely to be practical. The two- or three-vault options are considered possible, although the structure would require significant structural columns between each of the vaults. The option with mined tunnels between the tunnel bores would lead to an unattractive station configuration with extensive columns and is not recommended.

An alternative for station construction that does not appear to have been considered in the original analysis is the “binocular” tunnel configuration. In this arrangement, which has been used on London’s Crossrail project, smaller tunnel diameters can be used by having separate tunnels for each platform as well as a central concourse. A typical configuration is shown in Figure 4.6. This is an ideal method for construction in soft ground where large spans are not possible. Evaluation of the likely ground conditions has identified that the North Station is primarily in soil, while the Central Station is in rock, although with very shallow cover (see Figures 4.7 and 4.8).

For the two-platform station option, either a single cavern or a binocular tunnel configuration would be possible. If a third platform is needed to allow sufficient dwell time for Amtrak trains while still providing enough capacity for a high-frequency commuter service, some combination of these two arrangements would be needed.

4.5 As-built design of Central Artery project

A 3-D model is being built that incorporates the as-built design of the Central Artery Project. This will be analyzed separately for the purpose of updating the Schematic Design Report for this feasibility reassessment of the NSRL.

5 Design Criteria

Recommended design criteria for the NSRL assessment have been provided as a separate document for agreement with MBTA (included as an appendix to this document). Amtrak and MBTA design criteria and the previous study parameters were all reviewed, and a set of criteria proposed for use on the project. In most cases, reasonably conservative values were specified for preferred values, with a design exception process identified for conditions where preferred values cannot be met. To justify the use of exceptions, further analysis and documentation is required, including impacts to construction, operations, cost and schedule implications, etc.

Grades are the key area in which values have been identified in excess of MBTA and Amtrak preferred values. The proposed design criteria set out a preferred maximum grade of 2%, with an exception limit of 3%. This builds on work carried out in previous studies and allows a deep tunnel with portals at Back Bay and North Point. These values have been discussed and agreed with the MBTA as suitable for the NSRL project.

6 New Development at Tunnel Portal Locations

This section examines the current feasibility, ownership and required size of all proposed tunnel portals and construction laydown areas for the NSRL project.

6.1 North portals

The Fitchburg Line portal and the Lowell Line portal would be constructed adjacent to the existing rail lines and yard. The previous design called for a laydown area at North Point, now unavailable due to development of the site. Recent and planned developments in the area include:

NorthPoint Development. The NorthPoint infill development site occupies 45 acres in a triangle bounded by the Gilmore Bridge to the east, the O'Brien Highway to the south, and the MBTA commuter rail yard and maintenance facility to the north. Its 20 planned development parcels and 11 acres of open space are directly adjacent to tracks leading out of North Station.

Twenty|20. Opened in 2015, Twenty|20 is a 21-story residential tower directly west of the Gilmore Bridge and adjacent to the larger NorthPoint site, with several lower floors offering retail and extending farther north (towards the MBTA tracks) than the tower footprint.

Green Line Extension. The Green Line Extension (GLX) project extends the Green Line light rail from its Lechmere terminus in Cambridge to Somerville and Medford. Its two branches would use existing MBTA commuter rail rights-of-way, following the Lowell Line to Medford and the Fitchburg Line to Somerville. The proposed maintenance facility is adjacent to the existing MBTA commuter rail maintenance facility site.

6.2 South portals

6.2.1 Back Bay

The DEIR recommended excavating below Herald Street to allow additional space for the portal(s) in addition to the existing five tracks. The five tracks would be relocated and reconfigured to allow the appropriate disposition of NSRL tracks and connections.

Information on utilities was not gathered as part of the previous work and should be reviewed to confirm feasibility.

Portal constructability is a concern at this location, especially based on the experience of the Green Line Extension and construction access adjacent to operating commuter rail rights-of-way. This may require limited to extensive commuter rail service curtailments.

Recent and planned developments in the vicinity include:

321 Harrison Ave. This eight-story office building has been under construction since March 2017 at the intersection of Herald St and Harrison Ave. Herald St parallels the tracks out of South Station.

300 Harrison Ave. The Ink Block residential complex opened in 2015, occupies the former Boston Herald headquarters property, and is located across Harrison Ave, directly south of Herald St and the surface tracks leading into South Station. The development occupies the block bordered by Harrison Ave, Herald St, Albany St, and Traveler St. The two tallest buildings are five and eight stories, respectively, and are approximately 60 feet south of the surface tracks, though not at grade; all city streets in the vicinity are elevated above the tracks and I-90 travel lanes.

6.2.2 South portals

The South portals would both be constructed in existing railway lands with limited easements required during construction, in particular for TBM removal. Some track reconfiguration would be required for each alternative.

The Widett Circle Layover Facility proposed as part of the South Station Expansion Project would require some track relocations in the vicinity.

7 New Development Along the NSRL Corridor

Since the completion of the Central Artery project, substantial development has occurred along its alignment and in the surrounding neighborhoods. This section examines the feasibility of the original design concept from a land use standpoint, noting all new construction since the DEIR was completed in 2003 and its potential impact on the constructability and operation of the NSRL.

7.1 Methodology

7.1.1 Data sources

The following data sources were used in this analysis:

- MassBuilds.com data – A comprehensive dataset that provides an inventory of completed, current and future building projects in Massachusetts. The MassBuilds development database, administered by MAPC, has been collecting data on constructed and planned developments throughout the greater Boston area dating back to 2010.

  http://www.massbuilds.com/

- 2003 Rail Alignment – Digitized from Figure 2.5-1 from the 2003 DEIR for the NSRL project.

- Buildings data from the City of Boston (dated 2011) – Contains building outlines, as well as information including ground and building elevations.

  http://bostonopendata-boston.opendata.arcgis.com/datasets/492746f09dde475285b01ae7fc95950e_1

- LiDAR data from the MassGIS database (dating from 2013-2014)

  http://www.mass.gov/anf/research-and-tech/it-serv-and-support/application-serv/office-of-geographic-information-massgis/datalayers/lidar.html

7.1.2 Analysis

Two subsets of the MassBuilds.com data were created – one for all projects built between 2000 and 2017, and one for all future projects dated 2018 onwards. Of these, only projects that fell within 200 feet from the 2003 rail alignment were kept for further analysis. The data was then cross-referenced with the City of Boston Buildings Data. The ground elevation and building height was obtained from this dataset for all projects that were built by 2011. For all projects built after 2011 and for all future projects, the ground height was obtained by cross-referencing with the MassGIS LiDAR dataset. Building heights for these properties could only be obtained where it had been noted in the description of the property.

7.2 Background

There has been substantial development along the surface of the Central Artery since 2000. Several large projects have been completed in the last two decades, while others are in the planning phases (and anticipated to be executed in the next twenty years). This review of projects determines whether there are any impacts from new or planned construction that would affect the NSRL design concept presented in the 2003 DEIR.

Projects that fall within 200 feet of the DEIR alignments were plotted in Figure 7.1 (properties constructed or renovated between 2000 and 2017) and Figure 7.2 (planned developments). In addition, a series of historical satellite images of Boston (Figures 7.3 to 7.8) were reviewed to provide further information on the developments and identify any other locations where construction occurred that was not included in the MassBuilds database.

The information is summarized in Figures 7.9 to 7.17, which also show the proposed alignments from the DEIR.

7.3 Overview of development impacts on the DEIR alignment

Development that has occurred since the preparation of the DEIR is described below, using the same numbering and lettering system as shown in Figures 7.13 to 7.17:

1. Beverly St area, Parcel 1B (MTA) Bullfinch Triangle (The Merano) (west of alignment): This steel-framed building is currently under construction. The parking garage will be on the second floor. Additional information is needed to confirm the basement details and the type and size of the foundations. Since the development is above the Central Artery/Tunnel (CA/T), the building foundations may cause a direct obstruction to the proposed tunnels, and ground improvement work may be required to limit settlement impacts to the property.

2. 110 Beverly St, Boston (west of alignment): This is a newly constructed, luxury apartment building, The Victor by Windsor, constructed above the I-93 CA/T structure. The property has underground parking. Further research is needed to confirm the basement details, interaction with the CA/T structure, and the type of foundations used. Since the development is adjacent to the west side of the alignment and partially above it, the building foundations may cause a direct obstruction to the proposed tunnels, and ground improvement work may be required to limit settlement impacts to the property.

3. 101 Canal St, Boston (west of alignment): This is a new luxury apartment building, Avenir Apartments. There is no known parking on site, but additional research is needed to confirm this. This building has a height of 119 feet. Additional research is needed to determine the size and type of the foundations. Since the development is offset from the alignment by approximately 100 feet, the building foundations will not cause a direct obstruction to the proposed tunnels, but ground improvement work may be required to limit settlement impacts to the property.

4. One Canal St (west of alignment): This is a new luxury apartment building that includes underground parking, completed in 2016. The new foundation will be near or adjacent to the CA/T and DEIR alignment. Additional research is required to learn about the type and size of the foundations. Since the development is adjacent to the west side of the alignment

and partially above it, the building foundations may cause a direct obstruction to the proposed tunnels, and ground improvement work may be required to limit settlement impacts to the property.

5. 400 Atlantic Ave, Boston (east of alignment): This building was completed in 1890, and is 12 stories. The work on the building since 2000 is believed to have been a modernization. No new foundation work is likely but additional research will need to be done to determine the type and size of the foundations. Since the development is outside the northern reaches of the CA/T, and the foundations of the building predate the tunnel, the building foundations will likely not cause a direct obstruction to the proposed NSRL tunnels. Ground improvement work may be required to limit settlement impacts to the property.

6. 169-175 Purchase St, Boston (west of alignment): This construction appears to be the retrofitting of a preexisting structure. This would imply no new foundations have been added at this site. Since the development is offset from the alignment by approximately 45 feet, the building foundations will not cause a direct obstruction to the proposed tunnels, but ground improvement work may be required to limit settlement impacts to the property.

7. Independence Wharf, 470 Atlantic Ave, Boston (east of alignment): This building, along the Boston Harborwalk, was built in 1927 and modernized in 2001. The building has parking but additional research needs to be done to determine the location and size of the garage as well as the type of foundations used. However, these are not likely to have changed during the building modernization. This building has a height of 184 feet. The development is above the alignment for approximately 80 feet, but the building was built before the CA/T, so the building foundations will likely not cause a direct obstruction to the proposed tunnels. Ground improvement work may be required to limit settlement impacts to the property. This property is included because of changes made to it after the previous report and to ensure that all impacted properties are mentioned.

8. InterContinental Boston, 510 Atlantic Ave, Boston (east of alignment): This luxury hotel and condominium building opened in 2006 along the Harborwalk. The hotel has parking, but additional research needs to be done to learn the location of the parking garage and the type and size of the foundations. This building has a height of 253 feet. Since the approximately front 70 feet of development is above the northbound CA/T, and the building was built in 2006, the building foundations may cause a direct obstruction to the proposed tunnels. Ground improvement work may be required to limit settlement impacts to the property.

9. 110-112 Broad Street, Boston (west of alignment): This building is currently under construction. It is a concrete structure with a single-story 35-space below-ground parking garage, and will be 120 feet tall. Additional information is needed to determine the foundation size and type. Since the development is offset from the alignment by approximately 25 feet, the building foundations will not cause a direct obstruction to the proposed tunnels, but ground improvement work may be required to limit settlement impacts to the property.

10. Atlantic Wharf (formerly Russia Wharf), 280 Congress St, Boston (east of alignment): The new Silver Line tunnels were constructed under the historic Russia Wharf building and completed in 2004. The building is supported by timber piles. The new Atlantic Wharf

building, added to the site in 2011, is 456 feet tall. More research is needed to determine the foundation size and type. Since the new development is offset from the alignment by approximately 100 feet, the building foundations will not cause a direct obstruction to the proposed tunnels, but ground improvement work may be required to limit settlement impacts to the property. The preexisting Russia Wharf buildings were completed before the CA/T and the foundations will have no impact.

