Doubling Trans-Hudson Train Capacity at Penn Station

An Engineering Feasibility Study of Alternatives Within the Existing Station Footprint

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Acronyms and Abbreviations

AHJ	Authority Having Jurisdiction
ARC	Access to the Region's Core
ATC	Automatic Train Control
BOH	Back-of-house
CE, CatEx	Categorical Exclusion
cfm	Cubic feet per minute
CP	Control Point
EA	Environmental Assessment
EIS	Environmental Impact Statement
ENR	Engineering News-Record
ERY	Eastern Rail Yard
ESD	Empire State Development
FONSI	Finding of No Significant Impact
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HVAC	Heating Ventilation and Air Conditioning
HYCC	Hudson Yards Concrete Casing
IND	Independent Subway System, or MTA Subway B Division
IRT	Interborough Rapid Transit, or MTA Subway A Division
LIRR	Long Island Rail Road
MAS	Maximum Authorized Speed
MEP	Mechanical, electrical, and plumbing
MNR	Metro-North Railroad
MTA	Metropolitan Transportation Authority
MU	Multiple unit
NEC	Northeast Corridor
NEPA	National Environmental Policy Act
NFPA	National Fire Protection Association
NJ	New Jersey
NORAC	Northeast Operating Rules Advisory Committee
NTP	Notice to Proceed
NY	New York
NYCDEP	New York City Department of Environmental Protection
NYCT	New York City Transit
Penn Station	New York Penn Station (also referred to as NYP, NYPS, and NY Penn Station in other publications)
OCS	Overhead catenary systems
OSHA	Occupational Safety and Health Administration
PATH	Port Authority Trans-Hudson
PPDS	Primary Power Distribution System
ROD	Record of Decision
S & I	Service and Inspection
SCADA	Supervisory Control and Data Acquisition
SEM	Sequential excavation method
SOE	Support of excavation
TBM	Tunnel boring machine
tph	Trains per hour
USDOT	United States Department of Transportation
VCE	Vertical circulation elements
WRY	Western Rail Yard

Executive Summary

Amtrak, the Metropolitan Transportation Authority (MTA), and NJ TRANSIT (together, the Partners) are considering alternatives to at a minimum double the trans-Hudson train capacity of New York Penn Station (Penn Station), an effort called the Penn Station Capacity Expansion Project (Penn Capacity Expansion). Some of the options being evaluated by the Partners adapt the station to add capacity within the existing station footprint, while others expand the station boundaries. This report assesses the technical feasibility of two different alternatives for adapting Penn Station to add capacity within the existing station footprint. A separate, future analysis will evaluate alternatives that expand the station boundaries.

The current Penn Station and its operational infrastructure, which includes the tunnels under the Hudson and East Rivers and the interlockings on either side of the station, are functioning above capacity. Greater train capacity at Penn Station is urgently needed to accommodate existing and anticipated passenger demand between New Jersey and New York and to enable Penn Station to provide direct service to a larger network of branch lines than it does today. Long-overdue infrastructure improvements along the Northeast Corridor (NEC), including a new two-track tunnel beneath the Hudson River and rehabilitation of the existing tunnel, will create the capacity to at least double trans-Hudson train service from New Jersey and points west and south. Steady ridership growth along the NEC and population growth within communities in the New York metropolitan region have created demand for utilizing that new capacity. As a result, increasing train capacity and expanding service at Penn Station to accommodate both current and projected future demand will bolster sustainable transportation options and access to economic opportunity in the heart of the New York metropolitan region for decades to come.

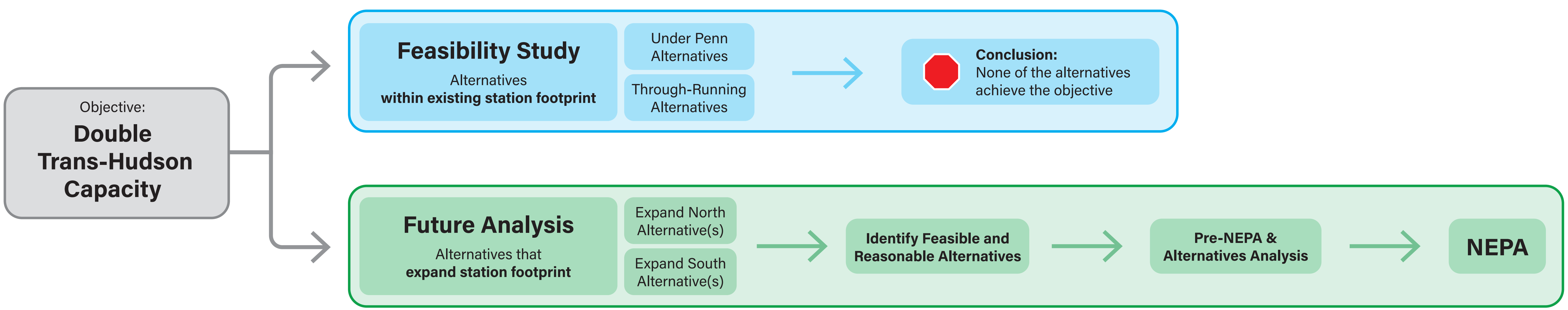
The Partners commissioned the WSP/FXC Team to develop and evaluate potential alternatives for at least doubling the trans-Hudson train capacity of Penn Station. This report documents alternatives that adapt the existing station footprint; alternatives that expand the station footprint will be documented in a separate, future analysis. Federal grant money from the U.S. Department of Transportation (USDOT) will be sought by the Partners for the project. As such, it is subject to environmental review under the National Environmental Policy Act (NEPA), which requires that reasonable alternatives be considered for any federal action. Implementing regulations define "reasonable alternatives" as "a reasonable range of alternatives that are technically and economically feasible, meet the purpose and need for the proposed action, and, where applicable, meet the goals of the applicant."

Contributing to the body of knowledge surrounding the Penn Station Capacity Expansion Project, the primary purpose of this study was to determine if the capacity requirements of the Gateway Program (described in the next section) — a minimum 48 trans-Hudson trains per hour (tph) — could be met within the station footprint. The report documents the process by which potential alternatives within the footprint of Penn Station were identified and details reasons why any alternative not recommended for further study was deemed infeasible.

A second goal of this feasibility study is to better understand the ability of these alternatives to support potential future cross-regional rail service.

Planning Context

The modernization of Penn Station and at a minimum doubling its trans-Hudson rail capacity are integral components of a larger program of regional rail infrastructure improvements centered on the NEC. A 457-mile-long rail corridor from Boston to Washington, D.C., the NEC is the busiest rail corridor in the country, the railroad spine of the East Coast, and an essential platform for metropolitan commuter networks along its length, including those in the New York metropolitan region. Penn Station, located at the midpoint of the NEC, is the busiest and most important station for Amtrak (the owner of the station) and for MTA Long Island Rail Road (LIRR) and NJ TRANSIT (the busiest and third-busiest commuter railroads in the country, respectively), both of which use the station under lease agreements with Amtrak. LIRR operates service on 10 branch lines that feed Penn Station, and NJ TRANSIT runs service on the NEC from Trenton to Penn Station and operates service on four other branches that merge into the NEC before running into New York, carrying over 80% of the ridership on this section of the NEC.



"The 'grow' vision prioritizes and embraces an advanced rail service that seamlessly integrates operations and services of Regional and Intercity operators and incorporates a new corridor-wide Metropolitan service to reach and connect local stations with hub and terminal stations. The vision incorporates operational efficiencies, including common ticketing and integrated planning, with the ability to transform the passenger experience by greatly enhancing convenience, reliability, travel-time savings, and travel choices. The seamlessly integrated rail services possible with operational efficiencies will make more effective use of public investments in infrastructure and will create greater transportation and economic benefits than continuing conventional separate operations."

— NEC FUTURE Tier 1 Final EIS Volume 1 (Preferred Alternative), page 4-24

NEC FUTURE

NEC FUTURE is a long-term investment plan for the entire NEC that aims to expand both intercity and regional commuter rail service throughout the corridor; increase reliability, connectivity, performance, and resiliency; promote equitable development; and bring NEC infrastructure to a state of good repair. Begun in 2012, the Federal Railroad Administration (FRA), an agency within USDOT, developed NEC FUTURE in collaboration with the eight states plus the District of Columbia along the corridor through their transportation agencies and metropolitan planning bodies; Amtrak; and the eight commuter railroads and six freight railroads that use the NEC.

FRA prepared a programmatic environmental impact statement (EIS) for this investment program under NEPA. Called a Tier 1 EIS, it assessed the corridor-wide environmental implications of three levels of expanded rail service across the NEC. The EIS process included extensive public outreach, with 2,500 public comments from 800 organizations and individuals received and responded to. The Record of Decision (ROD), issued in 2017, adopted a Selected Alternative that will grow rail service along the NEC and bring its infrastructure to a state of good repair to achieve modern, efficient passenger rail service for travelers.

The various infrastructure improvements for the New York metropolitan region identified in NEC FUTURE to meet the program goals fall into two groups:

1. At least doubling trans-Hudson rail service by adding two new tracks in a new tunnel below the Hudson River; rehabilitating the existing tunnel and tracks; expanding rail capacity at Penn Station; and numerous supporting infrastructure improvements in New Jersey.
2. Enabling cross-regional service at Penn Station in the longer term by adding two new tracks in a tunnel below Manhattan and the East River to Queens; rehabilitating the existing tunnels; and supporting infrastructure improvements in Queens and the Bronx.

The Tier 1 EIS is intended to be followed by project-specific environmental studies for the identified infrastructure improvements as planning and engineering for each one progresses. These are called Tier 2 studies. Implementing regulations provide for this tiered approach for programs like NEC FUTURE that are too large for a single environmental study to be practical.

