

5. Potential Alignments and Schematic Design

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5.1 2003 Alignments and Alternatives

All potential alignments to connect the northern and southern MBTA Commuter Rail lines that were evaluated in the 2003 DEIR followed the Central Artery/Tunnel project corridor between South Station and North Station. While a Congress Street alternative was initially considered, the alignment did not advance past the 2003 screening process because of anticipated construction and operational constraints in the limited rights-of-way underneath narrower downtown streets. In addition to a No Build alternative, the DEIR ultimately evaluated four tunnel alternatives along the Central Artery, with four different variables: the number of tracks in the tunnel, the location of southern portals, alignment of the underground South Station, and the inclusion of a Central Station, illustrated in Figure 19.

The build alternatives consisted of the following four configurations:

- Two-Track / Two-Station (Back Bay OR South Bay portals)
- Two-Track / Three-Station (Back Bay OR South Bay portals)
- Four-Track / Two-Station (Back Bay AND South Bay portals)
- Four-Track / Three-Station (Back Bay AND South Bay portals)

Each of the four alternatives was envisioned as one or more 41-foot-diameter deep tubes, with mined approaches and underground junctions but otherwise constructed primarily with tunnel boring machines along the length of the alignment underneath Central Boston.

All 2003 alternatives included tracks descending from a new Back Bay portal at a 3% grade (towards the new underground South Station). This new portal would serve all MBTA trains using the Northeast Corridor tracks from points south, as well as MBTA trains from Framingham/Worcester to the west, and those from Fall River and New Bedford from the south, following completion of the South Coast Rail Project. In addition, some Amtrak trains were anticipated to use the tunnel to connect to services north of Boston. The 2003 fourtrack alternatives also included South Bay portals connecting to the Fairmount and Old Colony Lines.



0 600 1200 Feet Figure 19: 2003 DEIR Alignment map

Source: NorthSouthRailLink Project •VHB/FRH, A JOINT VENTURE

Two underground South Station locations, illustrated in Figures 20 and 21, were proposed in 2003, but to avoid impacts to existing buildings, sites were considered only within the area bounded by Atlantic Avenue to the west and the Fort Point Channel to the east. The first alternative placed the new underground station directly underneath the surface tracks, east of Atlantic Avenue and connecting to the existing South Station headhouse. North of South Station, the rail tunnels intersect the footprint of the Federal Reserve Tower (the DEIR called for "close coordination with the Federal Reserve Bank" to mitigate construction impacts and "ensure the integrity of the building"). The second alternative placed the new underground South Station underneath Dorchester Avenue and the Fort Point Channel, avoiding the Federal Reserve property while continuing north under the Central Artery. The new underground North Station proposed in the DEIR was located underneath the Central Artery, with a precise site to be determined by more advanced engineering studies.



Source: NorthSouthRailLink Project •VHB/FRH, A JOINT VENTURE

In weighing the build alternatives, the 2003 DEIR considered several short-term construction impacts, including the need for access shafts, staging areas, and a minimally disruptive system for bringing excavated and construction material to and from the surface and off-site. The DEIR also identified potential conflicts between existing infrastructure and the alignment itself, particularly at the Back Bay approaches. While still in the portal area and at a shallow level underground, the proposed tunnels would pass through the I-93 and I-90 South Bay interchanges. The alignments could encounter multiple viaduct or approach ramp foundations for I-93, as well as tunnel jacking pit walls and drilled shafts for I-90. The proposed 2003 approaches did not directly conflict with any ramps or interchange structures, but underpinning would be necessary to pick up loads previously supported by interrupted caisson foundations.



Source: NorthSouthRailLink Project •VHB/FRH, A JOINT VENTURE

5.2 Current Design Assumptions/Criteria

The design criteria developed for the 2003 DEIR and reviewed by an MBTA technical committee form the basis for the criteria for this Feasibility Reassessment. Table 15 contains the engineering design criteria distilled from four design standards:

- MBTA Commuter Rail
- Amtrak
- 1996 NSRL schematic design (used in 2003 DEIR)
- South Station Expansion

These engineering design criteria have been reviewed and approved by MassDOT and MBTA for the purposes of this NSRL Feasibility Reassessment.

Ideal	Selected						
Horizontal Alignment							
1150ft	720ft						
5750ft							
Required							
3in	6in						
1.5in	2.75in						
Vertical Alignment							
2%	3%						
2%	3%						
0.5%	1%						
1 degree of curvature for every 0.04% vertical grade	No compensation						
0.5% per 100ft	1% per 100ft						
Clearances and Dimensions							
8.5ft							
14ft	13ft (plus curve compensation)						
19.5ft							
2.5ft							
Stations							
1050ft							
850ft							
22ft	12ft						
12ft	10ft						
	Ideal Horizontal Alignment 1150ft 575 Requination 3in 1.5in Vertical Alignment 2% 2% 2% 2% 0.5% 1 degree of curvature for every 0.04% vertical grade 0.5% per 100ft rances and Dimensions 8.5 14ft 19. 2.5 Stations 105 22ft 12ft						

Table 15: Engineering Design Criteria

5.3 Station Design Principles

For this Feasibility Reassessment, station designs are developed using a modular component approach; components can be easily added or removed to suit individual station dimensions and integration with the urban environment at the surface. This flexibility allows the stations to accommodate platform lengths of either 850, 1,050, or 1,320ft, as well as the track configurations necessary to conform to design criteria.

All stations share the five characteristics listed below. Standardized components are illustrated and labeled in Figure 22.

- Modular connections at either station end facilitate convenient platform access and ease pedestrian flow.
- Additional access points along the platform (at approximately 80ft from station ends to avoid dead ends) enable safe emergency evacuation.
- Headhouses to enable access to the underground stations are designed to minimize the area needed at surface and urban intrusion. The locations for these structures are conceptual and seek to maximize important urban connections, by locating near planned developments that may accommodate a new entrance.
- Station headhouses contain elevators and escalators for circulation as well as ventilation and other ancillary station functions. This allows the

platforms to remain virtually free of bulky backof-house areas. Ventilation shafts without entrance functions are also located in unobtrusive spaces, such as parking garages near the station.