11. Lovejoy Wharf, 100 Lovejoy Wharf (east of alignment): Opening during the summer of 2017, this new luxury condominium building is along the Charles River near North Station. Since the development is offset from the alignment by approximately 45 feet, the building foundations will not cause a direct obstruction to the proposed tunnels, but ground improvement work may be required to limit settlement impacts to the property.

12. Boston Garden Expansion, 80 Causeway Street (west of alignment): This is currently under construction. Phase 1 includes a four-story underground parking garage and a nine-story building. Slurry walls, about 60 feet deep, support the excavation, and deep foundation elements will support the above structure. This location conflicts with a proposed DEIR station ancillary structure.

In Figure 7.2, blue stars denote properties where construction is anticipated to begin after 2018. While these do not currently pose an obstruction to the DEIR alignment, there is potential for them to limit alignment options in the future. Details of the proposed developments are in the following table:

Table 7.1: Proposed Developments in the NSRL Alignment

ID	Proposed development	Location	Additional details
A.	North Point Parcel W Development	Northern Expressway	
B.	Parcel 1 (MTA) Bullfinch Triangle	Bullfinch Triangle	(Simpson Housing)
C.	CAT Parcel 6 - YMCA	Market St & New Chardon St & N Washington St	Projected 2030
D.	198 Hanover Street		Projected 2035 (mixed use)
E.	Greenway Planning - Cross Street Crescent		
F.	Greenway Planning - Parcel 11B	1252 Cross St	Projected 2035 (mixed use)
G.	Greenway Planning - Parcel 9		
H.	Haymarket Hotel - Parcel 9		
I.	Greenway Planning - Marketplace Center	200 State St.	Proposed 2035
J.	55 India Street		Proposed 2027
K.	Greenway Planning - India Street Sites	22 Wharf St	Projected 2035 (mixed use)
L.	102-110 Broad St	(See completed, number 9)	
M.	Greenway Planning	400 Atlantic	Proposed 2035
N.	Greenway Planning - Hook Site	436-440 Atlantic Ave	Proposed 2035 (mixed use)
O.	Greenway Planning - Richardson Block	234-236 Congress St	
P.	South Station Expansion Project		Planning for 2020 (mixed use, rehabilitation)
Q.	South Station tower		667’ tall, planning to start construction by late 2017, addl. foundation work reqd.

7.4 Underground excavations and alignment impacts

In addition to the property development described above, the Silver Line tunnel, which runs beneath the historic Russia Wharf buildings and the new Atlantic Wharf building, was constructed between 1998 and 2004. The proposals for the tunnel were known during the preparation of the DEIR and it was considered in the development of the alignment. The construction methods adopted, the as-built location, and the configuration of the Russia Wharf tunnel have been reviewed. This analysis reveals no new impacts to the DEIR alignment.

8 Amtrak and MBTA Commuter Ridership Trends

This section compares commuter rail and Amtrak ridership growth with projections from the 2003 DEIR, and speculates on some of the reasons this might be different from projected figures.

8.1 Ridership

To determine demand on both MBTA commuter rail and Amtrak, and to investigate whether this has changed since the last study of the NSRL, ridership figures were collected for each of these systems. Table 8.1 below shows 2012 weekday ridership data for MBTA commuter rail taken from the National Transit Database (NTD). To approximate ridership counts on the Amtrak NEC and Downeaster services, data was used from 2012 station ridership received from Amtrak, showing ons and offs at Back Bay, South, and North Stations (this was considered more accurate than full NEC ridership data, as these include ridership for the full length of routes running down to Washington, DC and Virginia). The counts available are average weekday ridership.

Table 8.1: 2012 Weekday Ridership Data – MBTA Commuter Rail and Amtrak

	Average Weekday Ridership (2012)
MBTA commuter rail	131,160
Amtrak – NEC incl. Acela (Back Bay and South Stations)	5,660
Amtrak – Downeaster (North Station)	1,340

Figure 8.1 provides a more detailed picture of the breakdown of MBTA commuter rail ridership, indicating typical weekday inbound and outbound boardings for each line, as well as the number of peak-hour (8:00-9:00am) inbound trains on each (including Amtrak)[1]. Ridership on the system is skewed towards the greater number of lines leading to South Station, which carry about 61,500 passengers (61%) both inbound and outbound on a typical weekday, as compared to the lines running into North Station, which carry about 38,500 passengers (39%). This is roughly in line with DEIR observations about the proportion of commuter rail passengers using each terminal.

8.2 Historical trends

Examining historical ridership trends on both the MBTA commuter rail lines and Amtrak sheds light on the trends in ridership, and how these may differ from projections made in the 2003 DEIR. Figures 8.2 and 8.3 show historical trends in both MBTA and Amtrak ridership. MBTA counts go back to 2000, while Amtrak data is available from 2001.

The 2003 DEIR contained projections for commuter rail ridership, which allows for a comparison of actual versus projected ridership to be displayed in Figure 8.2. For a 2025 no-build scenario, the forecast was 244,600 weekday trips[2]. But according to NTD data, MBTA ridership has been

[1] The detailed line-by-line data was taken from the 2012 CTPS MBTA Commuter Rail Passenger Counts
[2] Extrapolating from a base-year ridership of 131,650 in 2000 to 2025 in a linear fashion

declining since 2009 (when ridership was at a high of almost 147,000) by approximately 15% overall. Data through 2015, the last year NTD has made publically available, show that current commuter rail ridership is not keeping pace with the 2003 DEIR projections (see Figure 8.2).

Figure 8.3 shows historical average weekday ridership counts for Amtrak only at Back Bay, South and North Stations, used as proxies for NEC (incl. Acela) and Downeaster ridership, as explained above. Amtrak average weekday ridership figures, as opposed to commuter rail ridership, show steady growth at all Boston stations from 2001-2016. Amtrak ridership more than doubled over this period.

No ridership projections are provided for Amtrak in the DEIR, but another way to compare historical projections to the current situation lies in the number of Amtrak scheduled trips between Boston and New York. The DEIR used a 2002 baseline of 35 daily Northeast Corridor trains. The DEIR then estimated 52 trains a day (26 in each direction) would operate between Boston and New York in the 2025 no-build operations scenario.

The 2017 Amtrak schedule shows 19 Amtrak trains arriving at South Station and 20 trains departing every day, for a total of 39 daily trains. Amtrak's NEC Future planning process, currently undergoing environmental review, projects nearly a doubling of today's trains, which would then exceed DEIR projections from 2003 (these changes are not anticipated to be implemented until the middle of this century). This analysis also seems to indicate that DEIR projections were more optimistic than the current situation in 2017.

8.3 Qualifications

A number of factors may have had an impact on observed commuter rail ridership not keeping up with projections. Possible explanations include four fare increases since 2003 (factoring in inflation, commuter rail fares went up by more than 50% since 2003), lower gas prices from 2008 to 2010 and then since 2014, the impacts of severe weather in the winter of 2015 and the movement of more people into the urban core. In addition to this, the difficulty of accurately forecasting into the future is readily acknowledged amongst the planning community.

Generally, reliability and service frequency are seen as the key factors for maintaining transit ridership. The MBTA's reliability issues from severe weather, the increase in fares, and no significant increase in service would have all contributed to the difference between DEIR projections and today's ridership.

9 Demographic Trends

This section examines changes to demographic and land use patterns since the DEIR was completed in 2003. It explores shifts in both population and employment throughout the region, comparing trends in MBTA's Core service area to Gateway Cities and suburban areas (designated as the 'Other MBTA service area'), as defined in the MBTA's Focus40 planning exercise, defined in an appendix to this document and illustrated in Figure 9.1. It also aims to better understand travel markets through a review of auto ownership rates and Transit-Oriented Development (TOD) in the region. Data sources and methodology are detailed in an appendix to this document.

9.1 Summary of key findings

Comparison to the 2003 DEIR has yielded the following key findings:

- Population growth rates in the study area are slightly lower than DEIR projections, as were those for employment
- The Core service area accounted for a little under half of population growth and a little under a third of employment growth within the study area since 2003
- The large number of municipalities included in the Other MBTA service area saw the greatest gains in population and employment growth in the study area, indicating that growth was not concentrated in one area over this time.
- The Gateway Cities increased the number of jobs by 14% since 2003, making them the fastest-growing part of the study area in terms of employment, but they had a smaller share of the total population growth
- Auto ownership has changed very little in the study area since 2000, with a very slight decrease in the average vehicles per household in the Core service area and a very slight increase in the Gateway Cities, the suburban areas included in the Other MBTA service area, and the study area as a whole
- TOD has accounted for 9,627 new housing units and 6.5 million square feet of commercial floor area within a half-mile of commuter rail stations (either completed or under construction since 2010)
    - Future projects (expected to be constructed prior to 2035) within a half-mile of commuter rail stations account for an additional 11,923 housing units and 14.2 million square feet of commercial space
    - Of the total number of projects (completed, under construction and future) around MBTA commuter rail stations, 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.

9.2 Population and employment changes

9.2.1 Population

The population has grown in the study area examined in the 2003 DEIR, from 4.3 million in 2000 to 4.6 million in 2016. The DEIR, drawing from MAPC forecasts, indicated an increase in population of 15% between 1995 and 2025, an annual growth rate of about 0.5% a year. The actual percentage increase from the 16 years from 2000 to 2016 was approximately 6% (0.4% growth per year). Figure 9.2 shows population change in the study area by percent, with the MBTA commuter rail lines overlaid on the map. Figure 9.3 shows population change in the study area by absolute numbers. These show that some of the fastest-growing areas in the region (relative to their size in 2003) are towards the edges of the study area, and in some cases inaccessible by commuter rail lines. Areas that are shrinking the fastest include North Shore communities and some municipalities outside of the Core service area. A few areas saw a very large percentage increase in population (detailed in the tables below) but not a significant numerical increase.

The inverse was true of the urban core, which did not have large percent increases in population but saw large amounts of new people over this time (for example, Boston gained twice as many new people from 2000-16 than the TOTAL of the ten highest-ranked areas for percent population increase). Other areas with large population gains included municipalities clustered along the New Hampshire border near Haverhill and those just south of the Kingston/Plymouth line terminus.

Table 9.1 below shows the fastest-growing municipalities in the region (relative to their population in 2000). These were concentrated in the Other MBTA service area and beyond. Wrentham is the only municipality to be ranked for both numerical and percent growth. Of the municipalities in the table below, only Middleborough is directly on an MBTA commuter rail line.

Table 9.1: Ten Highest-ranked Municipalities - Percent Population Increase, 2000-16

Ranking	Municipality	Geography	Percent population increase, 2000-16	Numerical population increase, 2000-16
1	Wrentham	Other MBTA service area	126%	6,109
2	Upton	Other MBTA service area	44%	2,508
3	Berlin	No Focus40 designation	33%	797
4	Uxbridge	No Focus40 designation	28%	3,091
5	Northbridge	Other MBTA service area	25%	3,242
6	Middleborough	Other MBTA service area	23%	4,550
7	Raynham	Other MBTA service area	22%	2,551
8	Middleton	Other MBTA service area	22%	1,672
9	Millville	No Focus40 designation	20%	550
10	Bolton	No Focus40 designation[3]	20%	834
			TOTAL	**25,904**

[3] Municipalities that fell within the study area for the reassessment but did not have Focus 40 designations

Table 9.2 shows the municipalities with the highest numerical increase in population from 2000 to 2016. As expected, these were generally clustered in the Core service area. While these areas added large numbers to their populations, their populations generally did not grow by a significant percent over their original size.