Gateway Program

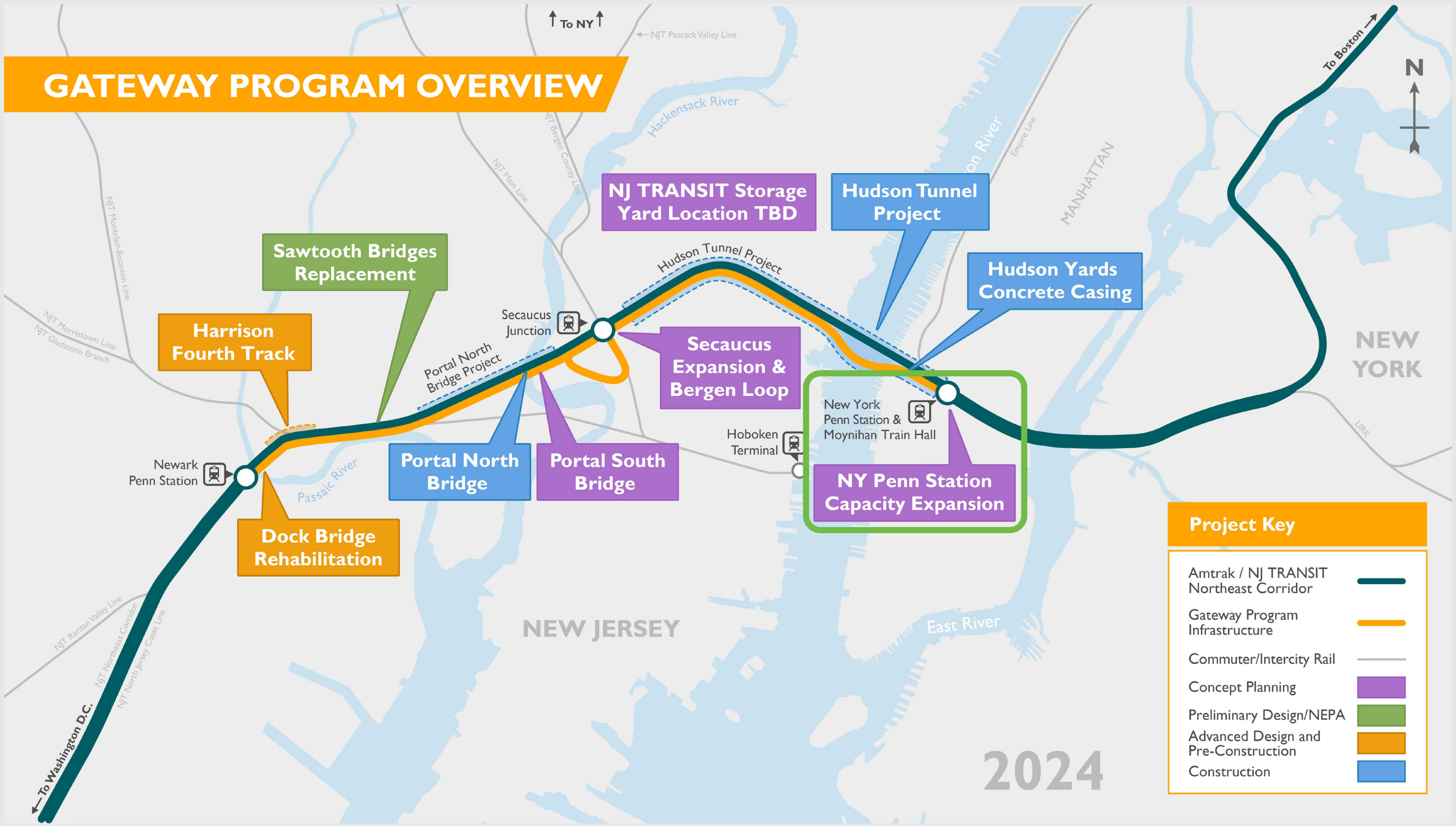
The Gateway Program is a subset of the infrastructure improvements identified in NEC FUTURE, specifically those needed to at least double trans-Hudson rail capacity and service. It is a comprehensive rail investment program to increase capacity and improve reliability, resiliency, and redundancy on the critical ten-mile section of the NEC between Newark Penn Station and New York Penn Station. It includes:

- Building the new two-track Hudson River Tunnel;
- Rehabilitating the existing two-track Hudson River tunnel (known by its original name, the North River Tunnel);
- Constructing concrete casings below Hudson Yards to preserve the Gateway right-of-way into Penn Station;
- Building, rehabilitating, or expanding trackage, bridges, connections, grade separations, and a rail yard in New Jersey; and
- At least doubling trans-Hudson rail capacity to support additional trains from New Jersey.

Figure E-1 illustrates the key components of the Gateway Program.

To achieve the NEC FUTURE vision for the New York metropolitan region, all of the Gateway projects, including at least doubling the trans-Hudson train capacity of Penn Station and the construction of the new Hudson River Tunnel, must be completed.

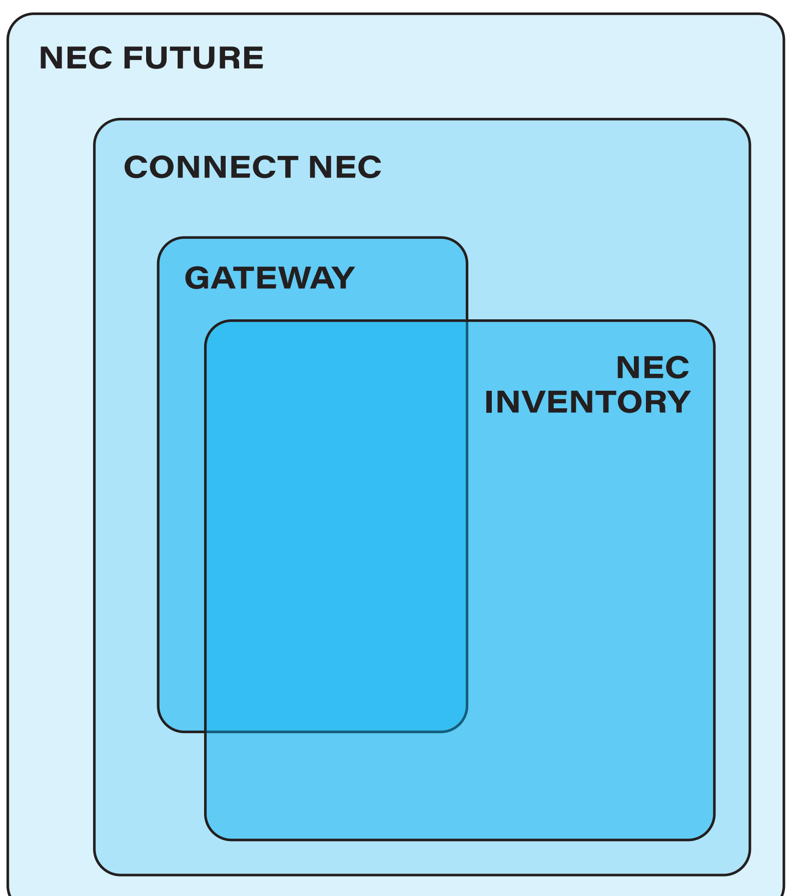
Figure E-1
Gateway Program Overview



Some environmental studies for Gateway projects have already been completed and approved, including EISs for the Hudson Tunnel Project, which is currently in procurement of major construction packages, and the Portal North Bridge in New Jersey, which is already in construction.

CONNECT NEC

The Northeast Corridor Commission (NECC) was established by Congress in 2008 to develop coordinated strategies to improve the Northeast's core rail network. It comprises representatives from each of the NEC states, Amtrak, and the USDOT. In 2021, the NECC published CONNECT NEC 2035 (C35), a 15-year service development plan and infrastructure planning process for the Northeast Corridor as the first phase of NEC FUTURE, identifying 173 potential rail infrastructure projects for implementation. In 2023, the NECC released CONNECT NEC 2037 (C37) as an update to this plan, defining in much greater detail the specific capital investments needed to achieve the service goals laid out in C35 and providing additional analysis of constraints and funding needs. Among the many projects proposed in CONNECT NEC is the expansion of track capacity Penn Station.



NEC Inventory

In 2022, FRA prepared the NEC Project Inventory, prioritizing 68 projects identified in C35 to compete for federal funding made available by the Bipartisan Infrastructure Law between 2022 and 2026. The Gateway projects — including the proposed expansion of Penn Station — are included in the NEC Inventory, as is the proposed modernization of Penn Station concourses. FRA has awarded funding to some projects on the Inventory and continues to allocate funds through the Federal-State Partnership for Intercity Passenger Rail and other grant programs.

Cross-Regional Rail Service and Through-Running

Cross-regional rail service, another major goal of NEC FUTURE for the region, is a general term for any system providing service that connects communities and business centers to an urban center and to each other in a greater metropolitan region. Its focus is on providing regular, all-day bi-directional service among multiple origins and destinations, serving multiple travel purposes.

Regional metro is a specific service concept for cross-regional rail, characterized by frequent, transit-style service (headways of 15 minutes or less) connecting urban and inner-suburban communities to each other, as well as to a city center. Regional metro systems rely on "through running" trains through major stations in urban centers to connect communities on opposite sides of the urban center to each other. This type of service supplements conventional intercity and commuter service on an inner portion of a regional rail network that is configured to accommodate it, and where markets can support it, but does not replace the conventional intercity and longer-haul commuter services that are essential to their regional economies. Regional metro service has been implemented successfully in various cities around the world.

The NEC FUTURE vision for achieving both increased train capacity and cross-regional service mirrors international best practices. At Penn Station, new tunnels and an expansion of the existing station are envisioned, which is a typical solution where regional metro service has been introduced.