 Walkways between headhouses and concourses utilize flexible elbow joints (see Figure 22) to allow a certain amount of leeway where station entrance locations can be placed at the surface and to accommodate future connections (if needed). For all stations, additional exits for emergency evacuation routes can be provided as necessary as local insertions into the urban environment. Standardized station components:

- Concourse "elbow" allows entrance location to suit urban context above providing flexibility for station entrance locations at surface
 - Prioritizes minimum land take and urban intrusion
- Concourses house majority of back of house requirements (i.e. Public restrooms, communications closets, etc.)
 - Prioritizes passenger flow, operation, and experience



Figure 22: Station Design Principles

5.4 Tunnel and Underground Construction

The NSRL tunnel construction methods depend on the chosen alignment and depth of profile, as well as the alignment's urban and geological context. Cut-and-cover and tunnel boring machine (TBM) construction methodologies are considered, with TBMs varying in diameter to suit the needs of corresponding alignments. Portal areas are constructed using boat sections (a U-shaped trench with a continuous base slab and supporting retaining walls) with nearby underground sections built as cut-and-cover. Once sufficiently deep, or approximately one TBM diameter from the surface, bored tunnels are constructed using one or more TBMs launched from the proposed northern portal, with the TBM excavating the tunnel in the direction of the proposed southern portal.

Advances in tunnel technology and tunneling experience suggest that a large-bore alignment

through the center of Downtown Boston is feasible. This represents an evolution from the methodology used in the 2003 DEIR, where the initial screening process, informed by contemporary tunneling capabilities, considered and rejected this alignment. While the proposed South Street right-of-way (see Section 5.8) is narrower than the Central Artery corridor, the evolution of TBMs since 2003 has reopened the viability of this two-track alternative. Specifically, today's TBMs are wider in diameter, more maneuverable, and less impactful to adjacent structures. Tunneling technology now allows for sharper curves than before and tube diameters of 51ft, all with minimal settlement of buildings on either side of the street. This has an impact on the alignments considered and those taken forward for further analysis. Figures 23 and 24 display examples of a TDM cross-section and a launch pit.

The zone of influence typically refers to the area where settlement has the potential to impact structures or utilities. Typically, as a project is designed, structures or utilities within the zone of influence are assessed to determine the potential for damage. Many will be found not likely to suffer any damage, but some structures or buildings are particularly vulnerable due to geometry or material type. In this case, mitigation measures such as more controlled excavation methods, ground improvement, or modifications to the structure/utility would be applied.

The majority of the bored tunnel length for the proposed alignments and the mined portions of the proposed stations are in the argillite bedrock, a compressed, layered sedimentary rock native to Boston. Settlement in bedrock will be extremely low



Figure 23: TBM Cross-Section



Figure 24: TBM Launch Pit

and is unlikely to be even measurable at the surface. Ground movements can occur around excavation for station entrances and ancillary buildings. These excavations will be similar to building basements, and there is a long track record of managing ground movements to avoid damage to adjacent structures.

At either end of the alignments, the tunnels will travel through layers of clay and soil, (known as the overburden materials). In these areas, ground movements due to the tunnel are possible, but will be controlled within acceptable limits by using pressurized face TBMs. This technology continues to improve, and recent projects such as the 57.5-foot-diameter SR-99 soft ground tunnel in Seattle was completed with maximum surface settlement of less than 0.5 inches, which is typically below the level that would cause damage.

The most challenging area will be the interface between soil and rock, which if unmitigated could cause more ground movement (as soft ground moves through the TBM more quickly than rock does). On the proposed alignment, these areas will be in the vicinity of the 190/193 junction at the southern end of the tunnel, and on the north side of the Charles River. Both these areas have surface access that would allow for mitigating ground treatment, should this be required.

5.5 Fire/Life Safety and Ventilation

Safety is the most important criterion in the design of the NSRL. Passengers and train crews using the tunnel need fresh air, and the tunnels must be designed to provide for quick and safe evacuation in the event of a fire or other unsafe condition. These fire/life-safety and other requirements are outlined in applicable codes and standards, with means of egress and ventilation as the two primary considerations. The safety systems, features, and procedures to meet those requirements result in specific implications for the physical design of the tunnel, above and beyond the alignments and stations described in the previous sections.

Appendix D outlines additional fire/life safety requirements considered for this project.

Means of Egress

In order to provide safe evacuation from tunnels and stations, building code and industry standards require certain means of egress features. The design of an egress system for emergencies overlaps with the passenger ingress/egress system used in normal operations (headhouses connected to vertical circulation), but may also result in additional design elements. These requirements are governed by the Massachusetts Building Code and the National Fire Protection Association Standard for Fixed Guideway Transit and Passenger Rail Systems (NFPA 130). Egress from underground infrastructure like the NSRL tunnel and stations can be accomplished by providing doorways, corridors, stairs, escalators, and elevators. There are a number of variables that are weighed when determining the safe capacity of underground infrastructure and in determining design decisions, with the most important being the passenger load within trains and on platforms. Regulations typically require design to accommodate a peak load, including multiple trains arriving at a station at once, and a mix of boarding and alighting passengers. Figure 25 shows an example of how tunnel egress might be achieved.



Figure 25: Example of Tunnel Egress

Within stations, a variety of design elements and performance-based tests must be met as per the standards, including the following:

- At least four exits must be provided for any space that serves greater than 1,000 people (as would be expected in NSRL stations).
- The maximum travel distance from any point on a platform to an exit from that platform is 325ft.
- Exits must be located within 82ft of each end of all platforms.
- The total evacuation time from the most remote area of a platform is four minutes to leave the platform, and six minutes to a Point of Safety (typically an above-ground area or an enclosed exit that leads to a public way or outside).

The details of permitted capacities, travel speeds, clear widths, and fire ratings for stations can be found in Appendix D.

Within tunnels, the required design elements vary based on the type of the tunnel system:

- For single tunnels, exits must be no more than 2,500ft apart (including exits at stations and tunnel portals).
- For dual tunnels, passageways between tunnels can be utilized in lieu of exits to ground level, and must be no more than 800ft apart (including exits at stations and tunnel portals).
- Single tunnels may be treated as dual tunnels if a fire-rated barrier is provided along the full length

of the tunnel between the two tracks.

- Walkways with minimum clear height of 80in must be located alongside tracks to provide a pathway from trains.
- Tunnel exits will have stairs to reach the surface, and an area of refuge (a hardened, fire-rated area) where people who cannot utilize stairs can await assistance.

The details of passageway size and capacity can be found in Appendix D.