Table 9.2: Ten Highest-ranked Municipalities - Numerical Population Increase, 2000-16

Ranking	Municipality	Geography	Percent population increase, 2000-16	Numerical population increase, 2000-16
1	Boston	Core service area	10%	56,429
2	Quincy	Core service area	10%	8,605
3	Revere	Core service area	18%	8,558
4	Lawrence	Gateway Cities	11%	8,167
5	Cambridge	Core service area	8%	8,131
6	Plymouth	Other MBTA service area	14%	7,441
7	Everett	Core service area	19%	7,062
8	Malden	Core service area	12%	6,608
9	Methuen	Other MBTA service area	15%	6,540
10	Wrentham	Other MBTA service area	126%	6,109
			TOTAL	**123,650**

The Focus40 process, managed by MassDOT, has been convened to develop an investment strategy for the MBTA's future, concentrating on improving performance and reliability, meeting future capacity needs, and involving local governments and the public in a robust planning process. When Focus40 is complete in early 2018, it will indicate areas for investment, targeted programs, and key policies that will help the MBTA continually improve and adapt to the needs of a changing region.

A closer look at growth in each of the Focus40 geographies helps to shed light on the spatial distribution of population growth. Between 2000 and 2016, the study area grew by nearly 273,000 people. 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, which grew at approximately the same rate (5%). The few municipalities inside the study area but not designated within the Focus40 geographies saw a high growth rate, but account for a small portion of all residents.

Table 9.3 – Population Change by Focus40 Geography, 2000-16

Geography	Population (2000)	Population (2016)	Numerical change in population	Percent change in population	Share of study area population growth
Core service area	1,433,672	1,548,925	115,253	8%	42%
Gateway Cities	526,850	551,032	24,182	5%	9%
Other MBTA service area	2,222,430	2,344,157	121,727	5%	44%
No Focus40 designation	124,849	137,536	12,687	10%	5%
TOTAL	**4,307,801**	**4,581,650**	**273,849**	**6%**	**100%**

9.2.2 Employment

Employment has also grown in the study area since the last time this was evaluated for the NSRL project, from 2.3 million in 2000 to 2.5 million in 2016. The DEIR, drawing from MAPC forecasts, indicated an increase in employment of 31% between 1995 and 2025, an annual rate of just under 1% a year. In fact, the study are has seen an approximate 8% increase in jobs over the 16 years between 2000 and 2016 (approximately 0.5% per year), falling below DEIR projections.

Figure 9.4 shows employment change in the study area by percent, with the MBTA commuter rail lines overlaid on the map. Figure 9.5 shows employment change in the study area by numerical values. These show that some of the corridors served by commuter rail lost jobs over the period from 2000 – 2016. However, some of the fastest-growing areas (including a few outliers described below) are also served by commuter rail, perhaps indicating new markets for rail travel to work outside the core. In terms of numbers of jobs gained, Boston and the Core service area still represent the largest share, with other pockets of growth throughout the region, including in Gateway Cities.

The fastest-growing municipalities in the region (relative to their number of jobs in 2000) were nearly all in the outer areas of the region (with the exception of Winthrop in the Core service area), detailed in Table 9.4 below. Harvard and Woburn are the only municipalities to be ranked for both numerical and percent growth.

Table 9.4: Ten Highest-ranked Municipalities - Percent Employment Increase, 2000-16

Ranking	Municipality	Geography	Percent employment increase, 2000-16	Numerical employment increase, 2000-16
1	Harvard	Other MBTA service area	535%	4,923
2	Plympton	Other MBTA service area	287%	617
3	Halifax	Other MBTA service area	165%	901
4	Woburn	Other MBTA service area	141%	20,112
5	Weston	Other MBTA service area	99%	3,312
6	Winthrop	Core service area	95%	2,027
7	Sherborn	Other MBTA service area	83%	430
8	Marshfield	Other MBTA service area	83%	3,955
9	Wrentham	Other MBTA service area	82%	2,650
10	Millville	No Focus40 designation	78%	127
			TOTAL	**39,054**

Table 9.5 shows the municipalities with the highest numerical increase in employment. While Boston and Brookline feature in the top 10, a large number of jobs was added to municipalities in the Other MBTA service area. Most notable of these is Harvard, its large increase due to the development of Devens, a former military base now run by Mass Development as an enterprise zone. Woburn, on the Lowell line, and Framingham, on the Worcester line, also have added a large number of jobs. A majority of the highest ranked municipalities are reachable by MBTA commuter rail.

Table 9.5: Ten Highest-ranked Municipalities - Numerical Employment Increase, 2000-16

Ranking	Municipality	Geography	Percent employment increase, 2000-16	Numerical employment increase, 2000-16
1	Boston	Core service area	6%	34,934
2	Woburn	Other MBTA service area	141%	20,112
3	Framingham	Gateway Cities	21%	9,047
4	Plymouth	Other MBTA service area	47%	8,415
5	Canton	Other MBTA service area	40%	8,027
6	Weymouth	Other MBTA service area	48%	7,221
7	Beverly	Other MBTA service area	32%	5,857
8	Brookline	Core service area	39%	5,705
9	Milford	No Focus40 designation	36%	5,024
10	Harvard	Other MBTA service area	535%	4,923
			TOTAL	**109,265**

Between 2000 and 2016, the study area gained nearly 172,000 jobs. About 60% of this growth occurred outside the Core Service Area 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.

Table 9.6 – Employment Change by Focus40 Geography, 2000-16

Geography	Number of jobs (2000)	Number of jobs (2016)	Numerical change in employment	Percent change in employment	Share of study area employment growth
Core service area	983,998	1,021,271	37,273	4%	22%
Gateway Cities	194,682	221,574	26,892	14%	16%
Other MBTA service area	1,072,433	1,176,559	104,126	10%	60%
No Focus40 designation	49,681	54,136	4,455	9%	2%
TOTAL	**2,300,794**	**2,473,540**	**172,746**	**8%**	**100%**

9.3 Auto ownership

Census data show that the rate of household vehicle ownership has changed very little for the study area in the period since the 2003 DEIR. There was a very slight decrease in the average vehicles per household in the Core service area. However, this change was offset by slight increases in the Gateway Cities and the Other MBTA service area. Overall, the average rate of household vehicle ownership increased by 2.3% (from 1.53 vehicle to 1.57, or about 4 additional cars per hundred households) for the study area as a whole. Table 9.7 details the change in average vehicles per household between 2000 and 2015 for the different geographies and for the study area in total.[4]

Table 9.7: Average Vehicles Per Household, 2000 and 2015

Geography	Average vehicles per household		Change
	2000	2015	
Core service area	1.16	1.15	(0.01)
Gateway Cities	1.38	1.40	0.02
Other MBTA service area	1.83	1.88	0.06
Entire study area	1.53	1.57	0.04

[4] Vehicle availability statistics derived from 2000 Decennial Census and 2011-2015 American Community Survey 5-year estimates. The study area for this analysis includes all 175 Focus40 municipalities and differs slightly from the population and employment analyses.

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 3 or 4 (or more) cars increased slightly. It is unlikely that this trend will have a major impact on travel throughout the study area. Figure 9.6 shows the geographic distribution of auto ownership in 2015.

9.4 Transit-oriented development

MAPC data was also utilized to determine the growth of TOD along commuter rail lines. The data provided was obtained from MassBuilds in May of 2017 and contains information on the number of residential units and commercial square footage in various stages of development within a half-mile distance of 187 individual MBTA stations.

These data show the following information for projects within a half mile of a commuter rail station:

- 9,627 new housing units were either completed or under construction since 2010
- 6.5 million square feet of new commercial space were either completed or under construction since 2010.

The MAPC data also contains information on future projects, categorized as either planned or projected. These projects are generally expected to be constructed prior to 2035, with a maximum completion date of 2042. Projects in the planning stages within a half-mile of commuter rail stations accounted for:

- An additional 11,923 housing units
- An additional 14.2 million square feet of commercial space

Longer-term projects designated as projected are planned to account for:

- 9,909 housing units
- 12.0 million square feet of commercial space

Of the total number of projects (completed, under construction and future) around MBTA commuter rail stations:

- 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
- Those around Back Bay accounted for 8% of housing units and 10% of commercial square footage.

Table 9.8 shows the development data for walksheds around commuter rail station, stratified by MBTA's Focus40 geographic typology. The data show that most of the recent and anticipated development around commuter rail stations has occurred or will occur in the Core service area. Of the recently completed TOD in the region, nearly half was located in the Core service area, while the 148 towns comprising the Other MBTA service area accounted for 35% and 40% of residential and commercial development, respectively. In the 10 Gateway Cities identified by MBTA, fewer than 1,000 new housing units and less than 1 million square feet of new commercial area have been completed since 2010.

The vast majority of future housing and commercial development intensity – categorized as under construction, planned, or projected – is slated to be sited around stations near the Core service area. While additional TOD is projected for the Gateway Cities and the suburban towns and areas in the Other MBTA service area, developments in active planning stages are expected to add only modest growth around stations in these geographies.

Table 9.8: Recent and Anticipated Residential and Commercial Development within 1/2 Mile of Commuter Rail Stations

Focus40 Geography	**Completed after 2010**		**Under construction**		**Planned**		**Projected**	
	Housing units	Commercial space (sq.ft.)	Housing snits	Commercial space (sq.ft.)	Housing units	Commercial space (sq.ft.)	Housing units	Commercial space (sq.ft.)
Gateway Cities	979	630,061	0	0	421	74,500	1,577	750,000
Core service area	3,124	2,331,311	3,214	1,539,028	9,689	13,952,805	6,170	8,543,130
Other MBTA service area	2,200	2,010,401	110	8,000	1,813	199,285	2,162	2,787,080
TOTAL	6,303	4,971,773	3,324	1,547,028	11,923	14,226,590	9,909	12,080,210

10 Desired End State

MassDOT developed both Study Objectives and Guiding Principles to shape this evaluation of the NSRL concept.

The Study Objectives outline the goals of this NSRL analysis - what the study will deliver and why it is of value to MassDOT.

The Guiding Principles are divided into primary principles that address the major problems the NSRL is intended to solve, and secondary principles – additional problems the NSRL can help address, but not the primary motivation for advancing the project concept. The primary principles will form the framework for creating the service plans for the different service alternatives, and will be the standards by which these alternatives will be evaluated. The secondary principles will help MassDOT to decide whether to prioritize the NSRL investment after this project assessment is completed.

These documents were presented to MassDOT separately and are available as an appendix to this document.

The Study Objectives in the DEIR aimed to determine service levels, operating and capital costs for a no-build and several build alternatives, as well as assessing the operational impact of build options. For this review of the NSRL concept, the Study Objectives generally fit with these objectives, with the addition of being centered around an update and reassessment of the conditions in the DEIR, with the purpose of enabling MassDOT to make a decision on whether to prioritize this project for investment.

The Guiding Principles in the DEIR aimed to reduce operating and capital costs, alleviate congestion at North and South Stations, provide better access to maintenance facilities and create more capacity on the system by through-running trains. The Guiding Principles in the new NSRL assessment are influenced by the MBTA's Focus40 outcomes (currently under development and intended to guide long-term investment in the system) and seek to prioritize service plans that adhere to these outcomes. Like the DEIR principles, these also seek to relieve congestion and increase capacity on the commuter rail network, with the added goals of reducing congestion on the MBTA rapid transit lines and improving transit accessibility to employment. Additional principles that were added in this iteration include reducing emissions from the commuter rail network (through electrification) and allowing the development of new urban core parcels by reducing the physical footprint of rail layover facilities.

11 Conclusion

This technical memo has explored the various aspects that would affect the construction of the NSRL as first assessed in the 2003 DEIR. The following conclusions can be drawn from this analysis:

Technology and regulatory environment:

The team undertook an assessment of the capability of Tunnel Boring Machines (TBMs), now more commonly used than when the DEIR was released in 2003. TBM technology has also improved the ability to excavate tunnels under high groundwater pressures, as well as reduce the amount of settlement caused by tunneling, likely to reduce the extent of mitigation needed to building foundations to avoid settlement damage.

This assessment assumes the use of dual-mode locomotives (see appendix for full report). Federal requirements for passenger equipment are unchanged since 1999, and therefore, FRA compliant locomotives are considered necessary for use across the network.