In cities where regional metro service has been added to existing commuter and intercity service, such as London, Paris, Madrid, Sydney, Berlin, Munich, and Zurich, and where it is being planned and implemented now, the portion of the regional rail network converted to regional metro service is limited to a smaller number and shorter length of branch lines than we have in the New York metropolitan region. In all cases, new tunnels have been built and major stations have been expanded so that the new regional metro service can run on tracks and platforms that are separate from intercity and commuter service, which run on different headways and which have different operating characteristics and require longer station dwell times at major city center stations. If the services were mixed on the same tracks in major stations, the regional metro service would not be able to achieve the transit-style close spacing of trains that makes it successful.

Cross-regional rail in the New York metropolitan area requires investment across the rail network where the service would be provided. It requires an integrated long-range plan for the entire regional rail network, which does not exist at the present time. There is no single entity with responsibility for rail transportation planning, investment, and operations at the scale of the multi-state region.

While not identified for immediate funding and implementation in Connect 2035 or the NEC Inventory, the

NEC FUTURE vision for cross-regional rail service through New York Penn Station includes through-running regional metro, in addition to maintaining longer-distance suburban commuter service and increasing intercity rail service. Supporting these three service types requires doubling trans-Hudson rail capacity at the station. The intent of the Penn Station Capacity Expansion Project is to achieve that doubling of trans-Hudson rail capacity while simultaneously laying the groundwork for the future implementation of cross-regional service once funding is available and railroads and planning bodies have reached agreement on how best to realize a regional metro network right-sized for our region.

Description of the Alternatives

This study begins with FRA's long-term vision to grow NEC rail service as laid out in NEC FUTURE. Although international practice favors delivery of high-density cross-regional rail service through construction of separate, purpose-built infrastructure through the center of the urban core, local stakeholders have expressed considerable interest in the feasibility of converting Penn Station to all through-running as an alternative to expanding the station footprint and as the basis for cross-regional service. Responding to the interest of stakeholders, and with the goal of applying real-world knowledge to otherwise conceptual ideas, the Partners identified two potential alternatives for doubling trans-Hudson rail capacity at Penn Station by adapting the station within its existing footprint (Figure E-2).

While each alternative has many potential variations, the concepts evaluated here are representative of the most common characteristics, including physical design, operation, and impacts. The WSP/FXC Team identified a total of four variations on these two alternatives, called design concepts, that aim to double trans-Hudson train capacity and support cross-regional rail service (Figure E-3).

Alternative 1 **Under Penn Station**

This alternative would aim to double trans-Hudson rail capacity at the station by adding a new track and platform level below the existing track level of Penn Station within the existing footprint of Penn Station. This alternative requires two additional lead tunnels from the new Hudson River Tunnel near Twelfth Avenue and does not provide any direct train connectivity from these new tunnels to Penn Station.

Two design concepts are considered:

Design Concept 1: **Underpinning — Single Level**

This design concept would add ten single-level station tracks within the existing Penn Station footprint, directly below the existing lower level of the station.

Design Concept 2: **Mined — Single Level**

This design concept would add ten single-level station tracks in multiple mined caverns configured side-by-side within the existing Penn Station footprint, directly below the existing lower level of the station.

Alternative 2 **Through-Running**

In this alternative, Penn Station would be converted to all through-running service within the existing footprint of the station, aiming to obtain the needed doubling of trans-Hudson rail capacity without expanding the station footprint.

Two design concepts are considered:

Design Concept 1: **Full Station Reconstruction with Side-by-Side Operations**

This design concept would completely reconstruct the tracks and platforms of existing Penn Station to optimize it for 100% through-running operations. Total reconstruction would maximize throughput capacity but would be extremely costly and disruptive.

Design Concept 2: **Limited Track and Platform Reconfiguration**

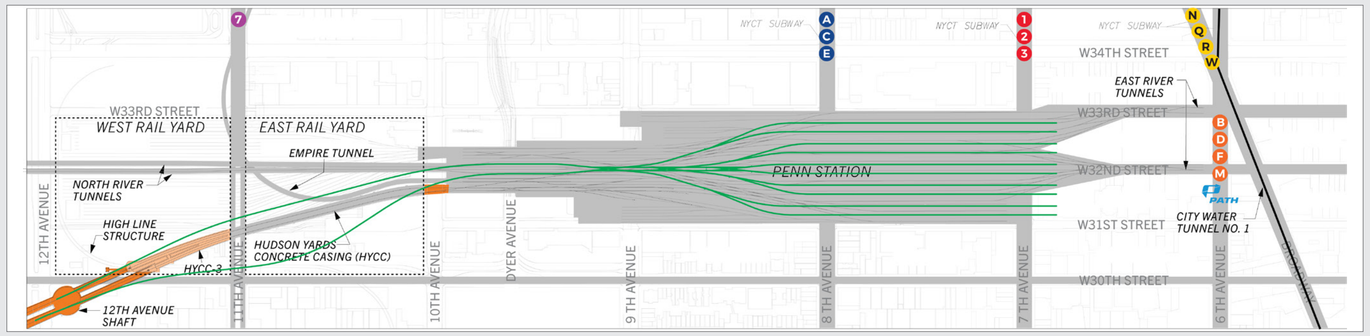
This design concept would deck-over every other track in the existing Penn Station configuration so that the existing platforms could be widened to support simultaneous boarding and alighting, which would shorten dwell times and increase train throughput on the 12 remaining tracks. The objective of this concept is to enable 100% through-running service between points east and west of New York City through Penn Station while minimizing the amount of capital investment required at Penn Station itself. It is based on proposals put forward by ReThinkNYC, an organization advocating for conversion of the existing Penn Station to a fully through-running operation..

Figure E-2

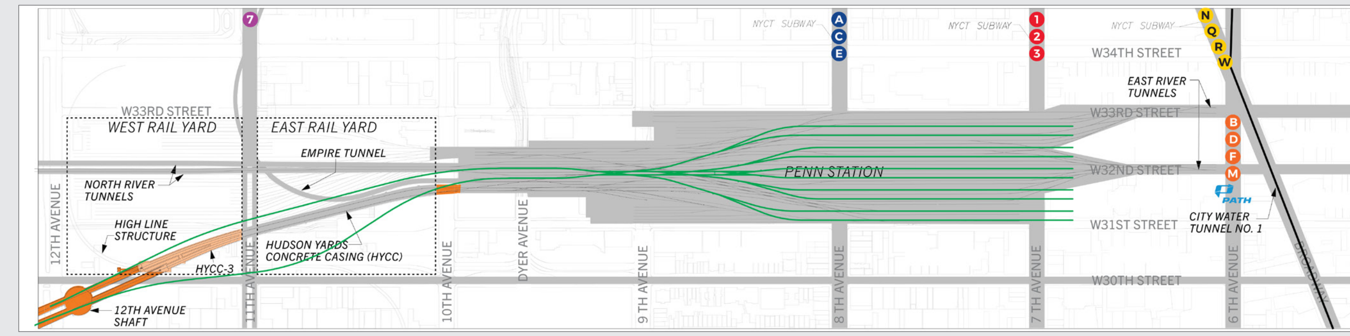
Two alternatives for maximizing rail capacity at Penn Station within the existing station footprint

Figure E-3

Design Concepts Evaluated



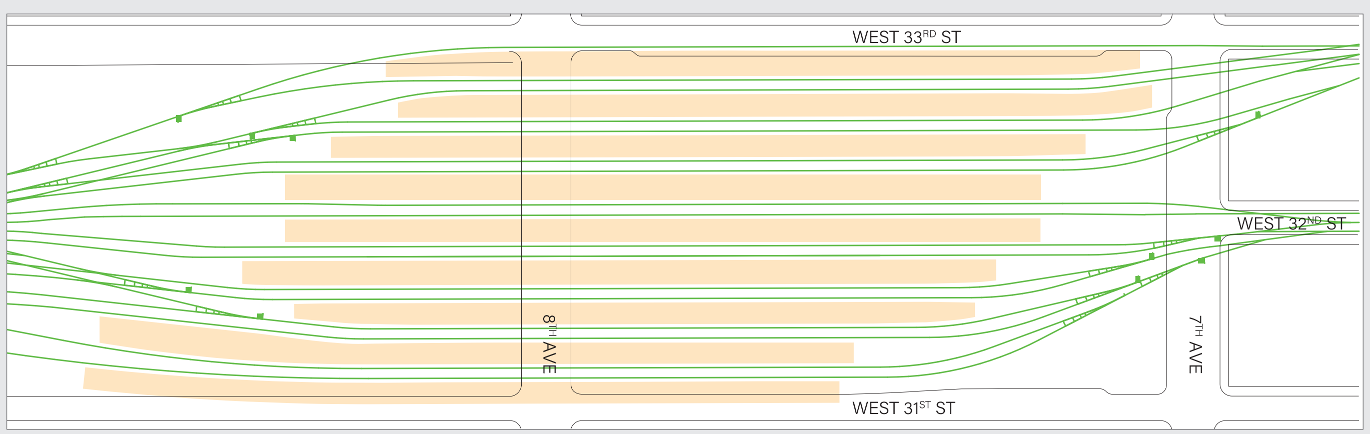
Alternative 1 (Under Penn) Design Concept 1: Underpinning — Single Level