All elements of an emergency egress path, whether in tunnels or stations, must be protected to control the spread of smoke and with emergency lighting.

The conceptual station and tunnel designs anticipate both day-to-day passenger flows and the emergency evacuation needs and requirements. A passenger faced with an evacuation scenario within a station would utilize the closest standard exit to reach the street level via passageways, stairs, and escalators. When faced with an evacuation scenario within a tunnel, passengers would exit the train onto a walkway and staff would direct passengers to the appropriate evacuation route. This route would lead to either a tunnel portal, station platform, emergency exit stairway (and area of refuge), or passageway between tunnels. Once in the opposing tunnel, passengers would continue along the walkway until reaching an emergency exit, station platform, or tunnel portal, each allowing exit to the surface. Given the travel distances and inherent safety

concerns with tunnels, trains will attempt to stop at stations, if possible, with tunnel evacuation as the last resort.

Ventilation

Ventilation must be provided within the NSRL tunnels to bring fresh air to the habitable spaces, and to exhaust air to the surface. Without a ventilation system, the air within the tunnels and stations would become stale – not appropriate for normal operations, and untenable during emergency conditions. The physical requirements for a ventilation system focus on emergency conditions, and must also allow for efficient operation during normal operations.

Ventilation is accomplished by moving air between two spaces, in this case, between the proposed stations and tunnels, and between the stations and above ground. This can be accomplished through two methods:

- Vertically, where vent intakes and exhausts are located above station and tunnel elements on the surface within a vent building and connected via vent shafts to structures on the surface. In this case, the equipment used to ventilate (the "fan plant") can be located either on the surface, or within the tunnel/station footprint.
- Horizontally, where jet fans are used to push and pull air into the tunnels via the portals at either end. In this case, the jet fans must be physically located within the tunnel diameter.

Boston's Central Artery tunnel uses both vent buildings and jet fans to provide ventilation to the highway tunnel system, and it is likely that a NSRL tunnel would similarly use both methods. In normal operation, fan plants provide fresh air to passengers on platforms and that diffuses throughout the stations. In addition, the piston effect, which is caused by air being pushed through the tunnel by moving trains, would be regulated by the fan plant shafts. This type of ventilation system would be optimized for electric trains and their reduced emissions; however, in the event a diesel train needs to access the tunnel (to rescue a disabled train, for example), the ventilation system would be able to clear diesel fumes from the tunnel for a short period of time.

In an emergency, smoke would be ventilated from the tunnel by using the push-pull principle, where the fan plant at one end of the affected tunnel segment will be operated in supply mode while the plant at the other end will operate in exhaust mode in order to replace the smoke with fresh air as quickly as possible, to provide safe air to breathe along escape routes, and to maintain a tenable means of egress system for the duration of an evacuation.

Fan plants need to be located at both ends of each station, as well as along the tunnel segments. Each vent shaft requires a vent building on the surface. If real estate is available, the fan plants can be located above grade inside the vent building (as in the Central Artery tunnel). In areas with limited real estate, the mechanics of the fan plant can be placed adjacent to the tunnel or station, with a smaller building on the surface. This option is typically more expensive, due to the need to expand excavations along the tunnel. A typical fan plant footprint (with electrical spaces for starters, transformers and controls) is approximately 75ft by 50ft. The maps in Appendix D show the possible locations where vent buildings (large or small) could be located along the alignments. The height of vent buildings would be determined by an environmental study that accounts for the location of the building, adjacent structures, wind patterns, and sensitive areas.

For the NSRL project, the number of vent buildings required to meet design needs would vary by alternative. However, in all cases, some sort of fan plant (jet fans or vent building) would be required over each portal. Each station would also require at least one, and likely two, vent buildings. The pairing of these buildings is vital in order to create directional flows of smoke away from affected passengers. The various alignments would require anywhere from six to eight vent buildings each.

5.6 Initial Alignments Considered

Initial NSRL Feasibility Reassessment studies identified a long list of multiple alignments to be examined at a high level and screened into a short list of alternatives. Five alignment alternatives were initially considered, as follows:

- Central Artery Two-Track This alternative descends out of Back Bay Station at a 2.75% grade and continues to a cut-and-cover South Station underneath the Fort Point Channel east of Dorchester Avenue. The two parallel tracks share a single 41-foot-diameter bored tunnel beneath the Central Artery, serve a mined underground North Station, and cross under the Charles River to a grade-separated portal complex connecting to the northern commuter lines. This alternative is similar to the 2003 DEIR's two-track alternative and is described in more detail in Section 5.8.
- Central Artery Four-Track This alternative adds two more tracks to the downtown segment of the Central Artery Two-Track alternative, with the existing Fairmount Line tracks descending into a second 41-foot-diameter bored tunnel, straightening out directly east of the tunnel from Back Bay, and serving the same South and North underground stations (plus an additional Central Station connecting to the Blue Line at Aquarium). Connections between the tunnels are at grade, and flying junctions allow all possible inbound/ outbound origin/destination pairs. This alternative is similar to the 2003 DEIR's four-track alternative and is described in more detail in Section 5.8.

- South/Congress This alternative descends at a 2.75% grade out of Back Bay and curves more sharply north than the Central Artery tracks while weaving into a stacked 51-foot-diameter bored tunnel. Both the underground South Station and State-Haymarket Station (a proposed alternative to North Station) are contained within the diameter of the tube, under South and Congress Streets, respectively. The northern connections are grade-separated to serve all commuter lines currently originating in the surface North Station. This alignment is described in more detail in Section 5.8.
- Pearl/Congress This alternative descends at a 2.75% grade out of Back Bay, diverging horizontally into two parallel 29-foot-diameter singletrack bores underneath the Fort Point Channel, with the northbound track continuing to descend until the tracks are separated by a horizontal city block. South Station comprises two underground single-track mined station boxes, and tracks

converge underneath Congress Street into two stacked single-track tunnels. State-Haymarket Station and the northern portals are located in a similar location to the South/Congress alternative. This alignment is described in more detail in Section 5.8.

 Merrimac – This alternative begins at Back Bay and its South Station locations are identical to either South/Congress or Pearl/Congress. This two-track alignment uses stacked tracks in either two 29-foot-diameter tubes or a single 51-footdiameter tube. Instead of connecting to the State and Haymarket MBTA rapid transit stations, North Station connects only to Haymarket and is located underneath Merrimac Street west of the current Government Center garage. This alignment was not pursued; see the following section for more details.