The NFPA 130 guidance for fixed guideway transit and passenger rail systems has changed in numerous relevant areas since the 2003 DEIR, and so these specific areas would need to be taken into account in a redesign of the NSRL system. Better tools for evaluating design fires have been developed since 2003, and this directly impacts the tunnel emergency ventilation capacities and design. Additionally, due to improved emergency ventilation systems and fire detection systems since the 2003 DEIR, this reassessment of the NSRL would benefit from using a holistic fire/life-safety approach that could develop a more cost-effective solution.

Major changes have also occurred in the regulatory environment for signaling, with Positive Train Control required by the Rail Safety Improvement Act of 2008. While the previous study assumed a modern signaling system for the new infrastructure, this legislation requires additional improvements to the existing network. Modern signaling systems allow more capacity (up to 24 trains per hour), although other constraints on the commuter rail network still need to be assessed before a baseline number of trains per hour can be established for this reassessment. The MBTA's installation of Positive Train Control is likely to be complete before NSRL construction begins so will not have a significant impact on the project.

It was previously assumed that the tracks in the tunnel would be electrified using an overhead catenary system, with the system treated as an extension of the electrification carried out under the NEC Improvement Project. This study notes that there is limited experience with rigid bar catenary systems for extended sections of track, so the long term reliability and maintenance implications are not well-understood.

Engineering assumptions:

This assessment deems that the tunnel diameters used in the DEIR are still adequate, and that there is potential for a reduction in the diameter of the single-track tunnels, based on MBTA criteria for the train envelope used to procure and qualify commuter rail revenue equipment. Where the proposed NSRL excavations for tunnels and stations are under or adjacent to existing structures, this assessment agrees that underpinning may be required. The extent of modifications needed range from doing nothing to underpinning or full replacement. Most of the affected properties were identified in the DEIR, but there are a few additional properties from new construction since 2003.

Resilience to storms has become more important in infrastructure design in recent years, and so this assessment determines that flood protection be provided for 500-year storms. Flood protection for the impacted portals of the NSRL can be provided by either setting the elevation of all entrances into the tunnel system (portals, station entrances, vent shafts etc.) above the predicted flood elevation, or by providing flood doors at the entrances. The South portals (Dorchester branch and Old Colony lines) are both currently within the 500-year floodplain, and the Back Bay and North portals will be in flood zones by no later than the 2070s.

Station construction is proposed to differ from the DEIR approach, which proposed an oval single vault with a large span. This assessment considers this approach unlikely to be practical, and also does not recommend two- or three-vault options. While these are considered possible, the structure would require significant structural columns between each of the vaults, leading to an unattractive station configuration. Instead, this assessment proposed a "binocular" tunnel configuration, using separate tunnels for each platform as well as a central concourse and allowing smaller tunnel diameters. For a two-platform station option, either a single cavern or a binocular tunnel configuration would be possible. If three platforms are required, some combination of these two arrangements would be needed.

Design criteria:

Recommended design criteria for this assessment have been provided to MassDOT after reviewing Amtrak and MBTA design criteria and the previous study parameters. In most cases, reasonably conservative values were specified for preferred values, with a design exception process. Values here and for grades are reasonably consistent with work carried out in previous studies, and have been discussed and agreed with the MBTA as suitable for the NSRL project. This document is attached to this technical memo as an appendix.

Tunnel portal locations:

Tunnel portal locations proposed in the DEIR have been reviewed, taking into account new development and other changes that would necessitate altering their design. The design of the North portals will need to be reconsidered because of redevelopment of the NorthPoint site. For the portal at Back Bay, it was recommended that information be gathered on utilities to confirm feasibility. Additionally, construction and support of a highway cap development here could restrict portal options, even within the existing right-of-way. For the South portals at South Station, it was assessed that they both would be constructed in existing railway lands with limited easements required during construction, in particular for TBM removal, and that some track reconfiguration would be required for each alternative.

New development along the NSRL corridor:

A considerable amount of development has occurred along the surface of the Central Artery since 2000. Large projects that have been completed in the last two decades in the path of the proposed NSRL alignment were assessed. For some of these, building foundations may cause a direct obstruction to the proposed tunnels, and for most of the new construction, ground improvement work may be required to limit settlement impacts to the property. For major construction anticipated to begin after 2018, there may be potential impacts on alignment options in the future (although this is not currently the case).

The Silver Line tunnel, which runs beneath the historic Russia Wharf buildings and the new Atlantic Wharf building, was constructed between 1998 and 2004 but its proposals were considered in preparation of the DEIR. The construction methods adopted, the as-built location, and the configuration of the Russia Wharf tunnel have been reviewed and no new impacts to the DEIR alignment have been identified.

Amtrak and MBTA commuter rail ridership trends:

Observations show that ridership on the MBTA commuter rail system is still skewed towards the lines leading to South Station (61% of all passengers, compared to 39% at North Station), which is in line with observations from the DEIR.

While direct comparison to DEIR ridership projections can be difficult due to changes in methodology since 2000 and the difficulty of collecting commuter rail ridership data, some patterns were observed. While Amtrak ridership into both North and South Stations has grown steadily since 2001, MBTA commuter rail ridership started to decline in 2009 and has declined approximately 15% between then and 2015. So although Amtrak has basically grown in line with projections (and is expected to expand dramatically in this century under the NEC planning process), MBTA ridership has fallen short of optimistic projections in the DEIR by about half.

Demographic trends:

Current demographic data shows that while both population and employment increased in the study area between 2000 and 2016, the area is not growing quite as fast as the DEIR projected it would. Geographically, employment growth was distributed throughout the study area, with a large rate of change in the Gateway Cities. Sixty percent of employment growth since 2003 occurred in the Other MBTA service area, indicating that growth is not tightly concentrated in one area. The Other MBTA service area also saw large absolute growth in both population and employment, while the smaller, more concentrated Core MBTA service area accounted for a larger proportion of population growth in the study area (42%) than jobs (22%).

A study of transit-oriented development shows that 9,627 new housing units and 6.5 million square feet of new commercial space were either completed or under construction within a half-mile of a commuter rail station since 2010. Nearly half of this was located in the Core service area, the Other MBTA service area accounted for 35% and 40% of residential and commercial development, respectively, and fewer than 1,000 new housing units and less than 1 million square feet of commercial area are located in the Gateway Cities. The vast majority of currently planned future housing and commercial development around commuter rail stations is slated to be sited in the Core MBTA service area.

Desired end state:

The Guiding Principles and Study Objectives for this assessment are largely in line with those developed for the DEIR, with the added influence of the Focus40 outcomes. These will influence the development of service plans for the NSRL alternatives, and will help MassDOT make decisions on future investment once the NSRL study is completed.

A1 DUAL-MODE LOCOMOTIVE REPORT

NORTH SOUTH RAIL LINK REASSESSMENT

Dual-Mode Locomotives Technical Memorandum

October 12, 2017

1 Purpose of Document

This memo augments the "Context Review Technical Memorandum" prepared for the North South Rail Link (NSRL) assessment and specifically identifies issues and opportunities related to the use of dual-mode locomotives (also called dual-power locomotives or electro-diesel locomotives) in the context of the NSRL project.

2 Introduction

A dual-mode locomotive is a locomotive that can operate either in an electric mode, powered by external electric power (such as from an overhead contact system [OCS] or an electrified third rail), or in diesel mode, powered by an onboard diesel engine.

The primary advantage of dual-mode locomotives is that they can operate in most track environments, including:

- Electrified track (and/or track where diesel locomotive operation is not feasible, such as in long tunnels or underground facilities)
- Non-electrified track (where electric locomotive operation is unavailable)

Table 1: Feasible Operating Environments, by Locomotive Type

Operating environment	Locomotive type		
	Diesel	Electric	Dual-mode
Non-electrified tracks	✓		✓ (in diesel mode)
Electrified tracks	✓	✓	✓ (in electric mode)[1]
Electrified tracks, poorly-ventilated tunnels		✓	✓ (in electric mode)
Electrified tracks, well-ventilated tunnels	✓	✓	✓ (in electric mode) [1]

Note 1: Operation in diesel mode is technically feasible, but generally undesirable in this particular operating environment.

3 Advantages and Disadvantages

3.1 Performance

Recent examples of dual-mode locomotives (specifically in North America, the ALP-45DP) have shown that dual-mode locomotives can offer performance in diesel and electric mode similar to that of single-mode diesel locomotives and electric locomotives, respectively.

An assessment by NJ Transit concluded that Bombardier ALP-45DP dual-mode locomotives, when operating in diesel mode, provide acceleration greater than provided by its existing diesel locomotives and, when operating in electric mode, provide acceleration comparable to its existing electric locomotives.[1]

Similarly, an assessment by Toronto Metrolinx concluded that Bombardier ALP-45DP dual-mode locomotives could provide approximately the same power and acceleration as their current diesel locomotives (MPI MP40PH-3C locomotives) when operating in diesel mode and 1.8 times the power of their current diesel locomotives when operating in electric mode.[2]

3.2 Operations

3.2.1 One-seat rides

A key benefit of dual-mode locomotives is the ability to provide "one-seat rides" to passengers. Without the benefit of dual-mode locomotives, certain routes would have to be operated as separate routes (thereby requiring a transfer for passengers) or with separate locomotive fleets.

3.2.2 Mode change procedure

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. If required mode changes can be completed during station stops, the mode change itself can have little impact on overall run time.

New Jersey Transit's ALP-45DP locomotives currently only change modes while stationary, and the mode change generally takes 100 seconds to complete.[3] Eventually, mode changes are expected to be possible while in motion.

Both Genesis P32AC-DM and EMD DM30AC locomotives are able to change modes while in motion.

[1] "NJ Transit ALP45DP Project Status." NJ Transit, March 2009.
[2] "Rolling Stock Technology Assessment." Metrolinx, December 2010.
[3] "The ALP-45 Dual Power Locomotive." Hooley, Martin, and Roy, 2011.

3.3 Costs

3.3.1 Locomotive capital costs

A recent study compared locomotive capital costs by technology, including dual-mode locomotives (see Table 2 below). The EPA sets “tiered” standards for locomotive emissions. A higher-numbered tier (e.g., Tier 4) requires lower emissions than lower-numbered tiers.) Capital costs can generally be expected to be greater for a dual-mode locomotive than for an equivalent diesel locomotive. (Note that “diesel-electric” refers to a typical diesel locomotive, not a dual-mode locomotive.)

Table 2: Estimated Locomotive Capital Costs, by Technology[4]

Type of operation	Tier 2 dual-mode	Tier 4 diesel-electric	Estimated Tier 4 dual-mode
Passenger	~$9 M	$6 M	$12 M
Freight	n/a	$3 M	$6 M

The costs of the New Jersey Transit’s Bombardier ALP-45DP can be compared with the capital cost of MBTA’s most-recently acquired MPI HSP46 locomotives (see Table 3 below).

Table 3: Locomotive Capital Costs

Locomotive	Purchase year	Locomotives	Average unit cost (2017 dollars)
Bombardier ALP-45DP dual-mode	2008	26	$13.5 M
Bombardier ALP-45DP dual-mode	2010	9	$9.8 M
MPI HSP46 diesel-electric	2010	20	$6.4 M
MPI HSP46 diesel-electric	2012	20	$6.7 M

3.3.2 Operating and maintenance costs

Dual-mode locomotives generally have maintenance costs comparable to single-mode diesel locomotives. However, dual-mode locomotives have significantly lower operating costs when operating in electric mode than when operating in diesel mode (see Table 4 below).

Table 4: Locomotive Operating and Maintenance Costs, by Type[5]

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	

[4] “Technology Assessment: Freight Locomotives.” California Air Resources Board, November 2016. Costs adjusted to 2017 dollars.