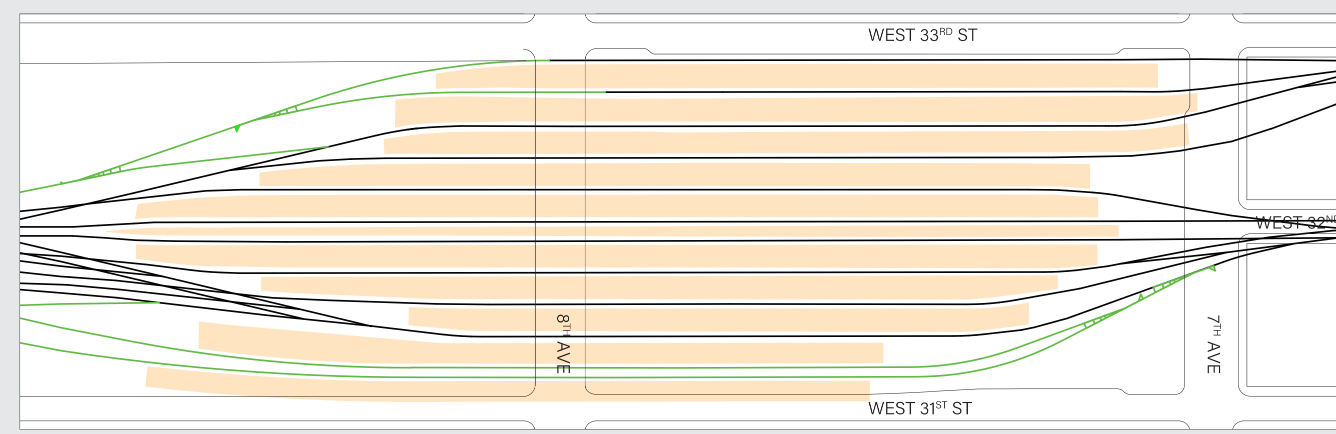
Alternative 1 (Under Penn) Design Concept 2: Mined — Single Level

Legend

- Existing below-grade infrastructure
- Hudson Tunnel Project below-grade infrastructure (30% Design)
- HTP HYCC-3 infrastructure (100% Design)



Alternative 2 (Through-Running) Design Concept 1: Full Reconstruction — Side-by-Side Operations



Alternative 2 (Through-Running) Design Concept 2: Limited Track and Platform Reconfiguration

Legend

- Reconfigured Track Alignment
- Existing Track Alignment
- Reconfigured Station Platforms

Determining Technical Feasibility

The four design concepts were evaluated with respect to their technical feasibility. For the purposes of this report, technical feasibility is a design concept's ability to meet basic engineering requirements, be constructable, and provide the minimum operational performance required for the Gateway Program and consistent with the NEC FUTURE Selected Alternative. Key considerations are:

1. Can the **track geometry** function operationally, and can it provide connections to the existing Penn Station, the existing North River Tunnel, the future Hudson River Tunnel, and the East River Tunnel?

2. Is the concept **reasonable to construct** from a structural and geotechnical perspective, without untenable impacts to existing train service, passenger flows, network operations, structures, utilities, and systems?

3. Can the concept **comply with governing regulations** for emergency egress and ventilation?

4. Can the concept provide total **operational capacity** sufficient to enable peak trans-Hudson rail service to increase to at least 48 tph in the peak direction (doubling the existing trans-Hudson capacity by enabling at least 24 tph in each direction through the new Hudson River Tunnel) while also maintaining existing levels of bi-directional suburban commuter services?

5. Is the concept compatible with the **future cross-regional rail** vision that includes creating a regional metro network, maintaining longer-distance suburban commuter service, and expanding intercity service?

Each alternative was studied for compatibility with the alignment and profile of the new Hudson River Tunnel and the geometry of the western and eastern interlockings (the collection of switches that allow trains arriving from the tunnel tracks to be connected to multiple platform tracks in the station). Conflicts with existing water tunnels, subways, bridges carrying city streets and avenues, and the foundations of existing buildings were considered. Whether ventilation and other fire and life safety needs could be met was considered as well.

The operational capacity of each alternative was estimated to assess if the station could accommodate the full capacity of the two tracks in the new Hudson River Tunnel (at least 24 tph in each direction), while also maintaining existing levels of bi-directional suburban commuter services. If Penn Station is unable to accommodate the 48 tph that the existing and new tunnels can deliver in each direction, then the benefit of that added tunnel capacity cannot be fully realized. Table E-1 presents the incremental trans-Hudson tunnel throughput that can be achieved by each alternative concept and indicates the infrastructure elements that constrain capacity. How well the alternatives would function to support the envisioned future regional rail network also was assessed.

Additionally, the analysis of Alternative 2 considered how trains would operate in the station and interlockings on either side of the station, and how well this alternative would function to support the representative future regional metro network and operating regime assumed for the purposes of analysis. The WSP/FXC Team assessed the necessary modifications to Penn Station tracks and platforms, including Moynihan Train Hall; the Hudson and East River tunnels; the interlockings on both sides of the station; the Harold Interlocking in Queens; the railroad configuration in New Jersey between the portals of the Hudson River tunnels and the Hackensack River; and other associated infrastructure.

The results of this analysis are summarized in **Table E-2**. For a detailed explanation of why alternatives were given the score they were for each criterion, please visit Chapter 5 of this report.

Table E-1

Incremental Trans-Hudson Rail Capacity, compared with Existing North River Tunnel

		Incremental Trans-Hudson Capacity* (tph)	Maintains Existing Level of Bi-Directional Commuter Service?	Capacity-Constraining Elements
Alternative 1: **Under Penn Station**	Design Concept 1: **Underpinning — Single Level**	+14	Yes	Interlocking and vertical circulation to lower platforms
	Design Concept 2: **Mined — Single Level**	+20	Yes	Interlocking
Alternative 2: **Through-Running**	Design Concept 1: **Full Reconstruction**	+24	No	Tunnels and Station
	Design Concept 2: **Limited Track and Platform Reconfiguration**	+16	No	Station

* Compared with capacity of existing North River Tunnel of 24 tph in the peak direction of travel (eastbound in AM peak and westbound in PM peak).

Table E-2

Assessment Summary

		Step 1 (Pass / Fail)					Step 2*	
		Track Geometry	Constructability	Fire-Life Safety	Operational Performance	Future Regional Rail Vision	Construction Cost	Construction Schedule
Alternative 1: **Under Penn Station**	Design Concept 1: **Underpinning — Single Level**	Pass	Fail	Fail	Fail	Pass	-	-
	Design Concept 2: **Mined — Single Level**	Pass	Fail	Fail	Fail	Pass	-	-
Alternative 2: **Through-Running**	Design Concept 1: **Full Reconstruction**	Pass	Fail	Pass	Fail	Fail	-	-
	Design Concept 2: **Limited Track and Platform Reconfiguration**	Pass	Pass	Pass	Fail	Fail	-	-

* None of the design concepts evaluated in this report passed the Step 1 technical feasibility screening.

Technical Feasibility of the Alternatives

Alternative 1: Expand beneath existing Penn Station
Alternative 1 was developed to examine the feasibility of an alternative that confines all underground station infrastructure within the existing footprint of Penn Station. This alternative has ten new station platform tracks on a single horizontal level below the existing track and platform level within the existing footprint of the station. The difference between the two design concepts developed for the alternative (Underpinning — Single Level and Mined — Single Level) is the method of constructing new station expansion infrastructure below the existing station footprint.

The Underpinning — Single Level design concept would require underpinning over 1,000 existing columns between Eighth and Seventh Avenues, which is not technically feasible. The Mined — Single Level design concept avoids this pitfall, but still has a critical remaining fatal flaw. The required operational capacity cannot be achieved due to train movement conflicts at the new single-level interlocking west of the station, which would feed the new lower-level platform tracks.

The Underpinning – Single Level design concept requires the removal of tracks within existing Penn Station to make vertical circulation possible between the station expansion and the main concourse. While a detailed design for the number of tracks that would have to be eliminated is not available at this time, the feasibility analysis showed that at least two, if not more, tracks would have to be removed from existing Penn Station, and therefore the capacity of the existing station would be reduced by three tph per track, or six tph. Therefore, the overall net increase in total station capacity would be substantially lower with this design concept, after taking into account the loss of tracks (and commensurate reduction in trains per hour) from the existing station.

The feasibility of a bi-level mined cavern concept was also investigated to address the capacity limitation of the single-level concept. A bi-level configuration could achieve 24 tph capacity, but the engineering alignment that would achieve reasonable grades would extend the underground station infrastructure eastward beyond Seventh Avenue, well outside the existing station footprint.

Alternative 1 is deemed not technically feasible and is not recommended for further study. Section 5.1 of this report provides a thorough discussion of this alternative and the reasons why it was determined to be not technically feasible.

Alternative 2: Convert the station to all through-running service without expanding its footprint
This alternative remains entirely within the existing footprint of Penn Station. All trains, except those arriving via the Empire Line, would run through the station.[1] Development of this alternative included a review of international practices to determine how to configure the alternative in Penn Station.

Through-running requires platforms 30 feet wide to alight and board passengers quickly and safely. All but one of the 11 existing platforms are between 17 and 23 feet wide. To address this shortcoming, both design concepts propose widening the platforms, at the cost of reducing the number of tracks, currently 21.

In order for through-running to work, both design concepts would require creation of a four-track trunk line with at least three stations — Penn Station in the middle, plus one new station in New Jersey in the vicinity of Secaucus and one new station east of Manhattan in Queens or the East Bronx. New train storage yards and train turnback facilities would need to be constructed at or near the New Jersey and Queens/Bronx trunk line stations. Amtrak NEC trains would run through the trunk line to NEC destinations as they do now. Regional metro trains would run through the trunk line in revenue service on select branch lines on both sides of Penn Station. All other suburban trains would either go into the new storage yards or turn back at the outer trunk line stations.

Design Concept 1, Full Reconstruction, completely reconfigures the track and platform level of the station, providing 17 tracks and nine 30-foot-wide platforms, all in new locations. It divides the station operationally into two side-by-side zones of seven tracks, each operating as its own through-running station, with the two zones separated by three central tracks reserved for Empire Corridor and Hudson Line turnback service and providing additional capacity to accommodate delayed long-distance trains.

This zonal configuration matches the zonal operation of Harold Interlocking in Queens, the busiest and most complex interlocking in the country. It is not feasible to reconfigure Harold to accommodate a "right-hand running" configuration in Penn Station, with the northerly tracks in the station used by westbound through-running trains and the southerly tracks in the station used by east-bound through-running trains. The Side-by-Side Operations design concept avoids this conflict at Harold Interlocking.