5.7 Short-Listing of Alternatives

Of the long list of alternatives described in the previous section, no significant barriers were identified to any of these alignments except for Merrimac. The Central Artery Two-Track alignment uses an existing highway corridor and reduces the likelihood/extent of right-of-way acquisition. The Central Artery Four-Track alignment can be accessed by the Fairmount Line and is closest to the four-track alternative evaluated in 2003. South/ Congress is a shorter route and avoids conflicts with deeper roadways, waterways, and transit tunnels, especially beneath and around South Station. Pearl/ Congress uses narrower single-track tubes along narrow streets.

The Merrimac alignment was not pursued due to three significant anticipated downsides:

- A prohibitively sharp (less than 720-foot radius) curve is necessary to connect Congress with Merrimac while remaining underneath the street right-of-way.
- This stretch of Merrimac between Market/New Chardon and Staniford/Causeway Streets, while as wide as Congress, is not necessarily long enough to reasonably fit an 850-foot-long underground station with passenger connections to Haymarket.



Figure 26: Short-Listed Alignment Alternatives

 In addition to these constraints, the tunnels would either require lengthening or further shifting of the alignment to avoid potential impacts to property west of Merrimac (including some MGH facilities) as the alignment climbs to connect to the existing at-grade northern commuter rail tracks.

Aside from the Merrimac alternative, each of the four other alignments has unique and promising characteristics recommending them for further analysis. An overview of each, including its tunnel diameter, number of tracks, stations provided, and station method of construction, is shown in Table 16. The alignments' routes through Central Boston are shown color-coded in Figure 26.

The next section elaborates on the alternatives above and their associated station layouts, along with tunneling methods and underground construction details unique to each alternative.

Alternative	Tracks	Number of Tunnels and Diameter	South Station	Central Station	North Station or State/Haymarket Station
Central Artery Two-Track	2	1 × 41 ft	Cut-and-Cover	N/A	Mined
Central Artery Four-Track	4	2 × 41 ft	Cut-and-Cover	Mined	Mined
South/Congress	2	1 × 51 ft	Bored	N/A	Bored
Pearl/Congress	2	2 × 29 ft	Mined	N/A	Mined

Table 16: Short List of Alignment Alternatives

5.8 Alignments and Stations

All four short-listed alignments utilize the North portals and Back Bay portal. The TBM is launched from the North portals and driven south. The Central Artery Four-Track adds the South Bay portal in order to run the Fairmount Line into the second tunnel.

The North portals require some separation via a flying junction that straddles the portal area, allowing grade-separated connectivity to all northern lines. The tunnels converge into a four-track mined cavern, with level crossovers allowing connectivity to all northern lines. One northern cavern portal carries the westernmost ("inner") two tracks to the Fitchburg Line, which climb to reach the surface via a portal directly south of the MBTA maintenance facility building's southwestern corner on the Cambridge/Somerville border. Another northern cavern portal carries the easternmost ("outer") two tracks to the Lowell, Haverhill, and Newburyport/ Rockport Lines, which continue northwest for another 1,500 feet, and emerge from a portal due east of the same building's northeastern corner.

The Back Bay portal is located east of the existing Back Bay Station, between Shawmut Avenue and Washington Street. The South Bay portal is located on the Fairmount Line, just east of Widett Circle. The approximate locations of the three portals are illustrated in Figures 27 to 29.



Figure 27: North Portals



Figure 28: Back Bay Portal



Figure 29: South Bay Portal

Central Artery Two-Track

Route and Description

Existing surface tracks from the Northeast Corridor and Framingham / Worcester Lines connect east of Back Bay Station and converge into a two-track boat section, passing over the Orange Line and descending at a 2.75% grade. Utilizing grades less than 2.75% results in the need for additional tunnel construction west and south of Back Bay Station. The tracks approach the portals in a retained cut and, once submerged, continue as mined tunnels before transitioning into a single 41-foot-diameter bored tube containing two tracks separated by 19ft (track centerline to track centerline). In the bored section, the tunnel roof (or 'crown') is approximately 30ft above the top of the rail. To provide increased separation between the new tunnel and existing structures, the tunnel crown can be lowered using a mined section when passing under the I-90 mainline tunnels or approaching the underground westbound ramp off I-90 into the South Bay Interchange. The tracks' steep grades substantially level out in the 41-foot-diameter tunnel as it runs underneath the Fort Point Channel at a depth of approximately 135ft. The two tracks also pass beneath the Red Line in the underground station area.

The underground South Station is constructed beneath the Fort Point Channel, with 1,050-foot platforms and connections to surface streets, the existing South Station headhouse, and the underground Red and Silver Line concourses. North of South Station, the alignment continues under the Fort Point Channel, passes under the Silver Line bus tunnels, and joins the Central Artery corridor, descending at a 0.5% grade to a maximum depth of 165ft. The underground North Station is beneath the Central Artery, southeast of the existing surface North Station.

Immediately north of North Station, the alignment climbs at a 2.3% grade, passing underneath the Orange Line and the Charles River. A flying junction straddles the north portal area, allowing grade-separated connectivity to all northern lines. The southbound tracks remain lower than the northbound tracks in a series of retained cuts. Beyond the northern approaches, all tracks level out and connect with the existing Fitchburg, Rockport/ Newburyport, and Lowell Lines.

Figure 30 shows the Central Artery Two-Track alignment plan and profile, starting at Back Bay.

Summary

- **Description:** Two tracks running from Back Bay portal under the Fort Point Channel, Central Artery, and Charles River to North portals
- Alignment length (between tunnel portals): 14,300 feet (2.7 miles)
- Maximum alignment depth (below street level): 165 feet
- **Tunnel type:** One 41-foot diameter (38-ft inner diameter) machine-bored tunnel carrying two side-by-side tracks
- **Construction methodology:** Cut-and-cover construction in the Fort Point Channel, mining around South Bay interchange ramps, rerouting of Worcester Line into North Station
- Stations Include:
 - South: Cut-and-cover, under the Fort Point Channel.
 - North: Mined underneath I-93, connecting to North Station
- Station Platform Dimensions: Two 16-foot-wide side platforms and one 30-foot-wide center platform
- Station Access: Requires dedicated headhouses on properties adjacent to stations



Figure 30: Plan/Profile, Central Artery Two-Track Alignment

Tunnel and Underground Construction

The Central Artery Two-Track alignment can be accommodated in a 38-foot-diameter tunnel constructed using a 41-foot-diamter TBM. The 38-foot inner diameter (ID) allows for a centerline track spacing of 19ft and a top-of-rail to top-oftunnel distance of 30ft. These dimensions, shown in Figure 31, provide the required clearances for the train dynamic envelope, egress walkways, and mechanical systems.