[5] West of Hudson Regional Transit Access Study Alternatives Analysis Phase I Screening Report Appendix D- Capital Cost and O&M Costs – Methodology and Estimates. Metro-North Railroad, May 2012. Costs adjusted to 2017 dollars.

3.3.3 Overhead contact system

A recent study reviewed recent rail electrification planning projects and identified average overall capital costs associated with rail corridor electrification (see Table 5 below). Costs include materials (including catenary, power supply, etc.), construction, labor, planning, and other project-related costs.

Table 5: Overhead Contact System Forecasted Capital Costs, by Type[6]

Study	Cost per Track-Mile (2017 dollars)
1992 SCRRA Electrification Study	$4.30 M
Caltrain Electrification EIR	$4.94 M
GO Electrification Report (Toronto)	$3.72 M
Average	$4.32 M
Average + 20% contingency	$5.18 M

Caltrain, a commuter rail operator in the San Francisco Bay Area, is currently undertaking an electrification project. A report from August 2017 indicates the costs detailed in Table 6.

Table 6: Caltrain Electrification Capital Costs[7]

Electrification	$697 M
Separate contract & support costs	$417 M
Total	$1.11 B
Project track-miles	135
Capital cost per track-mile	$8.25 M

3.3.4 Ventilation for diesel tunnels

Generally, all rail tunnels (with or without diesel locomotive operation) require some ventilation systems to ventilate smoke in the case of fire emergency conditions. For rail tunnels, MBTA Guidelines and Standards require that "fans capable of producing a velocity of five hundred (500) feet per minute in any of the adjacent segments of a tunnel (stations and tunnel extensions excepted) shall be provided."[8]

However, the presence of diesel equipment in a rail tunnel adds the additional requirement of near-continuous ventilation. MBTA Standards and Guidelines require that "in stations and tunnels in which internal combustion traction power equipment operates (such as diesel-electric locomotives or rail cars), special ventilation shall be provided, if required, to reduce any contamination to the latest applicable codes and standards."[9]

[6] "Task 8.3: Analysis of Freight Rail Electrification in the SCAG Region." Cambridge Systematics, April 2012. Costs adjusted to 2017 dollars.
[7] August 2017 Monthly Progress Report. Caltrain, August 2017.
[8] Guidelines and Standards, Part XI, Ventilation, Massachusetts Bay Transportation Authority, 1977.
[9] Guidelines and Standards, Part XI, Ventilation, Massachusetts Bay Transportation Authority, 1977.

A proposed rail tunnel in Baltimore with diesel locomotives anticipates four modes of operations[10]:

- **Normal operation**: trains run at their scheduled speed, providing sufficient ventilation through the piston effect, or "push-pull" movement.
- **Congested operation**: trains run at slower speeds and do not provide sufficient passive ventilation, necessitating active mechanical ventilation.
- **Maintenance operation**: while work is being performed in the tunnel, trains would not provide sufficient passive ventilation, requiring active mechanical ventilation to provide a safe atmosphere for workers. Ventilation plants maintain safe air quality by automatically turning on fans when sensors indicate air is nearing air quality standards for nitrogen dioxides, an indicator pollutant, regulated by the Occupational Safety and Health Administration (OSHA). The diesel emissions discharged from the fan plants will meet national ambient air quality standards (NAAQS). The ventilation plants will also reduce heat generated by train operations.
- **Emergency operation**: in a potential emergency situation, active mechanical ventilation is needed to control heat and smoke to provide a tenable environment for first responders and emergency egress.

Two key standards can be referenced when considering ventilation requirements for tunnels with diesel locomotive operations (see below). Importantly, nitrogen oxides (NO_x) are the most strictly-regulated air pollutant generated from diesel locomotive operation.[11]

- **Amtrak Regulations for Overbuilds**[12]
  - The design criteria shall be 5ppm of Nitrogen Dioxide at an elevation of 14 feet above the top of rail.
  - The ventilation systems shall be energized when the NO_2 concentration at this elevation reaches 3 ppm.
  - In the event of normal operations train idling is no greater than ten train-minutes per hour, no analysis needs to be made.
  - It shall be assumed that the emergency ventilation systems can be operated in such a manner as to purge diesel emissions from the station or built-over tunnel when the 3ppm concentration is reached.
- **NFPA 130**[13]: Standard for Fixed Guideway Transit and Passenger Rail. This standard requires that no more than one train should be in any given ventilation zone (i.e., tunnel segment between any pair of stations and/or ventilation shafts) at any time. Greater capacities will require more ventilation shafts, thereby increasing capital and maintenance costs.

In some cases, diesel locomotives do operate in poorly ventilated underground facilities. One prominent example is MBTA's Back Bay Station.[14] At this station, the existing ventilation is largely non-functional and the original design is inadequate for current train volumes. See Section 3 of the "Context Review Technical Memorandum" for greater details on fire, ventilation and egress requirements, and in particular, changes to relevant standards since 2003.

[10] Draft Environmental Impact Statement & Section 4(f) Evaluation. Federal Railroad Administration, December 2015.
[11] Baltimore & Potomac (B&P) Tunnel Project Final Environmental Impact Statement & Section 4(f) Evaluation. Federal Railroad Administration, November 2016.
[12] Proceedings from the Seventh International Symposium on Tunnel Safety and Security. March, 2016.
[13] NFPA 130: Standard for Fixed Guideway Transit and Passenger Rail Systems. National Fire Protection Association, 2017.
[14] Back Bay Station Community Presentation – Ventilation & Concourse Improvements. Massachusetts Bay Transportation Authority, September 2016.

4 Precedents in North America

Today in North America, dual-mode locomotives only operate in four general corridors:

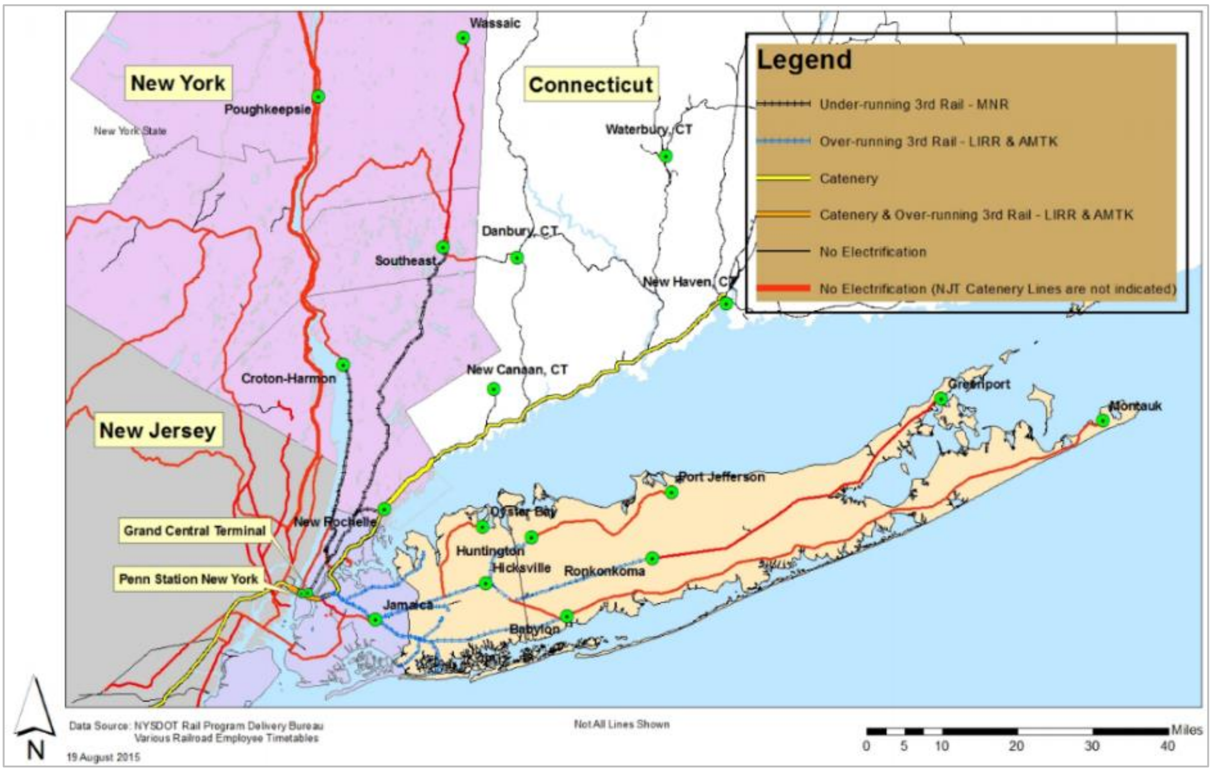
- Three corridors to/from underground rail stations in New York City (Pennsylvania Station [Penn Station] and Grand Central Terminal)
    - New Jersey Transit services to Penn Station
    - Amtrak and MTA Metro-North Railroad services to Penn Station and Grand Central Station, respectively
    - Long Island Rail Road services to Penn Station
- Réseau de transport métropolitain (AMT) commuter rail in the Greater Montreal region.

4.1 New York area

Generally, on rail corridors to/from New York City, electrified track infrastructure exists in various forms within the immediate vicinity of the city. In this region, dual-mode locomotives operate in electric mode. Farther away from the city, however, these corridors generally lack electrified track infrastructure and dual-mode locomotives accordingly operate in diesel mode.

Electrified track infrastructure in the New York region includes:

- Overhead contact system (OCS) / catenary
- "Over-running" electrified third rail (i.e., locomotive electrical "shoes" ride upon an electrified third rail)
- "Under-running" electrified third rail (i.e., locomotive electrical "shoes" ride beneath an electrified third rail)



Source: Next Generation Equipment Committee

Figure 1: Track Electrification in New York Area

4.1.1 New Jersey Transit Bombardier ALP-45DP

New Jersey Transit, New Jersey’s public transportation corporation, currently operates 35 Bombardier ALP-45DP (Dual Power) dual-mode locomotives. The first of these locomotives began operation in 2011. These locomotives predominantly operate in diesel mode except in the North River Tunnels and New York Penn Station, where they operate in electric mode, powered by AC overhead catenary.