Nonetheless, three fatal flaws were identified in the Full Reconstruction with Side-by-Side Operations design concept:

1. It would require the complete reconstruction of the track and platform level at both Penn Station and Moynihan Train Hall and of much of the passenger levels above to accommodate enough tracks and platforms to meet the operational performance requirement. Approximately 1,045 structural columns supporting Penn Station, Madison Square Garden, the PENN 2 office building, Moynihan Train Hall, Farley Post Office Building, Eighth Avenue, and the Eighth Avenue subway lines would have to be relocated or removed and their loads transferred

1 There is only enough capacity on the four East River Tunnel tracks to accommodate through-running of trains from the four tracks in the existing and new Hudson River Tunnels. Accommodating through-running of the trains from the single-track Empire Tunnel would necessitate building an additional tunnel across Manhattan and under the East River. It would not be cost effective to build a tunnel solely for Empire Corridor and Hudson Line service, so those trains are assumed to turn back at the station in Alternative 2. Development of this alternative included a review of international practices to determine how best to configure the rail service and track and platform infrastructure in Penn Station.

to other adjacent columns, with those columns strengthened, their foundations underpinned, and transfer beams and bracing added at the passenger levels. This would be an unprecedented task. The number and extent of required modifications would exceed the practical ability to design a rational structural system.

2. Even if it were technically feasible, the construction staging within Penn Station and Moynihan Train Hall and at the track and platform level would reduce train service at Penn Station by approximately 30% for approximately 12 years, an unacceptable disruption of service in the heart of the NEC that would ripple through the regional economy. The long construction schedule is driven by the complexity of the work required, the need to keep the station operating, and federal regulations governing Railroad Worker Protection (RWP) for construction activity on or adjacent to an active operating railroad.

3. This concept cannot meet the operating requirement to provide an additional 24 tph in revenue service in each direction, or 48 tph total, due to a self-defeating flaw in the trunk line operating logic. Currently, about 12 commuter trains from New Jersey turn back at Penn Station to provide reverse-peak-direction revenue service in the morning peak hour. These turning trains currently use two North River Tunnel slots — one inbound in the peak direction and one outbound in the reverse peak direction. A similar number of Long Island trains enter Penn Station from the east and turn back at the station, using two East River Tunnel slots.

If the New Jersey commuter trains were to turn back at the outer trunk stations instead of at Penn Station, they would need to run through Penn Station twice, now using four tunnel slots in the same peak hour eastbound through the North River and East River tunnels, and then returning westbound through the East River and North River tunnels. The return trip to New Jersey, as it passes through the East River Tunnel back towards Penn Station, would claim a westbound slot in the East River tunnel that otherwise could be used by more heavily patronized trains from Long Island in the peak direction of LIRR travel. Similarly, LIRR morning peak trains turning back at a trunk line station in northern New Jersey would claim an eastbound slot crossing the Hudson River that then would not be available for NJ TRANSIT peak direction trains from the New Jersey suburban branch lines.

Since tunnel slots are the ultimate constraint on the capacity of the Penn Station complex, a 100% through-running service at Penn Station with far-side turnbacks is inherently inefficient and would prevent full utilization of the tunnel tracks by peak-direction trains. All 48 peak-direction tunnel slots on both sides of the station are needed to accommodate the increase in service due to the Gateway Program and Penn Station Access Project, which is extending the Metro-North Railroad (MNR) New Haven Line to reach Penn Station. Each turning train would displace the same number of revenue-service trains. Eliminating reverse-peak-direction service is not a viable option, nor is full integration of the suburban rail networks to enable peak trains from one side of the region to provide suburban reverse-peak service to the outer portions of the network on the other side of the region. Therefore, this flaw makes it impossible to meet the new operating capacity requirement.

Some of these turning trains could eventually be incorporated into the regional metro system, reducing the demand for tunnel slots. But the introduction of new NJ TRANSIT and MNR branches via the Gateway and Penn Station Access programs will require some new suburban trains to turn back to provide reverse-peak-direction service for those new branches. This would counteract the through-running benefits of regional metro service. Further, LIRR trains that run through to storage go into the LIRR West Side Yard in Manhattan without using a tunnel slot in either the existing North River Tunnel or new Hudson River Tunnel. Access to the West Side Yard would be eliminated in a 100% through-running alternative, so those trains would now have to use another Hudson River Tunnel slot to reach a new yard in New Jersey, displacing an Amtrak through-running NEC train or a future regional metro through-running train.

Finally, although running trains through Penn Station reduces the dwell time for each train, the turning suburban trains would now be at a Penn Station platform twice — once inbound and once outbound — canceling out the through-running dwell time benefit for those trains.

There is no interim or final configuration that can deliver the required operating capacity.

Given these fatal flaws, this design concept is not technically feasible and is not recommended for further study.

Design Concept 2, Limited Track and Platform Reconfiguration, helps to address the technical infeasibility of relocating over 1,000 columns. It borrows the physical layout of the station from a plan proposed by ReThinkNYC. The design concept widens seven existing platforms to approximately 30 feet, both extends and widens two existing platforms, and retains two existing platforms in their current configuration.[2] Of the 21 existing station tracks, 12 would be retained in their existing locations. This reduces, but does not totally eliminate, the need for structural modifications and track re-alignment under both Penn Station and Moynihan Train Hall.

Although Design Concept 2 would greatly reduce the number of columns to be removed or reframed, the construction would still entail extensive and complex construction work. It would require a multi-year construction schedule, with substantial impacts to rail traffic and station operations.

In this design concept, the station is divided operationally into two side-by-side stations, each operating as a through-running station, as in Design Concept 1. The north side

2 Existing Platform 10 is already more than 30 feet wide, and the existing Platform 6 in the center of the station would not be widened for geometric reasons.

through-running station zone has four tracks (for regional metro service), and the south side station zone has eight tracks (for all other intercity and suburban rail services).

This design concept has the same fatal flaw in its operating logic as Design Concept 1, with respect to the provision of suburban reverse-peak service. Beyond that flaw, 12 station tracks are not enough to meet the operational performance needs of through-running regional metro service and the remaining suburban services, Amtrak's planned growth in NEC intercity service, and rail service from the Empire Corridor or Metro-North Hudson Line. The throughput capacity of the 12 station tracks is insufficient to handle the three types of train service (intercity, regional metro, and suburban) at 48 tph in the peak direction of flow through the Hudson and East River tunnels, in addition to trains using the Empire Tunnel. It is therefore not technically feasible and is not recommended for further study.

There is no combination of through-running tracks and platforms within the footprint of the existing station that can meet the operational performance needs and still be constructed without massive and unacceptable disruption to service, and there is no lesser modification plan that can be constructed within acceptable limits of disruption of service and still meet the operational performance needs. With fatal flaws in both design concepts, Alternative 2 is deemed not technically feasible and is not recommended for further consideration. Section 5.2 of this report provides a thorough discussion of this alternative and the reasons why it was determined to be not technically feasible.

Conclusion

International best practice for achieving high-density cross-regional rail service includes building purpose-built tunnels and station expansions. Through this study, focused on the specific characteristics of New York Penn Station and its associated infrastructure, it has been found that achieving the needed doubling of trans-Hudson capacity and accommodating regional metro service entirely within the envelope of existing Penn Station is not feasible, so it will be necessary to evaluate the construction of an expansion of Penn Station beyond its existing footprint and provide additional tracks and platforms to meet the operational performance needs.

A separate, future analysis will evaluate alternatives that expand the footprint of Penn Station.

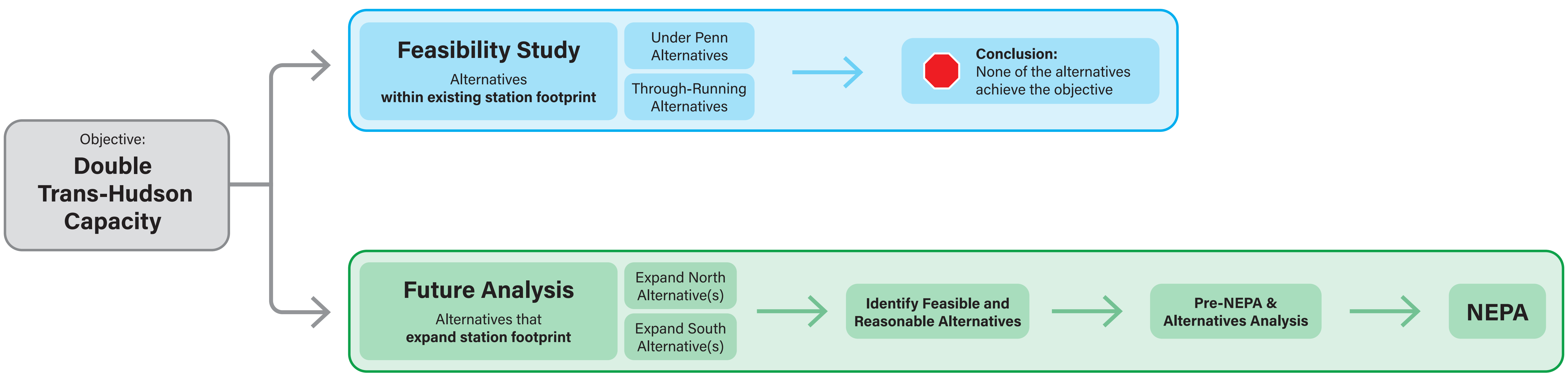
1 Introduction

Amtrak, the Metropolitan Transportation Authority (MTA), and NJ TRANSIT (together, the Partners) are considering alternatives to at a minimum double the trans-Hudson train capacity of New York Penn Station (Penn Station), an effort called the Penn Station Capacity Expansion Project (Penn Capacity Expansion). Some of the options being evaluated by the Partners adapt the station to add capacity within the existing station footprint, while others expand the station boundaries. This report assesses the technical feasibility of two different alternatives for adapting Penn Station to add capacity within the existing station footprint. A separate, future analysis will evaluate alternatives that expand the station boundaries.