The proposed South Station is built using cutand-cover. The station's proximity to the Fort Point Channel will necessitate constructing a sheet-piled cofferdam inside the channel that will be drained to create a dry worksite for constructing the station. Upon completion of the station, the cofferdam is removed and the channel bottom backfilled to the original contours. Precedent for this approach to station construction is available from the Central Artery/Tunnel project, where sheet piling was installed in the Fort Point Channel to permit dry construction of the tunnel under half of the channel while normal tidal flushing and navigation continued in the other half of the channel.

The two 100-year-old tubes of the Red Line pass over the proposed South Station. These tubes will require underpinning, and the station excavation will likely be mined in the vicinity of the tubes.



Figure 31: Tunnel Cross-Section, Central Artery Two-Track Alignment

The new underground North Station site has limited space at street level. Cut-and-cover station box construction would be disruptive to streets and buildings and mined station construction has been identified as a less disruptive approach. Mined stations are created by hand, excavating the ground area around the tunnel bore to create a wider cavern for the station area. Connections to the MBTA rapid transit lines at the new underground North and South Stations require mined pedestrian tunnels to create 15- to 25-foot-wide passenger walkways.

Innovative subsurface excavation techniques have been carried out in Boston to minimize the impacts on existing structures and roads above. The MBTA's relatively new Silver Line tunnel was constructed under Russia Wharf (three 100-year-old buildings), using a mixture of ground freezing and the New Austrian Tunneling Method (a form of mined tunnel construction). A binocular-shaped tunnel was used to minimize the required excavation volume and overall tunnel size. This precedent experience will aid in the design and construction of mined stations on the NSRL project.

Station Layout

The proposed stations for the Central Artery Two-Track alignment are configured as side platforms, fed from above by entrances at either end of the station. From these two connection points, passengers arrive at one of two large concourses spanning both tracks. The concourses allow passengers a central point of decision-making, with access to either escalators or elevators down to the platforms. Passengers can use this area to wait for trains without creating undue congestion on the platforms. In addition, the concourse provides a line of sight down to the trains below and can assist with the wider wayfinding strategy. The proposed underground South Station, shown in Figure 32, is reached from a connection to the existing South Station at its northern end via the Red and Silver Line concourse. At its southernmost point, South Station is reached by a combined entrance and ventilation headhouse on the eastern



Figure 32: South Station, Central Artery Two-Track Alignment

side of the Fort Point Channel within the Fort Point District 100 Acres Master Plan. Since the proposed South Station will be built using cut-and-cover construction, there are significant opportunities to place ancillary and back-of-house space (such as the tunnel ventilation fans) into levels above the platform and below the street. Potential additional headhouse locations include the vicinity of the existing South Station.

The proposed underground North Station, shown in Figure 33, has two primary means of access for passengers: one directly adjacent to the TD Garden to the north and one at Haymarket Station to the south. Both connections are built in anticipation of future links to planned developments in those areas. The connection at Haymarket also provides access to the Orange and Green Lines. Tunnel ventilation can be facilitated via a shaft located within the parking lot at 37 Merrimac Street. Potential headhouse locations include the vicinity of the existing North Station and the Haymarket Square on one or more corners of Merrimac, Market, or New Chardon Streets.

Fire/Life Safety

The Central Artery Two-Track alignment could be designed with a hardened, fire-rated barrier between the two tracks, eliminating the need for any emergency-only exits. If this barrier is not included, emergency exits would be needed between the two stations, and between each station and the portals, as those distances are greater than 2,500ft.



Figure 33: North Station, Central Artery Two-Track Alignment

Central Artery Four-Track

Route and Description

This alternative is comparable to the Central Artery four-track alternative proposed in 2003, with three minor differences: (1) only a single South Bay portal is included, connecting to the Fairmount Line, (2) both the Central and North Station platforms are 850ft long (the 2003 study assumed Amtrak trains would be stopping at both the underground North and South stations, and so the platforms at North Station in that study were designed to have a length of 1,050 feet), and (3) a grade-separated switch area, at or near the north portals, is proposed to allow conflictfree movements between commuter rail service in opposite directions.

Existing surface tracks from the Northeast Corridor and Framingham/Worcester Lines connect east of Back Bay Station and converge into a two-track boat section, passing over the Orange Line and descending at a 2.75% grade. Utilizing grades less than 2.75% requires additional tunnel construction west and south of Back Bay Station. The tracks approach the portals in a retained cut and, once submerged, continue as mined tunnels before transitioning into a 41-foot bored tube containing both tracks separated by approximately 19ft. In the bored section, the tunnel roof is approximately 30ft above the top-of-rail. Where the height of the proposed tunnels is constrained by existing infrastructure, overhead clearances could be lower in a mined section. Potential locations for lowering tunnel roofs includes the area under I-90

mainline tunnels or approaching the ramp from I-90, as described in the section about the Central Artery Two-Track alignment.

Tracks from the Fairmount Line descend at a 2.75% grade, curving east and entering an identical 41-foot-diameter tube. Horizontal separation between the new Fairmount Line tunnel and the tube containing Back Bay tracks is approximately 21ft, which is considered acceptable for tunnel separation at this stage of the design. All four tracks, in parallel 41-foot-diameter tunnels carrying two tracks each, pass beneath the Red Line in the station area. The station tracks are straight, on a 0.5% grade, and approximately 135ft below street level.

The new underground South and North Stations are constructed in the same manner as for the Central Artery Two-Track alternative. Central Station is proposed to be built using mined construction techniques beneath the MBTA Blue Line at Aquarium. Immediately north of North Station, the alignment climbs at a 2.3% grade, passing underneath the Orange Line and the Charles River.

Figure 34 shows the Central Artery Four-Track alignment plan and profile; the plans start both at Back Bay and at the prevailing grade on the Fairmount Line. The profile in Figure 34 gives only the vertical alignment for the Fairmount Line approach, as the Back Bay tracks are identical to the Central Artery Two-Track alternative profile (displayed in Figure 30).