Source: Bombardier Transportation

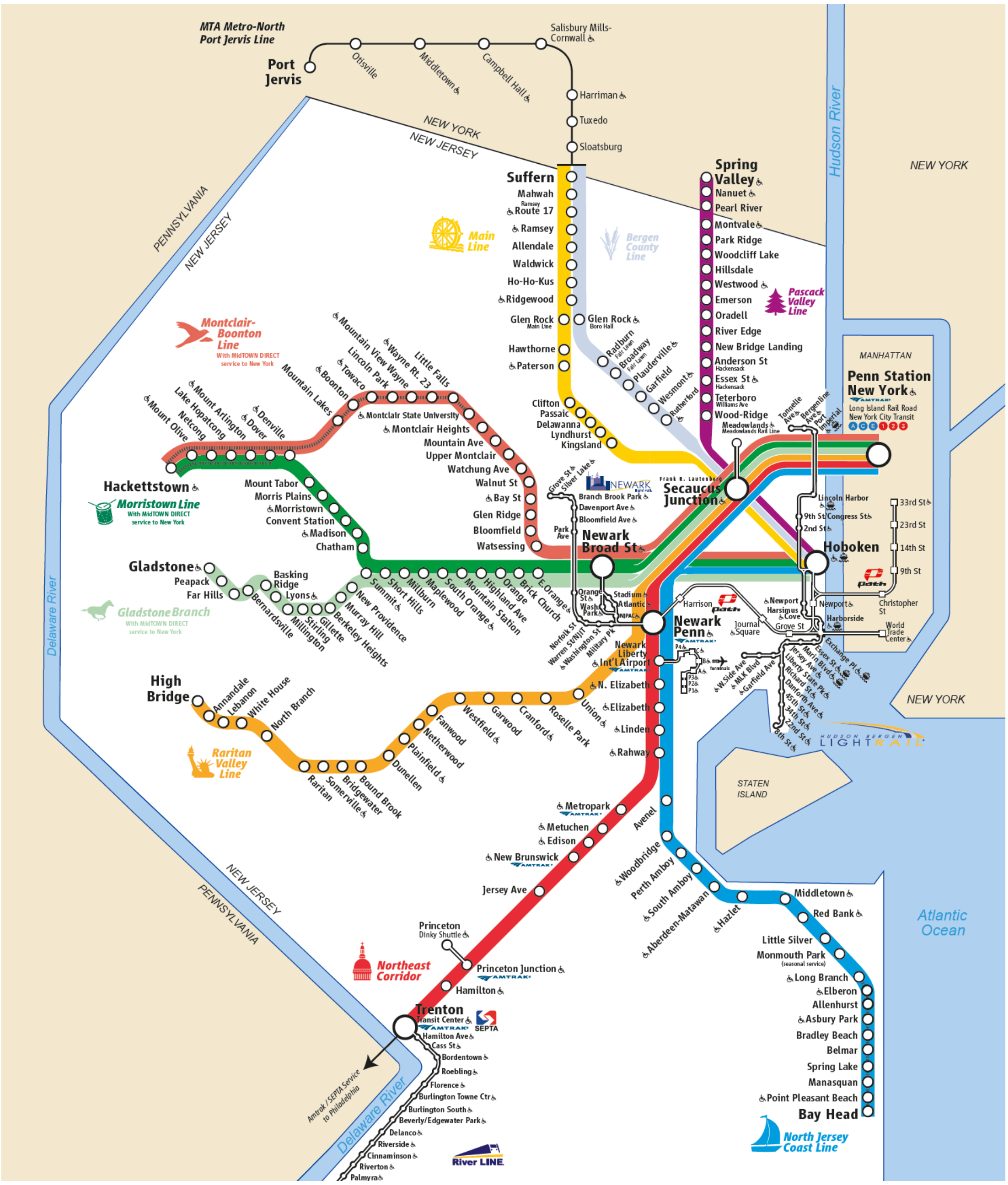
Figure 2: Bombardier ALP-45DP Locomotive

Penn Station in Manhattan is the eastern terminus for the New Jersey Transit rail system (see Figure 3 below). In 1903, New York state law prohibited the operation of steam and diesel locomotives in the Park Avenue Tunnel; the law had since been expanded to apply to other New York City rail tunnels (including the North River Tunnels, through which New Jersey Transit trains operate).[15]

These dual-mode locomotives were key to achieving a longtime goal of New Jersey Transit: one-seat rides from non-electrified portions of its network to New York Penn Station.[16] Prior to the arrival of the ALP-45DP locomotives, passengers who began trips on non-electrified lines had to transfer to electrified trains at Newark Penn Station or Secaucus Junction.

[15] “Standardized Technical Specification- PRIIA Dual Mode (DC 3rd Rail) Passenger Locomotive- Requirements Document.” Amtrak, 2015.

[16] “The ALP-45 Dual Power Locomotive.” Hooley, Martin, and Roy, 2011.



Source: New Jersey Transit, 2017

Figure 3: New Jersey Transit Service

New Jersey Transit ordered 26 ALP-45DP locomotives from Bombardier Transportation in 2008 and ordered an additional nine units in 2010.[17] New Jersey Transit jointly procured these locomotives with Réseau de transport métropolitain (AMT), the commuter rail operator in the Greater Montreal region. Order costs and average unit costs are shown in Table 7 below.

Table 7: Bombardier ALP-45DP Unit Costs[18,19]

Purchase year	Locomotives	Average unit cost (2017 dollars)
2008	26	$13.5 M
2010	9	$9.8 M

Table 8: Bombardier ALP-45DP Key Statistics[20]

	Mode of operation	
	Diesel	**Electric**
Maximum speed	100 mi/hr	125 mi/hr
Maximum power at wheels	3,600 HP	5,360 HP
Weight	288,000 lbs	
Electrical power system	-	Overhead catenary: 12.5 kV 25 Hz AC 25 kV 60 Hz AC

While switching modes between diesel and electric modes is expected to eventually be done while the ALP-45DP locomotives are in motion, currently New Jersey Transit's ALP-45DP locomotives only change modes while stationary, as described above in Section 3.2.2.[21]

4.1.2 Amtrak and Metro-North GE Genesis P32AC-DM

Two rail operators in the New York area operate General Electric Genesis P32AC-DM dual-mode locomotives:

- **Amtrak** operates 18 P32AC-DM locomotives on several of its intercity rail services operating on the Empire Corridor (between New York and Niagara Falls), including:
    - Empire Service (between New York Penn Station and Buffalo)
    - Ethan Allen Express (between New York Penn Station and Rutland, VT)
    - Lake Shore Limited- New York section (between New York Penn Station and Chicago, with P32AC-DMs operating no further west than Albany)
    - Maple Leaf (between New York Penn Station and Toronto, with P32AC-DMs operating no further west than Albany)

[17] "NJ Transit Approves FY 2011 Spending." Railway Gazette, 2010.
[18] "NJ Transit Unveils First Dual-Mode Locomotive in North America." NJ.com, May, 11, 2011. Costs adjusted to 2017 dollars.
[19] "NJ Transit Approves FY 2011 Spending." Railway Gazette, 2010. Costs adjusted to 2017 dollars.
[20] "NJ Transit ALP45DP Project Status." NJ Transit, March 2009.
[21] "The ALP-45 Dual Power Locomotive." Hooley, Martin, and Roy, 2011.

- **MTA Metro-North Railroad** (a service of the Metropolitan Transportation Authority [MTA]) operates 31 P32AC-DM locomotives, on all of its routes that serve New York Grand Central Terminal.

These locomotives primarily operate in diesel mode except when approaching Penn Station or the Park Avenue Tunnel and Grand Central Terminal, where they operate in electric mode, powered by a 650-V DC electrified third rail. Amtrak's P32AC-DM locomotives use retractable shoes to contact the "over-running" third rail to access Penn Station. Metro-North's P32AC-DM locomotives use fixed shoes to contact the "under-running" third rail to access Grand Central Terminal.

Importantly, both Amtrak and Metro-North P32AC-DM locomotives do not have thermal ratings to operate continuously in electric mode; their use is limited to approximately ten minutes of electric operation near and in the New York electrified tunnels.[22] P32AC-DM locomotives are relatively weak in electric mode, owing to moderate voltage third-rail shoes.

Source: Wikipedia User Bebo2good1

Figure 4: GE P32AC-DM Locomotive

Amtrak services on the Empire Corridor terminate at New York Penn Station and several Metro-North routes terminate at Grand Central Terminal. Services to Grand Central Terminal also pass through the Park Avenue Tunnel to access the station.

[22] "Rolling Stock Technology Assessment." Metrolinx, December 2010.

Source: Metropolitan Transportation Authority 2017

Figure 5: Metro-North Service to New York Grand Central Terminal

Both Amtrak and Metro-North placed their P32AC-DMs into operation between 1995 and 1998.

Table 9: GE P32AC-DM Key Statistics [23]

	Mode of operation	
	Diesel	**Electric**
Maximum speed	110 mi/hr	60 mi/hr
Maximum power at wheels	3,200 HP	-
Weight	274,400 lbs	
Electrical power system	-	Third rail: 600 V DC

4.1.3 Long Island Rail Road EMD DM30AC

The Long Island Rail Road (LIRR, a service of the MTA) currently operates 21 EMD DM30AC dual-mode locomotives.

The locomotives primarily operate direct service on LIRR's non-electrified lines in eastern Long Island (including the Port Jefferson, Oyster Bay, and Montauk branches), on the western electrified main lines, through the East River tunnels, and into New York Penn Station.

Source: Adam E. Moreira

Figure 6: EMD DM30AC Locomotive

[23] "Amtrak Genesis Series 2." General Electric Transportation, 2006.

These locomotives predominantly operate in diesel mode, except in the East River Tunnels and Penn Station, where they operate in electric mode powered by AC overhead catenary.

Source: MTA website

Figure 7: Long Island Rail Road Service to Penn Station

Long Island Rail Road placed its EMD DM30ACs into operation between 1997 and 1999.

Table 10: EMD DM30AC Key Statistics [24]

	Mode of operation	
	Diesel	**Electric**
Maximum speed	99 mi/hr	81 mi/hr
Maximum power at wheels	3,000 HP	2,885 HP
eight	282,240 lbs	
Electrical power system	-	Third rail: 750 V DC

4.2 Montreal RMT Bombardier ALP-45DP

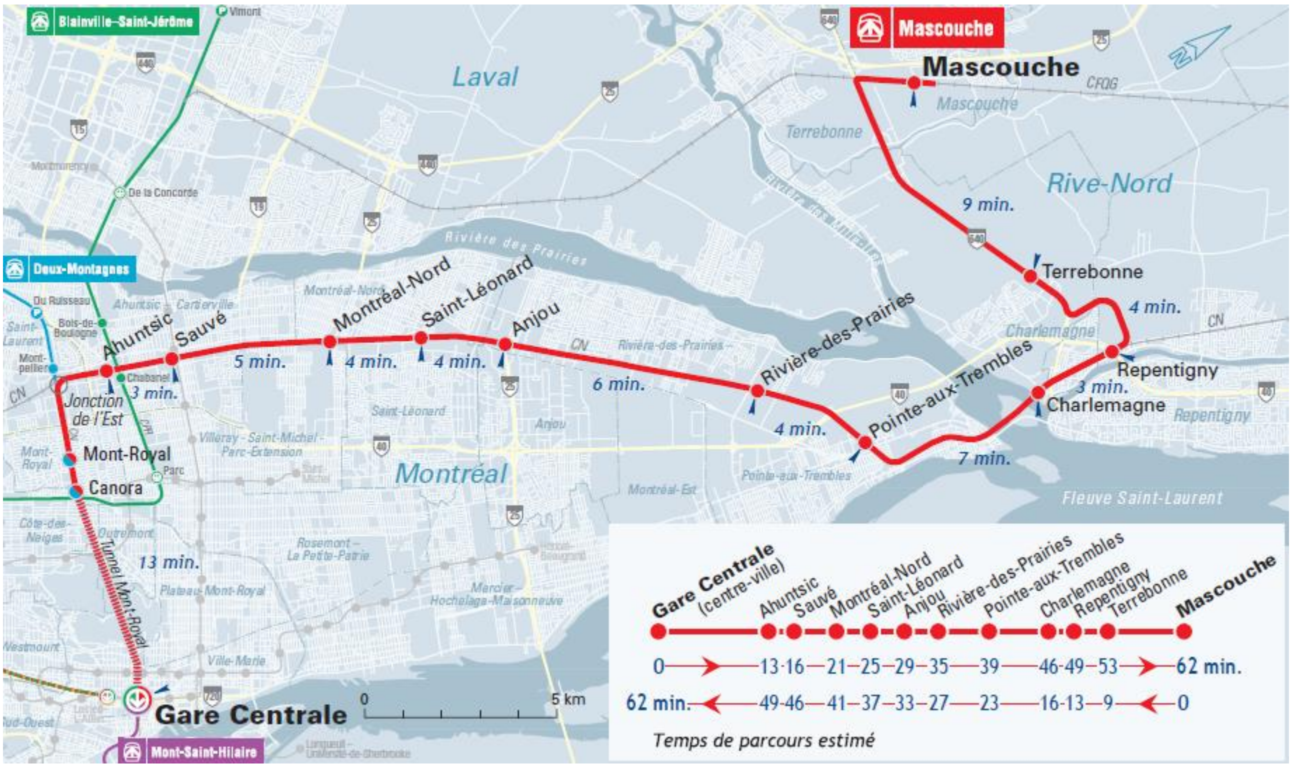
The Réseau de transport métropolitain (RTM), operator of commuter rail services in the Greater Montreal region, currently operates 20 Bombardier ALP-45DP (Dual Power) dual-mode locomotives.