The current Penn Station and its operational infrastructure, which includes the tunnels under the Hudson and East Rivers and the interlockings on either side of the station, are functioning above capacity. Greater train capacity at Penn Station is urgently needed to accommodate existing and anticipated passenger demand between New Jersey and New York and to enable Penn Station to provide direct service to a larger network of branch lines than it does today. Long-overdue infrastructure improvements along the Northeast Corridor (NEC), including a new two-track tunnel beneath the Hudson River and rehabilitation of the existing tunnel, will create the capacity to at least double trans-Hudson train service from New Jersey and points west and south. Steady ridership growth along the NEC and population growth within communities in the New York metropolitan region have created demand for utilizing that new capacity. As a result, increasing train capacity and expanding service at Penn Station to accommodate both current and projected future demand will bolster sustainable transportation options and access to economic opportunity in the heart of the New York metropolitan region for decades to come.

The Partners commissioned the WSP/FXC Team to develop and evaluate potential alternatives for at least doubling the train capacity of Penn Station. This report documents alternatives that adapt the existing station footprint; alternatives that expand the station footprint will be documented in a separate, future analysis. Federal grant money from the U.S. Department of Transportation (USDOT) will be sought by the Partners for the project, so it is subject to environmental review under the National Environmental Policy Act (NEPA) which requires that reasonable alternatives be considered for any federal action. NEPA defines "reasonable alternatives" as "a reasonable range of alternatives that are technically and economically feasible, meet the purpose and need for the proposed action, and, where applicable, meet the goals of the applicant." Contributing to the body of knowledge surrounding the Penn Station Capacity Expansion Project, the primary purpose of this study was to determine if the capacity requirements of the Gateway Program (described in the next section) — a minimum of 48 trans-Hudson trains per hour (tph) — could be met within the station footprint. The report documents the process by which feasible alternatives within the footprint of Penn Station were identified and details reasons why any alternative not recommended for further study was deemed infeasible.

A second goal of this feasibility study is to better understand the ability of these alternatives to support potential future cross-regional rail service.



Section 1.1

Planning Context

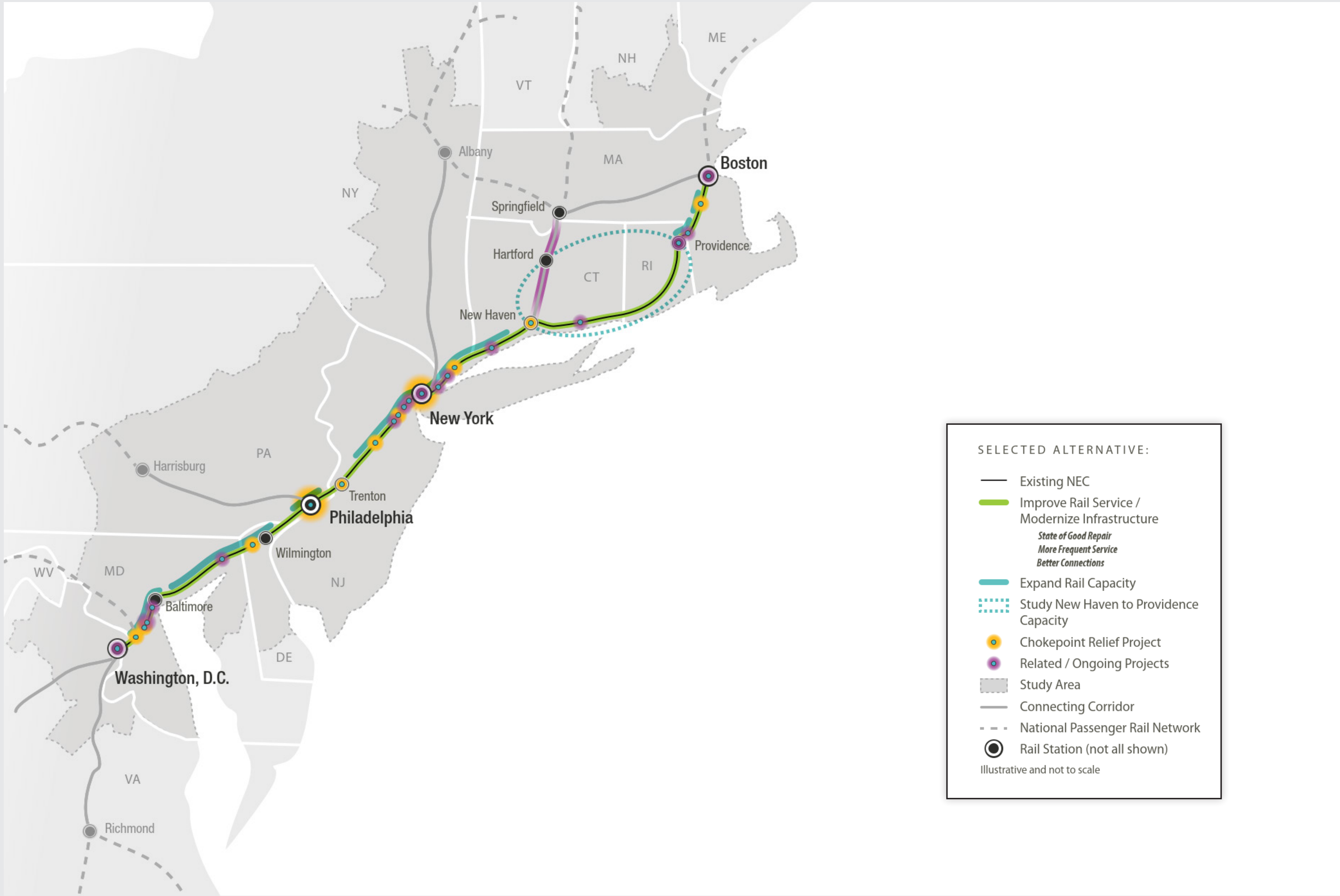
The modernization of Penn Station and at a minimum doubling its trans-Hudson rail capacity at the station are integral components of a larger program of regional rail infrastructure improvements centered on the NEC. A 457-mile-long rail corridor from Boston to Washington D.C., the NEC is the busiest rail corridor in the country, the railroad spine of the East Coast, and an essential platform for metropolitan commuter networks along its length, including those in the New York metropolitan region. Penn Station, located at the midpoint of the NEC, is the busiest station for Amtrak (the owner of the station) and for MTA Long Island Rail Road (LIRR) and NJ TRANSIT (the busiest and third-busiest commuter railroads in the country, respectively), both of which use the station under lease agreements with Amtrak. LIRR operates service on 10 branch lines that feed Penn Station, and NJ TRANSIT runs service on the NEC from Trenton to Penn Station and operates service on four other branches that merge into the NEC before running into New York, carrying over 80% of the ridership on this section of the NEC.

NEC FUTURE

NEC FUTURE is a long-term investment plan for the entire NEC that aims to expand both intercity and regional commuter rail service throughout the corridor; increase reliability, connectivity, performance and resiliency; promote equitable development; and bring NEC infrastructure to a state of good repair (Figure 1-1). Begun in 2012, the Federal Railroad Administration (FRA), an agency within USDOT, developed NEC FUTURE in collaboration with the eight states plus the District of Columbia along the corridor and their transportation agencies and metropolitan planning bodies; Amtrak; and the eight commuter railroads and six freight railroads that use the NEC.

FRA prepared a programmatic environmental impact statement (EIS) for this investment program under NEPA. Called a Tier 1 EIS, it assessed the corridor-wide environmental implications of three levels of expanded rail service across the NEC. The EIS process included extensive public outreach, with 2,500 public comments from 800 organizations and individuals received and responded to. The Record of Decision (ROD), issued in 2017, adopted a Selected Alternative that will grow rail service along the NEC and bring its infrastructure to a state of good repair to achieve modern, efficient passenger rail service for travelers.

Figure 1-1
NEC FUTURE Selected Alternative



The various infrastructure improvements for the New York metropolitan region identified in NEC FUTURE to meet the program goals fall into two groups:

1. At least doubling trans-Hudson rail service by adding two new tracks in a new tunnel below the Hudson River; rehabilitating the existing tunnel and tracks; expanding rail capacity at Penn Station; and numerous supporting infrastructure improvements in New Jersey.
2. Enabling cross-regional service at Penn Station in the longer-term by adding two new tracks in a tunnel below Manhattan and the East River to Queens; rehabilitating the existing tunnels; and supporting infrastructure improvements in Queens and the Bronx.

The Tier 1 EIS is intended to be followed by project-specific environmental studies for the identified infrastructure improvements as planning and engineering for each one progresses. These are called Tier 2 studies. Implementing regulations provide for this tiered approach for programs like NEC FUTURE that are too large for a single environmental study to be practical.

The Gateway Program

The Gateway Program is a subset of the infrastructure improvements identified in NEC FUTURE, specifically those needed to at least double trans-Hudson rail capacity and service. It is a comprehensive rail investment program to improve reliability, resiliency, and redundancy while creating new capacity on the critical ten-mile section of the NEC between Newark Penn Station and Penn Station New York. It includes:

- Building the new two-track Hudson River Tunnel;
- Rehabilitating the existing two-track Hudson River Tunnel (known by its original name, the North River Tunnel);
- Constructing concrete casings below Hudson Yards to preserve the Gateway right-of-way into Penn Station;
- Building, rehabilitating, or expanding trackage, bridges, connections, grade separations, and a rail yard in New Jersey; and
- At least doubling trans-Hudson rail capacity to support additional trains from New Jersey (Figure 1-2).

Some environmental studies for Gateway Program projects have already been completed and approved, including EISs for the Hudson Tunnel Project, which is currently in procurement of major construction packages, and the Portal North Bridge in New Jersey, which is already in construction.