Summary

- **Description:** Two tracks from Back Bay portal join two tracks from South portal, running under the Fort Point Channel, Central Artery, and Charles River to North portals
- Alignment length (between tunnel portals): 14,300 feet (2.7 miles) from Back Bay portal, 14,600 feet (2.8 miles) from South portal
- Alignment depth (below street level): 165 feet
- **Tunnel type:** Two adjacent 41-foot diameter (38-ft ID) machine-bored tunnels, each carrying two horizontally parallel tracks
- **Construction disruption:** Cut-and-cover construction in the Fort Point Channel, mining around South Bay interchange ramps, rerouting of Worcester Line into North Station
- Stations Include:
 - South: Cut-and-cover, under the Fort Point Channel
 - Central: Mined underneath I-93, connecting to Aquarium
 - North: Mined underneath I-93, connecting to North Station
- Station Platform Dimensions: Two 16-footwide side platforms and one 30-foot-wide center platform
- Station Access: Requires dedicated headhouses on properties adjacent to stations



Figure 34: Plan/Profile, Central Artery Four-Track Alignment

Tunnel and Underground Construction

This alignment is very similar to the Central Artery Two-Track alignment but considers the use of two 41-foot TBMs (along the same alignment) to form two bored 38-foot ID tunnels. The internal dimensions are the same as the Central Artery Two-Track alignment and provide the required clearances for the train, egress walkways, and mechanical systems. Figure 35 is a cross-section of the parallel tunnels separated by 21ft.

The proposed South and North Stations are constructed in the same way and location as in the Central Artery Two-Track Alignment. The four-track alternative also includes a third proposed station, Central Station, which is mined. Mining has been selected over cut-and-cover due to the depth of the station and the location in the center of Downtown Boston.

Station Layout

The Central Artery Four-Track alignment station designs are consistent with those used for the Central Artery Two-Track designs, albeit with an additional centrally loaded platform to serve the two additional tracks. The stations within this alignment are wider to accommodate these additional tracks and platform; however, the overall configuration remains the same as described in the previous section and depicted in Figures 32 and 33. As with the Central Artery Two-Track alternative, potential South Station headhouse locations include the vicinity of the existing South Station as well as the eastern bank of the Fort Point Channel, and potential North Station headhouse locations include the vicinity of the existing North Station and Haymarket Square on one or more corners of Merrimac, Market, or New Chardon Streets.

The proposed Central Station is situated south of State Street underneath John F. Fitzgerald Surface Road / Atlantic Avenue. This location has access at either end — from Aquarium Station on the north side as well as from a new headhouse entrance and ventilation shaft located at the parking lot at India Street and the John F. Fitzgerald Surface Road. Figure 36 shows the Central Station and its proximity to the Blue Line. Potential Central Station headhouse locations include Long Wharf and the sidewalks of Atlantic Ave or the John F Fitzgerald Surface Road at or near the Milk Street intersection.



Figure 35: Tunnel Cross-Section, Central Artery Four-Track Alignment

Fire/Life Safety

The Central Artery Four-Track alignment would have two tunnels. With connections between them at least every 800ft, there is no requirement for additional emergency-only exits to the surface. A fire-rated barrier within each tunnel may also be an alternative. The decision to mine crosspassageways between the two tunnels, a firerated barrier along the length of the tunnel, and emergency-only exits to the surface are all subject to further review. Emergency exits to the surface become less costly for the portal portions, as the distance to the surface is shorter.



Figure 36: Central Station, Central Artery Four-Track Alignment

South/Congress

Route and Description

The South/Congress alignment is of particular interest for four main reasons:

- The alignment is shorter than either Central Artery alignment.
- The alignment does not interact longitudinally with the underground I-93 tunnel for nearly as far, or with as little vertical separation, as either Central Artery alternative.
- The stations themselves can be contained within the bored tube.
- The alignment avoids station construction beneath the Fort Point Channel, deep Red Line tubes, I-90 mainline lanes and exit ramps, and the Silver Line tunnels.

Just as in both Central Artery alternatives, existing surface tracks from the Northeast Corridor and Framingham/Worcester Lines connect east of Back Bay Station and converge into a two-track boat section, passing over the Orange Line and descending at a 2.75% grade. Utilizing grades less than 2.75% results in the need for additional tunnel construction west and south of Back Bay Station. The tracks approach the portals in a retained cut, and once submerged, continue as mined tunnels, curving sharply north with a radius of 720ft. The southbound track levels out at a depth of about 110ft while the northbound track descends under

the southbound track. In this transition, the downward grade changes from 2.75% to 0.5%, entering a large single bore with a diameter of approximately 51ft. This allows trains to operate through the curve at 25 miles per hour.

South Station platforms are 1,320ft long and constructed inside the tube beneath South Street and the Red Line tubes, one block west of the existing station headhouse. North of South Station, the alignment joins Congress Street, continuing to descend at a 0.5% grade and passing under the Blue, Orange, and Green Lines. The alignment proposes a new State-Haymarket commuter rail station replacing today's North Station, with platforms 850ft long that are also contained within the tube and connect to both State and Haymarket MBTA Rapid Transit Stations.

Immediately north of the proposed State-Haymarket commuter rail station, the alignment continues descending, realigns with the Central Artery tunnels, and begins climbing at a 2.3% grade, passing underneath the Orange Line and the Charles River.

Figure 37 shows the South/Congress alignment plan and profile, starting at Back Bay.

Summary

- **Description:** Two tracks running from Back Bay portal under South, Congress, Central Artery, and Charles River to North portals
- Alignment length (between tunnel portals): 13,100 feet (2.5 miles)
- Alignment depth (below street level): 110-160 feet
- **Tunnel type:** One 51-foot diameter machinebored tunnel, containing two vertically stacked tracks and station platforms
- **Construction disruption:** Limited, with downtown station construction primarily off sidewalks and streets, rerouting of Worcester Line into North Station
- Stations Include:
 - South: Inside bored tube underneath Congress Street, connecting to South Station
 - North (State-Haymarket): Inside bored tube underneath Congress Street, connecting to State and Haymarket
- Station Platform Dimensions: Two 16-foot-wide stacked side platforms
- Station Access: Requires dedicated headhouses on properties adjacent to stations



Figure 37: Plan/Profile, South/Congress Alignment

Tunnel and Underground Construction

The South/Congress alignment incorporates a single 51-foot bored tunnel, as shown in Figure 38, with the tracks stacked and station platforms within the tunnel bore. A tunnel of this configuration has been used for the subway system in Barcelona, where containing the stations within the bore and stacking the tracks has saved money and space in a congested city. Tunnels have been constructed with diameters of up to 57ft for highway tunnels in Seattle and Hong Kong. This method is increasingly being considered for transit systems as it allows all the underground space to be constructed by TBM, which is a highly mechanized and efficient operation, and avoids most of the more complex cut-and-cover or mined excavation work for the stations. As a result, both the proposed underground South Station and State-Haymarket commuter rail stations are located within the bored tunnels, with mined station entrance areas. The tunnel alternatives along this alignment use the South Street width as the limiting dimension of the tunnel.