These locomotives operate on the Mascouche Line to Montreal Central Station via the electrified Mount Royal Tunnel.

[24] "Diesel-Electric Passenger Locomotives DE30AC and DM30AC." Siemens AG, 2011.

Source: Wikipedia User Mtlfiredude

Figure 8: Bombardier ALP-45DP Locomotive



Source: AMT, 2010

Figure 9: RTM Mascouche Line

AMT (Agence métropolitaine de transport), RTM's predecessor agency, began operation of the Mascouche line in 2014. The 3.2-mile Mount Royal tunnel connects Montreal Central Station with the north end of the Island of Montreal and Laval. The tunnel, completed in 1918, has only ever served electric train service, owing to limited ventilation. Prior to 2014, the tunnel only served RTM's Deux-Montagnes electric commuter rail line.

AMT ordered 20 ALP-45DP locomotives from Bombardier Transportation in 2008, jointly procured these locomotives with New Jersey Transit.[25] Order costs and average unit costs are shown in Table 11 below.

Table 11: Bombardier ALP-45DP Unit Costs[26]

Purchase year	Locomotives	Average unit cost (adjusted to 2017 dollars)
2008	20	€8.6 M ($11.7 M)

The RMT ALP-45DP locomotives have the same operating characteristics as the New Jersey Transit ALP-45DP locomotives (see Section 4.1.1 above for details).

[25] "Bombardier to supply electro-diesel locos." Railway Gazette, August 19, 2008.
[26] "Bombardier to supply electro-diesel locos." Railway Gazette, August 19, 2008. 2008 US dollars calculated based on 2008 Euro-US exchange rate and adjusted to 2017 dollars.

5 Fire and Life-Safety

NFPA 130 includes the following discussion about the potential use of onboard fire suppression in Annex G.

5.1 Onboard fire suppression system

Onboard fire suppression systems (e.g., mist systems), while relatively new in the passenger rail and fixed guideway industry, have been successfully used on a number of passenger rail and diesel powered light rail systems outside of the United States.

The applications for this type of system can range from protection of diesel engine compartments to the interior of passenger rail vehicles. The use of a fire suppression system could:

- save lives in the incident vehicle during a fire condition;
- minimize damage to the train, tunnel, and the station which it has entered;
- reduce or eliminate potential use of station sprinklers;
- reduce or eliminate the need for down-stands;
- significantly reduce the impact of designing for fire emergencies on station architecture;
- reduce tunnel ventilation capacities by approximately 40 percent;
- reduce the number and/or diameter of emergency ventilation fans at each end of each station and within the tunnels, thus reducing structure sizes;
- decrease shaft airflow cross section areas by approximately 40 percent; and
- decrease tunnel ventilation shaft portal areas that correspond to the required fan sizes/velocities

When considering the addition of a fire suppression system, several design challenges should be met by the rail vehicle manufacturer. These challenges include:

- type of extinguishing medium used, which all must be approved,
- size and number of medium canisters and where on the vehicle to place them for easy access for maintenance;
- resultant increased energy consumption caused by the increase in weight of the suppression system;
- maintenance intervals;
- cost of the system;
- testing and commissioning of the system; and
- cost and difficulties associated with retrofitting vehicles

It is recommended that the potential use of an onboard fire suppression system be evaluated in the next project phase to explore its feasibility and cost-benefit to the NSRL.

6 Battery Technology in Trains

Batteries and ultracapacitors have begun to be tested by railroads in North America and worldwide. These technologies are widely expected to continue to improve considerably in the coming years, bringing down prices and improving their economic feasibility.

6.1 Precedents in streetcars and trams

Catenary-free tram systems have seen increased development in recent years.

Catenary-free trams systems fall into two categories[27]:

- Systems based on on-board energy storage devices (including onboard batteries or supercapacitors)
- Systems based on continuous power source from the track bed (including third rail or inductive energy transfer devices)

Examples of catenary-free technology include:

- **Nice Tramway, Nice, France**[28]: Line 1 opened in 2007 with a railcar fleet equipped with onboard nickel metal hydride batteries to power railcars through two public plazas (Place Masséna and Place Garibaldi). In these locations, overhead catenary systems were rejected due to anticipated negative visual impacts.
- **Nanjing Hexi Tram, Nanjing, China[29]-** The Hexi tram opened in 2014, with six vehicles operating over 90 percent of the line without overhead catenary systems.

Source: Wikipedia user Myrabella

Figure 10: Nice Tramway, France

[27] Catenary-free trams: Technology and recent developments. Global Mass Transit Report, 2014.
[28] Nice Tramway, France. Railway-technology.com, 2014.
[29] Bombardier's Battery Powered Tram Sets Range Record. Bombardier, November 2015.

6.2 Precedents in mainline railroad operations

In 2007, GE unveiled a prototype hybrid road locomotive based on its Tier 2 locomotive platform.[30] Onboard sodium nickel chloride batteries store energy dissipated during braking; this stored energy can reduce fuel consumption by 15 percent and emissions by 50 percent.

Under GE's concept, a Tier 4 locomotive could be retrofitted with similar batteries for cross-country operation and continuously alternate between battery and diesel operation. For example, fully-charged batteries could fully power such a locomotive for 30 miles, after which point the locomotive would revert to Tier 4 diesel-electric operation. At 70 miles of diesel-electric operation, the batteries would be fully charged, and the locomotive would resume battery operation, and so on.

6.3 Future projections

Battery technology has been examined for use in freight locomotives to reduce diesel fuel consumption.[31] One study forecasts that "future advances in battery technology could allow freight interstate line haul locomotives to achieve up to a 25 percent reduction in diesel fuel consumption and GHGs [greenhouse gases]. Further, these batteries may ultimately allow interstate line haul locomotives to achieve zero exhaust emissions for a significant portion of operations in and around railyards while in lower power settings."

In the same study as above, three battery technology options were considered.[32]

- All-battery, or near-all-battery, powered switch (yard) locomotives
- On-board battery augmented freight interstate line haul locomotives (see also Section 6.2 above)
- Battery tenders (railcars) to fully power freight interstate line haul locomotives over local to regional distances

To date, several railroads have adopted battery-powered locomotives for use as lower-power switch locomotives for yard operations.[33] Examples include the Railpower (RP) Green Goat Battery-Hybrid Switch Locomotive and the Norfolk Southern (NS) All-Battery Powered Switch (Yard) Locomotive.

However, current battery technologies lack the energy density to fully power freight interstate line haul locomotives over long distances and under extreme duty cycles. Given that limitation, battery tender cars 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.[34] 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.

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[30] "Task 8.3: Analysis of Freight Rail Electrification in the SCAG Region." Cambridge Systematics, April 2012.
[31] "Technology Assessment: Freight Locomotives." California Air Resources Board, November 2016.
[32] "Technology Assessment: Freight Locomotives." California Air Resources Board, November 2016.
[33] "Technology Assessment: Freight Locomotives." California Air Resources Board, November 2016.
[34] "Task 8.3: Analysis of Freight Rail Electrification in the SCAG Region." Cambridge Systematics, April 2012.

Source: Transpower

Figure 11: Example of Battery Tender Concept (Transpower)

Battery component costs are forecasted to decrease by two-thirds between 2012 and 2030.[35] This trend is expected to decrease the differences in cost between conventional diesel locomotives and near-zero or zero-emission locomotives. Battery tender technology remains in the conceptual stage; additional research will be needed.

[35] "Technology Assessment: Freight Locomotives." California Air Resources Board, November 2016.

A2 PROPOSED DESIGN CRITERIA DOCUMENT

BOSTON NORTH-SOUTH RAIL LINK DESIGN CRITERIA

<-- SOURCES (HIDDEN)

	MBTA COMMUTER RAIL	AMTRAK	1996 SCHEMATIC DESIGN	SSX	PROJECT (Draft)
HORIZONTAL ALIGNMENT					
Minimum Radius					
Preferred	See Figure 3.1	-	1,146' (5° curvature)	-	1150'
Absolute	522' (11° curvature)	-	717' (8° curvature)	459' (12° 30' curvature)	720'
In Stations	1,433' (4° curvature)	-	5,730' (1° curvature)	-	5750'
Spiral Transitions	Required	L = 1.63*Eu*Vmax (L in ft, Eu in inches, Vmax in mi/hr)	Required	Required on main line approaches	Required
Minimum Curve Length (not incl. spirals)	100'	100' or 3x speed in mi/hr	-	100' or 3x speed in mi/hr	100' or 3x speed in mi/hr
Minimum Tangent Length between Curves/Spirals	100' (exceptions possible where design speed <= 50 mi/hr)	100' or 3x speed in mi/hr	-	100' or 3x speed in mi/hr	100' or 3x speed in mi/hr
Minimum Actual Superelevation	1"	1/2" (except curves less than 0°-15’ curvature)	-	1"	1"
Maximum Actual Superelevation		-			
Absolute	6"	5.5"	6"	6"	6"
Desirable where freight trains operate or trains regularly stop	4"	-	-	-	
Desirable in stations	3"	-	-	-	
Maximum Unbalanced Superelevation					
Preferred	1.5"	-	1.5"	1.5"	1.5"
Absolute	2.75"	4"	2.75"	2.75"	2.75"
Turnouts					
Mainline crossovers and junctions	No. 20	No. 32.75 (speeds <= 80 mi/hr) No. 20 (speeds <= 45 mi/hr) (Advanced tech. turnouts)	-	-	No. 20
Mainline crossovers and junctions with insufficient room or design speed <= 30 mi/hr	No. 15	No. 15 (speeds <=30 mi/hr) No. 10 (speeds <= 15 mi/hr) (Advanced tech. turnouts)	-	-	No. 15 No. 10 (speeds <= 15 mi/hr)
Sidetrack connections to main line, yard leads, and yard tracks	No. 10	-	-	-	No. 10
Within yards (exceptional)	No. 8	-	-	-	No. 8

	MBTA COMMUTER RAIL	AMTRAK	1996 SCHEMATIC DESIGN	SSX	PROJECT (Draft)
VERTICAL ALIGNMENT					
Maximum Grade					
Preferred	0.7%	-	2%	0.7%	2%
Absolute	1.5%	1.5% 2.5 % (max compensated)	3% (tangent), reduced on curves	1.5%	3%
In Stations, Preferred	0.5%	0%	0.5%	0.5% (in terminal area)	0.50%
In Stations, Absolute	0.75%	-	1%	0.75% (in terminal area) 2.0% (in station)	1%
Turnouts and special trackwork	3%	-	3%	-	3%
Minimum Length of Constant Grade					
Preferred	200'	-	-	-	200'
Absolute	75'	-	-	-	75'
Compensation of grade for curvature		1° horizontal curve = 0.04% vertical grade	1° horizontal curve = 0.04% vertical grade	-	Preferred - 1° horizontal curve = 0.04% vertical grade Minimum - no compensation
Maximum Rate of Vertical Grade Change					
Preferred	0.05% per 100 ft (sags) 0.10% per 100 ft (crests) (AREA critieria in 1996)	0.4% per 100 ft	0.5% per 100 ft	-	0.5% per 100 ft
Absolute	0.8% per 100 ft (sags)	-	1% per 100 ft	-	1% per 100 ft
Maximum Lateral Force					
Preferred	-	-	0.02 g	-	
Absolute	-	-	0.05 g	-	