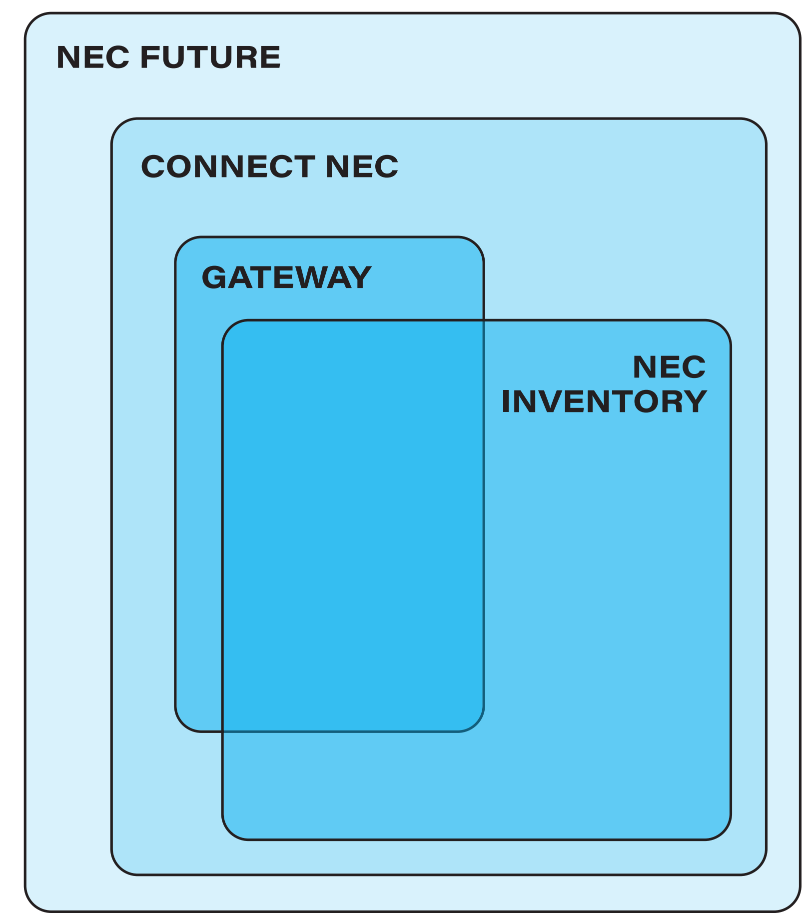
> **To achieve the NEC FUTURE vision for the New York metropolitan region, all of the Gateway projects, including at least doubling the trans-Hudson train capacity of Penn Station and the construction of the new Hudson River Tunnel, must be completed.**

CONNECT NEC

The Northeast Corridor Commission (NECC) was established by Congress in 2008 to develop coordinated strategies to improve the Northeast's core rail network. It comprises representatives from each of the NEC states, Amtrak, and the USDOT. In 2021, the NECC published CONNECT NEC 2035 (C35), a 15-year service development plan and infrastructure planning process for the Northeast Corridor as the first phase of NEC FUTURE, identifying 173 potential rail infrastructure projects for implementation. In 2023, the NECC released CONNECT NEC 2037 (C37) as an update to this plan, defining in much greater detail the specific capital investments needed to achieve the service goals laid out in C35 and providing additional analysis of constraints and funding needs. Among the many projects proposed in CONNECT NEC is the expansion of track capacity Penn Station.

NEC Inventory

IIn 2022, FRA prepared the NEC Project Inventory, prioritizing 68 projects identified in C35 to compete for federal funding made available by the Bipartisan Infrastructure Law between 2022 and 2026. The Gateway projects — including the proposed expansion of Penn Station — are included in the NEC Inventory, as is the proposed modernization of Penn Station concourses. FRA has awarded funding to some projects on the Inventory and continues to allocate funds through the Federal-State Partnership for Intercity Passenger Rail and other grant programs.



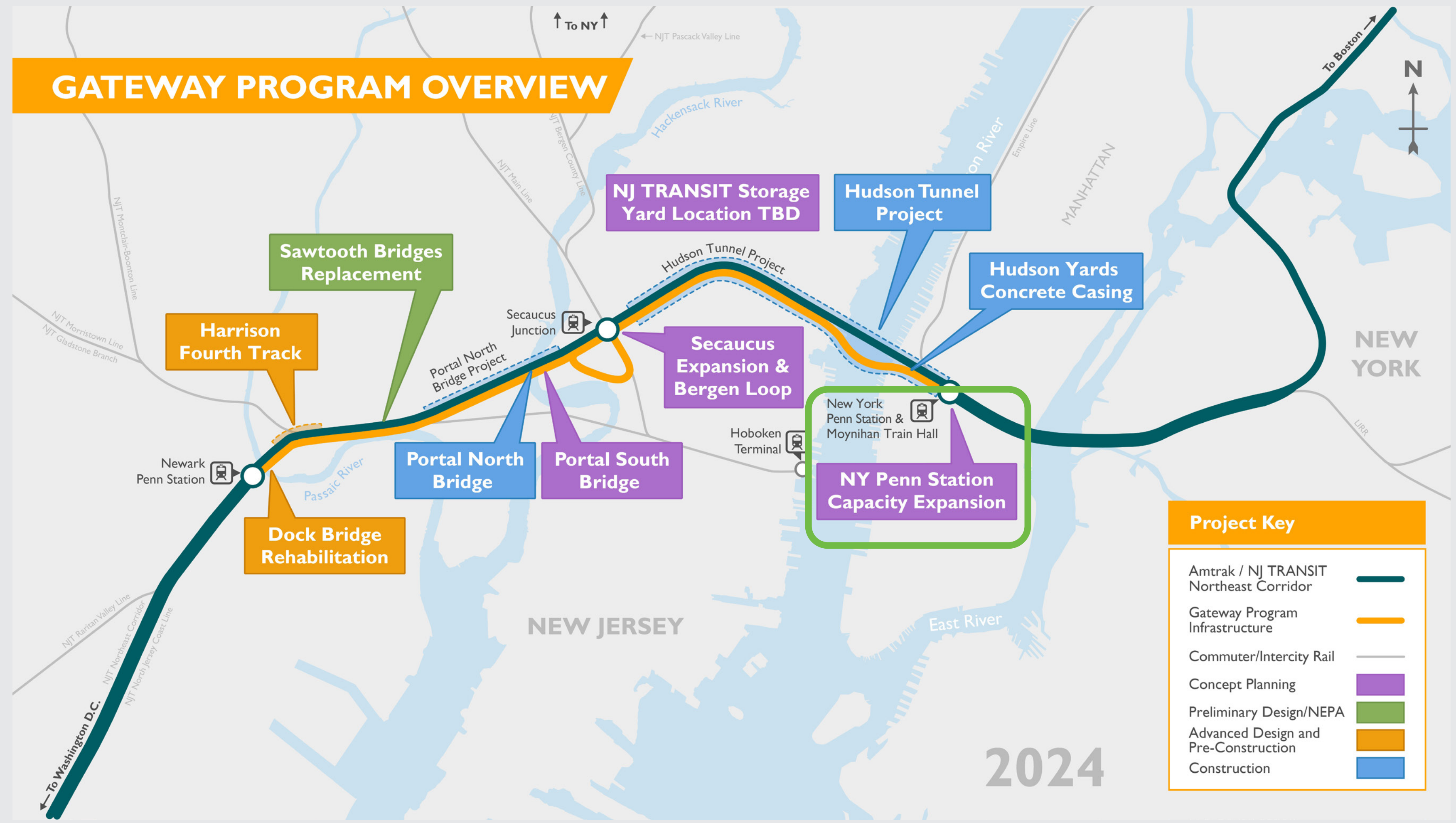
Cross-Regional Rail Service and Through-Running

Cross-regional rail service, another major goal of NEC FUTURE for the region, is a general term for any system providing service that connects communities and business centers to an urban center and to each other in a greater metropolitan region. Its focus is on providing regular, all-day bi-directional service among multiple origins and destinations, serving multiple travel purposes.

Regional metro is a specific service concept for cross-regional rail, characterized by frequent, transit-style service (headways of 15 minutes or less) connecting urban and inner-suburban communities to each other, as well as to a city center. Regional metro systems rely on "through running" trains through major stations in urban centers to connect communities on opposite sides of the urban center to each other. This type of service supplements conventional intercity and commuter service on an inner portion of a regional rail network that is configured to accommodate it, and where markets can support it, but does not replace the conventional intercity and longer-haul commuter services that are essential to their regional economies. Regional metro service has been implemented successfully in various cities around the world.

> **The NEC FUTURE vision for achieving both increased train capacity and cross-regional service mirrors international best practices. At Penn Station, new tunnels and an expansion of the existing station are envisioned, which is a typical solution where regional metro service has been introduced.**

Figure 1-2
Gateway Program Overview



In cities where regional metro service has been added to existing commuter and intercity service, such as London, Paris, Madrid, Sydney, Berlin, Munich, and Zurich, and where it is being planned and implemented now, the portion of the regional rail network converted to regional metro service is limited to a smaller number and shorter length of branch lines than we have in the New York metropolitan region. In all cases, new tunnels have been built and major stations have been expanded so that the new regional metro service can run on tracks and platforms that are separate from intercity and commuter service, which run on different headways and which have different operating characteristics and require longer station dwell times at major city center stations. If the services were mixed on the same tracks in major stations, the regional metro service would not be able to achieve the transit-style close spacing of trains that makes it successful.

Cross-regional rail in the New York metropolitan area requires investment across the rail network where the service would be provided. It requires an integrated long-range plan for the entire regional rail network, which does not exist at the present time. There is no single entity with responsibility for rail transportation planning, investment, and operations at the scale of the multi-state region.

Section 1.2

Description of Alternatives

This study begins with FRA's long-term vision to grow NEC rail service as laid out in NEC FUTURE. Although international practice favors delivery of high-density cross-regional rail service through construction of separate, purpose-built infrastructure through the center of the urban core, local stakeholders have expressed considerable interest in the feasibility of converting Penn Station to all through-running as an alternative to expanding the station footprint and as the basis for cross-regional service. Responding to the interest of stakeholders, and with the goal of applying real-world knowledge to otherwise conceptual ideas, the Partners identified two potential alternatives for doubling trans-Hudson rail capacity at Penn Station by adapting the station within its existing footprint (**Figure 1-3**).