The South/Congress alignment passes under (and offers connections with) the Red and Silver Lines at South Station and the Green, Blue, and Orange Lines at State-Haymarket.



Figure 38: Tunnel Cross-Section, South/Congress Alignment

Station Layout

Both the South and State-Haymarket Stations in the South/Congress alignment are constructed within the 49-foot ID of the single-tunnel bore with stacked tracks and platform. As in other stations and alignments, vertical circulation is provided from a series of tunnels that lead to the surface. The existing South Station is connected to the new underground commuter rail station platforms via cascading stairs and escalators from the waiting room to the basement. The connection between the surface and subway tracks then descends under Essex Street, connecting to the south end of the new commuter rail station. In addition, passenger walkways can be provided within the station complex and parallel to the station platform (requiring an additional bore) to allow passenger access and evacuation. As in the other stations, the back-of-house and ancillary requirements are offloaded to the concourse and shaft locations.

The proposed South Station, depicted in Figure 39, is accessed via the Red and Silver Line concourse, within the Essex Street right-of-way. In addition, a headhouse with entrance and ventilation shafts can be located adjacent to 133 Federal Street.

A drawback to accommodating the stations within a 51-foot diameter bore is the limitation of platform widths to 16ft. Passenger demand at the proposed State-Haymarket Station is unlikely to exceed station capacity with 16-foot platforms. However, the underground South Station passenger demands



Figure 39: South Station, South/Congress Alignment



Figure 40: State-Haymarket Station, South/Congress Alignment

could result in platform overcrowding. At South Station, the platforms will be 1,320ft (400 meters) long, allowing for the staggering of MBTA trains and the spreading of passenger loads. For example, northbound trains to Newburyport/Rockport could stop at the far northern end of the platform, while trains to Lowell could stop at the midpoint of the platforms. This strategy effectively doubles passenger platform capacity at a low cost (since the station enclosure is already provided within the 51-foot tunnel).

The proposed State-Haymarket Station, shown in Figure 40, has two primary means of access, one at the rapid transit Haymarket Station to the north and another at the rapid transit State Street Station to the south. This facilitates passenger connections to the Orange, Green, and Blue Lines.

Fire/Life Safety

For the South/Congress alignment, separation of the two tracks with a hardened barrier is feasible close to the portals (when tracks are level with each other) and close to, and between, stations (where tracks are stacked). However, as the tracks transition from level to stacked between the portals and stations, this separation (and associated walkways) may not be feasible. This may result in either the need for emergency exits or for extra mining around the tunnel to allow for separation and walkways.

Pearl/Congress

Route and Description

The two-track/two-tunnel Pearl/Congress alignment is a combination of the Central Artery and South/ Congress concepts. The approaches are similar to the Central Artery alternatives, but this alignment follows Congress Street and includes a new underground State-Haymarket Station between the MBTA rapid transit State and Haymarket Stations on the Blue/Orange and Orange/Green Lines, respectively.

Just as in previous alternatives discussed in this section, tracks from the Northeast Corridor and Framingham/Worcester Lines connect east of Back Bay Station and converge into a two-track boat section, passing over the Orange Line and descending at a 2.75% grade. Using grades less than 2.75% would result in the need for additional tunnel construction west and south of Back Bay Station. The tracks approach the portals in a retained cut, and once submerged, continue briefly as mined tunnels before diverging and entering single-track bores with a diameter of approximately 29ft. The southbound, higher track levels out to a 0.25% downward grade, and the northbound, lower track continues to descend until it is 43 feet deeper than the southbound track before itself transitioning to a 0.25% downward grade in turn. The tracks curve northwest under the Fort Point Channel. The new underground South Station consists of two 1,050-foot platforms, both mined, one underneath

Pearl Street and the other underneath Congress Street near Post Office Square.

North of South Station, both tracks converge underneath Congress Street and stack, with the lower (northbound) tube directly beneath the upper (southbound) tube when passing under the Blue, Orange, and Green Lines. The proposed commuter rail State-Haymarket Station, with platforms 850ft long, is mined and connects to both State and Haymarket rapid transit stations.

Immediately north of the proposed State-Haymarket commuter rail station, the lower (northbound) tracks diverge horizontally and climb to meet the upper (southbound) track. The northbound track climbs at a 1.6% grade, and once reaching the southbound track, both climb together at a 2.3% grade to the north portals, passing underneath the Orange Line and the Charles River.

Figure 41 shows the Pearl/Congress alignment plan and profile, starting at Back Bay. While the profile displays both tracks' elevation, the tracks are not parallel; at South Station, for example, the northbound and southbound tracks are separated by 250ft.

Summary

- **Description:** Two tracks running from Back Bay portal under Pearl alongside Congress (one track under each), Congress (both tracks) Central Artery, and Charles River to North portals
- Alignment length (between tunnel portals): 15,400 feet (2.9 miles)
- Alignment depth (below street level): 125-185 feet
- **Tunnel type:** Two 29-foot diameter machinebored tunnels, each carrying a single track, transitioning from horizontally parallel to vertically stacked
- **Construction disruption:** Mining around South Bay interchange ramps, rerouting of Worcester Line into North Station
- Stations Include:
 - South: Parallel mined stations underneath Pearl and Congress Streets, connecting to South Station
 - North (State-Haymarket): Mined underneath Congress Street, connecting to State and Haymarket
- Station Platform Dimensions: Two 16-foot-wide side platforms
- Station Access: Requires dedicated headhouses on properties adjacent to stations



Figure 41: Plan/Profile, Pearl/Congress Alignment

Tunnel and Underground Construction

The Pearl/Congress alignment has been studied using two 29-foot-diameter TBMs launched from north of the current North Station. Due to space constraints, these two tunnels have different alignments. The tunnels follow the streets to avoid building foundations and other obstacles, and are spaced vertically for the northernmost segment of the tunnels. They are stacked north of Post Office Square, in the configuration shown in Figure 42, because Congress Street is wider north of Post Office Square than to its south; furthermore, Pearl Street is narrower along the tangent where the station is proposed. The 29-foot bored tunnels are separated by about 14ft from the top of the tunnel to the bottom of the tunnel. South of Post Office Square, the tunnels spread in both horizontal and vertical planes, as shown in Figure 43, and are a city block apart at South Station.