	MBTA COMMUTER RAIL	AMTRAK	1996 SCHEMATIC DESIGN	SSX	PROJECT (Draft)
CLEARANCES / CROSS-SECTION					
Minimum Vertical Clearance					
Preferred	22' 6"	-	-	-	
Absolute	16' 4"	-	-	-	
Overhead bridges and other structures, except in electrified territory	-	23'	-	-	
Overhead bridges and other structures, electrified territory, 22' trolley wire height	-	24' 3"	-	-	24' 3"
Overhead bridges and other structures, electrified territory, 24' 6" trolley wire height	-	26' 9"	-	-	
Minimum Horizontal Clearance	8' 6" (limited exceptions allowed)	Bridge piers, abutments, buildings, and other permanent structures: 18' preferred 16' absolute Thru bridges and all permanent obstructions on side tracks: 9'	-	-	8.5'
Min Track Spacing (centerline to centerline)					
Preferred	14'	- 14' (speed <= 80 mi/hr) 15' (80 <= speed <= 125 mi/hr) 16' (speed >= 125 mi/hr)	-	-	14'
Absolute	13'	-	13' (plus curve compensation)	15'	13'
Min Dist From Track Centerline to Structure	-	-	8.5' (plus curve comp.)	-	8.5'
Min from Top of Rail to Catenary or Any Obstruction	-	20.5'	19.5'	-	19.5'
Min from Top of of Vehicle Dynamic Envelope to Underside of Tunnel (for catenary)	-	-	2.5'	-	2.5'
Single-Track Tunnel Box Dimensions					
Exterior Width	-	-	29'	-	29'
Interior Width	-	-	26'	-	26'
Wall Width	-	-	1.5'	-	1.5'
Offset from Track Centerline to Wall	-	-	8.5' (on tangent)	-	8.5' (on tangent)
Offset from Track Centerline to Catwalk	-	-	5.1'	-	5.1'
Double-Track Tunnel Box Dimensions					
Exterior Width	-	-	41'	-	41'
Interior Width	-	-	38'	-	38'
Wall Width	-	-	1.5'	-	1.5'
Offset from Track Centerline to Wall	-	-	8.5' (on tangent)	-	8.5' (on tangent)
Offset from Track Centerline to Catwalk	-	-	5.1'	-	5.1'

	MBTA COMMUTER RAIL	AMTRAK	1996 SCHEMATIC DESIGN	SSX	PROJECT (Draft)
STATIONS					
Platform Length					
Preferred	765' (9-car train + 20')	700' Acela Express 1,000' NE Regional 1,200' Long Distance	-	-	
Minimum	190' (2-car train + 20')	550' Acela Express (NEC) 850' NE Regional (NEC) 850' Long Distance (NEC)	-	850' MBTA 1,050' Amtrak	850' MBTA 1,050' Amtrak
Platform Width, Center Island					
Preferred	22' (may taper to 12' at ends)	24'	-	22' (for minimum of half platform length)	22'
Minimum	-	20'	-	12' (at tapered ends)	
Platform Width, Side					
Preferred	12' (may taper to 8' at ends)	12' (no baggage loading)	-	12'	12'
Acceptable	10'		-	10'	
Minimum	8'	10' (no baggage loading)	-	8'	10'
Platform Height (above top of rail)	8" (low level) 48" (high level)	48" (high-level)	-	-	48"
Platform Offset (from track centerline)	5' 1" (low level) 48" (high level)	5' 7" (for 48"-high platforms)	-	-	
Minimum horizontal curve radius in stations	1,433' (4° curvature)	0' preferred	5,730' (1° curvature)	-	5750'
Maximum Grade In Stations					
Absolute	0.5%	-	1%	0.5%	1%
Preferred	0.75%	0%	0.5%	2%	0.50%

A3 DEFINITIONS

The Focus40 Geographies are the major regional delineations used for the analysis in this memo. They are classified as follows.

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: Mid-size post-industrial cities in the MBTA service area outside of Greater Boston. 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. Includes Abington, Acton, Amesbury, Andover, Ashburnham, Ashby, Ashland, Attleboro, Auburn, Ayer, Bedford, Bellingham, Berkley, Beverly, Billerica, Boxborough, Boxford, Braintree, Bridgewater, Burlington, Canton, Carlisle, Carver, Chelmsford, Cohasset, Concord, Danvers, Dover, Dedham, Dracut, Duxbury, East Bridgewater, Easton, Essex, Foxborough, Franklin, Freetown, Georgetown, Gloucester, Grafton, Groton, Groveland, Halifax, Hamilton, Hanover, Hanson, Harvard, Hingham, Holbrook, Holden, Holliston, Hopkinton, Hull, Ipswich, Kingston, Lakeville, Lancaster, Leicester, Lexington, Lincoln, Littleton, Lunenburg, Lynnfield, Manchester-by-the-Sea, Mansfield, Marblehead, Marlborough, Marshfield, Maynard, Medfield, Medway, Merrimac, Methuen, Middleborough, Middleton, Millbury, Millis, Milton, Nahant, Natick, Needham, Newbury, Newburyport, Norfolk, North Andover, North Attleborough, North Reading, Northborough, Northbridge, Norton, Norwell, Norwood, Paxton, Peabody, Pembroke, Plymouth, Plympton, Princeton, Randolph, Raynham, Reading, Rehoboth, Rochester, Rockland, Rockport, Rowley, Salisbury, Saugus, Scituate, Seekonk, Sharon, Sherborn, Shirley, Shrewsbury, Southborough, Sterling, Stoneham, Stoughton, Stow, Sudbury, Sutton, Swampscott, Taunton, Tewksbury, Topsfield, Townsend, Tyngsborough, Upton, Wakefield, Walpole, Wareham, Wayland, Wellesley, Wenham, West Boylston, West Bridgewater, West Newbury, Westborough, Westford, Westminster, Weston, Westwood, Weymouth, Whitman, Wilmington, Winchester, Woburn, Wrentham.

A4 METHODOLOGY – DEMOGRAPHICS

A4.1 Data Sources

For the purposes of this analysis, the 2000 population and employment data used for the 2003 DEIR were compared to 2016 figures provided by the Central Transportation Planning Staff (CTPS) of the MAPC. These datasets were linked at the municipality level, as this was the common shared attribute between the two. Forecasts from the DEIR were taken from MAPC projections between 1995 and 2025.

2000 household auto ownership rates were not available in the original dataset used in the 2003 DEIR analysis, so these were collected from the US Census. For a more consistent comparison, these were analyzed relative to 2015 American Community Survey (ACS) data with the same parameters.

TOD data were collected from the MassBuilds database administered by MAPC (described earlier in Section 7).

A4.2 Analysis

Change in population and employment from 2000 to 2016 were calculated at the municipal level, as well as for the three major geographies: the Core MBTA service area, Gateway Cities and the suburban areas that make up the Other MBTA service area.

Auto ownership data (calculated as average vehicles per household) were analyzed for both 2000 and 2015, taking account of how these data have changed in the region during this period. This information was obtained at the County Subdivision level from the 2000 Decennial Census and 2011-2015 American Community Survey 5-year Estimates.

The TOD analysis was conducted by querying an MAPC database created in May of 2017 that displays housing units and commercial square footage within a half-mile walkshed of a transit station. This measurement is commonly used in planning as a boundary within which TOD is evaluated. The commuter rail stations were identified and development data within a half-mile of their locations were analyzed.

A4.3 Constraints/Limitations

While CTPS data for 2016 (and projections for 2040) is available at the more fine-grained Traffic Analysis Zone (TAZ) level (used for regional travel demand modeling), the 2000 data that was utilized in the DEIR is only available at the municipality level. This necessitated the aggregation of 2016 TAZs to match the municipalities included in the 2000 study area. Boundaries for these municipalities were found to be fairly consistent between 2000 and 2016.

The 2016 and 2040 TAZs also cover a wider area than the 2000 data. This meant that some of the suburban areas and three Gateway Cities (Fitchburg, Leominster and Worcester) could not be included in the direct comparison of 2000 to 2016 data. However, the joined datasets cover a large enough service area for the commuter rail to be generally representative of population and employment trends between the publication of the DEIR and today.

Because information on auto ownership in the region was not available in the original 2000 dataset, data for 2000 and 2015 needed to be collected separately from the US Census and ACS databases. These two time points are very reasonably close to the 2000-to-2016 data utilized for the rest of this analysis, and so were deemed suitable.

TOD data were provided by MAPC as a summary of the MassBuilds database. TOD is understood to mean any development occurring within a half-mile walkshed of a transit station, including all rail and bus rapid transit stations. For the purposes of this review, only development around commuter rail stations was considered. The data contain information on the aggregate intensity of development (number of residential units or square footage of commercial space) for each station, but not for individual development projects. In addition to completed development and development under construction, this data contains information for projects that are planned or projected to be completed in the future, based on input from various stakeholders. Planned projects have entered into some phase of the land use planning process, while projected developments are expected to begin the planning process at some (undetermined) point in the future. The summary of this data should be understood to represent new development, and not a net change in housing or commercial development with respect to any year.

A5 PROJECT PRINCIPLES AND OBJECTIVES

A5.1 NSRL Study Objectives

The MassDOT North-South Rail Link Study considers the technical feasibility, constructability and cost of connecting the MBTA rail lines terminating in South Station with those rail lines terminating in North Station. These stations are about one mile distant.

The objectives of the MassDOT North-South Rail Link Study are:

1. Reassess prior work that analyzed the North South Rail Link and conduct and summarize the necessary technical and financial analysis.
2. Consider the current technical viability of the previous alignments and consider potential alternative alignments.
3. Consider the impacts and benefits of improved tunnel technology and tunnel construction experience on the NSRL project compared to the previous study.
4. Consider the implications of any changes to the regulatory environment compared to the previous study.
5. Identify NSRL project costs (design, construction, management) and project risks.
6. Assess NSRL project costs and benefits compared to alternative MBTA rail capacity and expansion projects (identified and under consideration) that assume the absence of NSRL.
7. Consider overall project benefits (i.e., ridership increases, service reliability improvements, economic development) and quantify the benefits at a level appropriate to this stage in the project development process.
8. Deliver definitive information to MassDOT that enables decisions on whether to proceed with additional planning and design of a NSRL, including whether the project right-of-way should be protected indefinitely, acknowledging that in its absence new development along the possible route may further complicate such a connection in the future.

A5.2 NSRL Guiding Principles

This document summarizes the identified rationale for and desired “end-state” resulting from the North South Rail Link Project, and sets out the goals that define these. The Problem Statement provides detail on the regional context within which this project is proposed, highlighting the inadequacies in the system. The Guiding Principles are the framework for creating the service plans for the different service alternatives, and they are the standards by which these alternatives will be evaluated.

The North-South Rail Link Project proposes connecting the MBTA rail lines terminating in South Station with those rail lines terminating in North Station through a downtown Boston tunnel.

Problem Statement: The MBTA’s commuter rail network is a divided system, with South Station-destined trains serving the Back Bay and the commercial core of downtown Boston, while

North Station-destined trains arrive at the northern end of downtown – an area with much lower employment density. This division creates disincentives for commuters in the northern suburbs to use train service for jobs in downtown Boston and Back Bay. Operationally, this divided system creates inefficient terminals which limit train throughput and ultimately system capacity. This division also complicates the efficient maintenance of the commuter rail fleet, forces many commuter rail passengers onto the crowded MBTA rapid transit system to complete trips, and makes any travel between areas south and north of Boston's urban core cumbersome.

Guiding Principles: The guiding principles of the MassDOT North-South Rail Link Project are as follows:

Primary Principles (that address the major problems the NSRL is intended to solve)

1. Design a system to enable service patterns that support the MBTA Focus40 goals and objectives

2. Increase the capacity of the MBTA's commuter rail network to bring commuters into employment centers like Downtown Boston, Back Bay, the Seaport, and Longwood Medical Area during peak commuting hours.

3. Improve the transit accessibility to employment opportunities in Boston's urban core, particularly for residents on the north side of the Boston metropolitan area, by reducing travel times and generating more direct connection to employment opportunities.

4. Relieve congestion on the MBTA's rapid transit network (in particular on the Orange Line southbound) by directly connecting commuters with their final destination.

5. Improve the MBTA's ability to efficiently maintain its rail fleet.

6. Reduce highway automobile usage, lowering congestion and emissions.

Secondary Principles (additional problems the NSRL can help address, but not the primary motivation for advancing the project concept)

1. 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.

2. Reduce the emissions associated with the commuter rail system in the urban core through the electrification of portions of the network.