This alternative considers two proposed belowgrade commuter rail stations: a new South Station and a new State-Haymarket Station. The proposed South Station is a mined station, similar to the Crossrail stations in London in that there is a platform tunnel for each track and concourse tunnels in the middle connecting the two. At the proposed State-Haymarket Station location, the tunnels are stacked, and the station is mined. The station tunnels (26 to 30ft in diameter) are mined using the sequential excavation method (SEM), which was previously used in the area for the Russia Wharf tunnel (Silver Line).



Figure 42: Tunnel Cross-Section, Pearl/Congress Alignment (Stacked)



Figure 43: Tunnel Cross-Section, Pearl/Congress Alignment (Adjacent)

Station Layout

The proposed South Station, shown in Figure 44, is accessed from a connection at Post Office Square at its northern end and from the Red and Silver Line concourse and the existing surface South Station. A concourse between the two mined tracks provides a centralized passenger circulation area. Each platform is designed to host a separate passageway (parallel to the platform) as a continuous bypass that can also be used for emergency egress. Potential headhouse locations include the vicinity of Post Office Square and the blocks to the south.



Figure 44: South Station, Pearl/Congress Alignment

Figure 45: State-Haymarket Station, Pearl/Congress Alignment

The proposed commuter rail State-Haymarket Station, shown in Figure 45, is a stacked-track configuration with circulation adjacent to the platform to facilitate passenger movement between northbound and southbound tracks. There are two primary means of access: one at the Haymarket rapid transit station to the north and another at the State Street rapid transit station to the south, facilitating passenger connections to the Orange, Green, and Blue Lines.

Fire/Life Safety

The Pearl/Congress alignment has a similar fire/ life safety design as the Central Artery Four-Track system because of the parallel tunnels. Connections are made between them at least every 800ft, so there is no requirement for additional emergencyonly exits to the surface. A fire-rated barrier within each tunnel may also be an alternative. The decision to mine cross-passageways between the two tunnels, a fire-rated barrier along the length of the tunnel, and emergency-only exits to the surface are all subject to further review.

Platform Alternatives

Figures 46 and 47 show the proposed platform locations for North and South Stations for each alignment, as well as their relative location compared to the existing rail termini. Potential headhouse locations are indicated by the small circles. Table 17 shows station depths for all alignments.

Figure 46: North Station: Platform Alternatives

Figure 47: South Station: Platform Alternatives

Alignment	South Station Depth (ft)	North Station Depth (ft)
Central Artery	135	140
South/Congress	130	140
Pearl/Congress (Southbound)	130	135
Pearl/Congress (Northbound)	185	195

 Table 17: Station Depths by Alignment

5.9 Upstream Improvements

Currently, 14 MBTA trains are scheduled from Back Bay into South Station in the peak hour and peak direction. During the same period, 13 MBTA trains arrive into North Station.

Both systems are using the full existing capacity of their respective track infrastructure. To allow a more efficient use of the NSRL tunnel, modest upstream improvements to the rail network outside of the tunnel, both north and south, will allow another three trains from the south and four trains from the north to access the tunnel. This allows for a total of 16 to 17 trains (per hour, per direction) to access the NSRL tunnel under the two-track options. The four-track alternative can only allow for an additional four trains per hour, because of the limitations of the northern system to accommodate further trains from the southern system.

To realize these increases in train movements, operational and capital improvements are required on the existing commuter rail system. At this level of scheduled service, the NSRL will be operating at about 80 to 85% of its potential capacity (assuming Amtrak operates two trains per hour, per direction in the tunnel). The following upstream improvements and interventions are necessary to increase train movements and levels of service, as well as serve the following priorities:

- Remove conflicts between train movements
- Provide adequate platform capacity and minimize bottlenecks at stations
- Reduce train headways between signals
- Reduce headways between trains traveling on the same single-track sections (e.g., through reducing headways between trains traveling through the same junctions, or providing sidings at key locations)
- Increase capacity on currently single-track portions of the network
- Reduce turnaround times at terminals

The full list of improvements and interventions for each service alternative proposed is included as Appendix B.

5.10 Construction/Operational Impacts

Every alternative includes significant construction impacts to existing operations and requires temporary terminations, reroutings, and other measures during construction. The following service changes required to complete Back Bay portal works are among the most impactful:

- Temporary rerouting of some or all Providence, Stoughton, and Franklin Line commuter rail service via the Fairmount Line into South Station.
- The Fairmount Line would require electrification if Amtrak service into South Station is run via this line during construction.
- Limited single-tracking from Back Bay into South Station, impacting Amtrak and the Needham Line.
- Termination of the Worcester Line west of Back Bay, unless a viable rerouting (e.g., via the Grand Junction Line into North Station) is identified.
- Potential rail replacement routes on buses running from Back Bay into the Financial District.

There will be other service delays and interruptions as the north portal grade separations are constructed, but these will likely be less severe than the Back Bay–South Station impacts.

The placement of new tunnel infrastructure within an urban environment poses some challenges, with potential impacts on streets, subways, utilities and foundations. Accommodating station headhouses may cause some disruption at the surface level, and in some cases, require the taking of property. In terms of tunneling methodologies, cut-and-cover tends to have major surface impacts, requiring the complete excavation of the tunnel route and the re-routing of streets and utilities while work is being undertaken. Tunnel boring, on the other hand, has a minimal impact on the surface but requires a staging area for the launch of the TBM. Both cutand-cover and tunnel boring can cause concerns with building settlement (the buildings adjacent to the cut-and-cover trench or the buildings directly above the tunnel bore) and the settlement/relocation of utilities. Using TBM to bore tunnels for the NSRL alignments, while a more expensive method, has fewer surface impacts than excavating the tunnels through cut-and-cover.