While each alternative has many potential variations, the concepts evaluated here are representative of the most common characteristics, including physical design, operation, and impacts. The WSP/FXC Team identified a total of four variations on these two alternatives, called design concepts, that aim to double trans-Hudson train capacity and support cross-regional rail service. This report describes and evaluates the following alternatives and design concepts (**Figure 1-4**).

Alternative 1
Under Penn Station

This alternative would aim to double trans-Hudson rail capacity at the station by adding a new track and platform level below the existing track level of Penn Station within the existing footprint of Penn Station. This alternative requires two additional lead tunnels from the new Hudson River Tunnel near Twelfth Avenue and does not provide any direct train connectivity from these new tunnels to Penn Station.

Two design concepts are considered:

Design Concept 1:
Underpinning — Single Level

This design concept would add ten single-level station tracks within the existing Penn Station footprint, directly below the existing lower level of the station.

Design Concept 2:
Mined — Single Level

This design concept would add ten single-level station tracks in multiple mined caverns configured side-by-side within the existing Penn Station footprint, directly below the existing lower level of the station.

Alternative 2
Through-Running

In this alternative, Penn Station would be converted to all through-running service within the existing footprint of the station, aiming to obtain the needed doubling of trans-Hudson rail capacity without expanding the station footprint.

Two design concepts are considered:

Design Concept 1:
Full Station Reconstruction with Side-by-Side Operations

This design concept would completely reconstruct the tracks and platforms of existing Penn Station to optimize it for 100% through-running operations. Total reconstruction would maximize throughput capacity but would be extremely costly and disruptive.

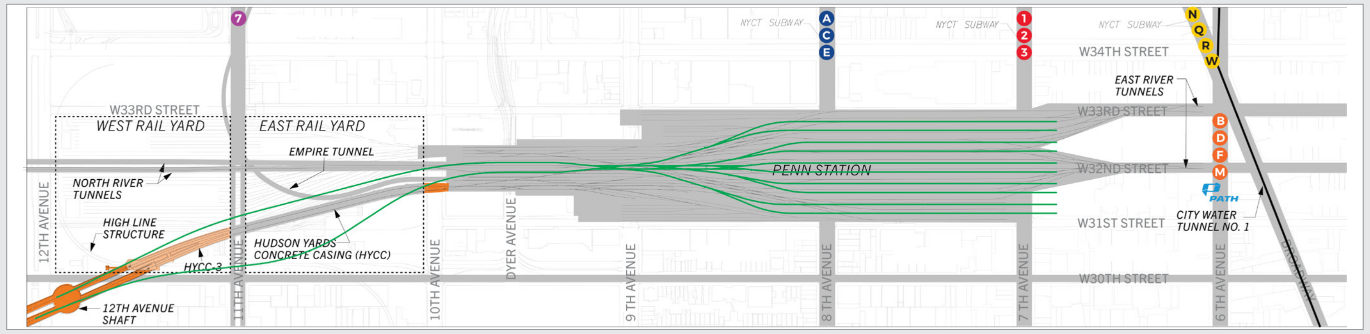
Design Concept 2:
Limited Track and Platform Reconfiguration

This design concept would deck-over every other track in the existing Penn Station configuration so that the existing platforms could be widened to support simultaneous boarding and alighting, which would shorten dwell times and increase train throughput on the 12 remaining tracks. The objective of this concept is to enable 100% through-running service between points east and west of New York City through Penn Station while minimizing the amount of capital investment required at Penn Station itself. It is based on proposals put forward by ReThinkNYC, an organization advocating for conversion of the existing Penn Station to a fully through-running operation.

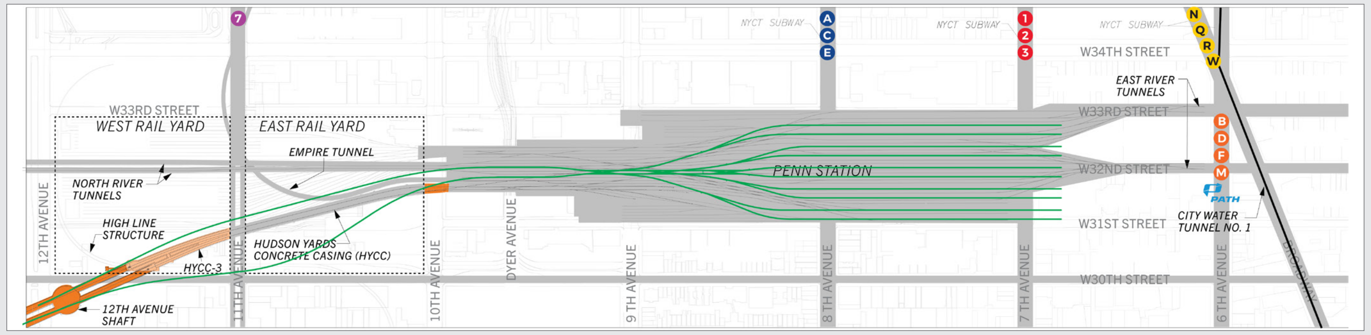
Figure 1-3
Two alternatives for maximizing rail capacity at Penn Station within the existing station footprint

Figure 1-4

Design Concepts Evaluated



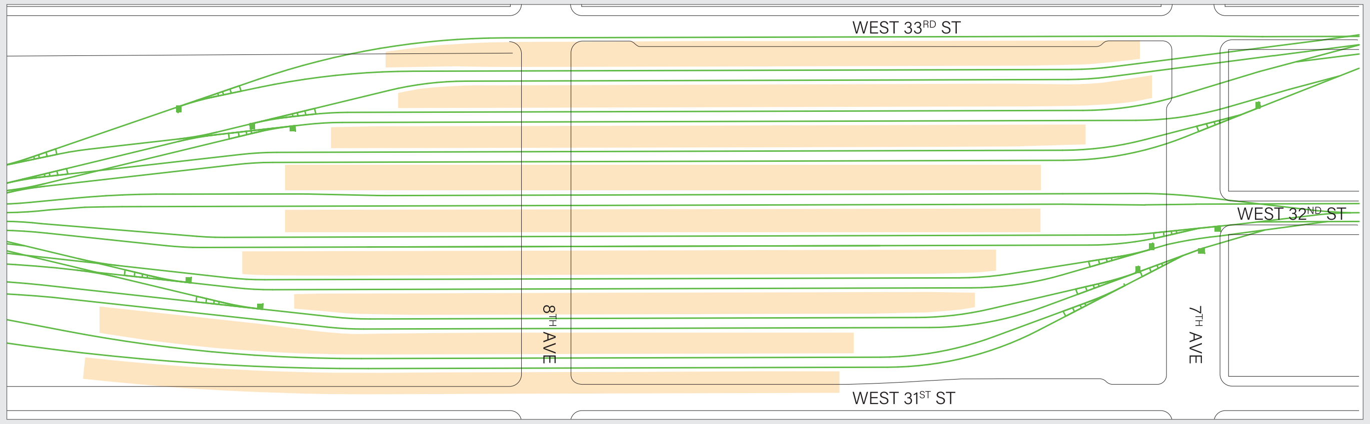
Alternative 1 (Under Penn) Design Concept 1: Underpinning — Single Level



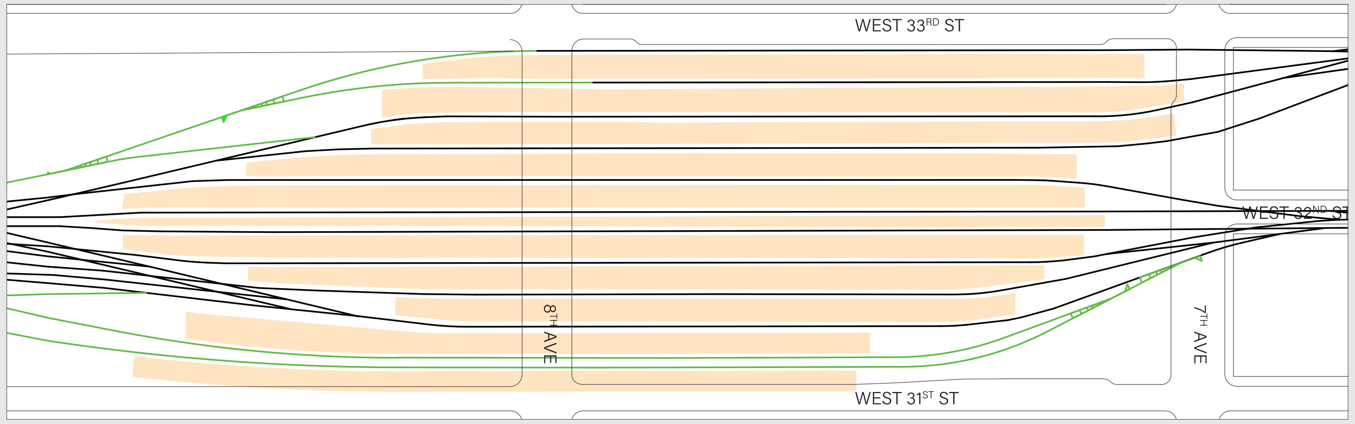
Alternative 1 (Under Penn) Design Concept 2: Mined — Single Level

Legend

- Existing below-grade infrastructure
- Hudson Tunnel Project below-grade infrastructure (30% Design)
- HTP HYCC-3 infrastructure (100% Design)



Alternative 2 (Through-Running) Design Concept 1: Full Reconstruction — Side-by-Side Operations



Alternative 2 (Through-Running) Design Concept 2: Limited Track and Platform Reconfiguration

Legend

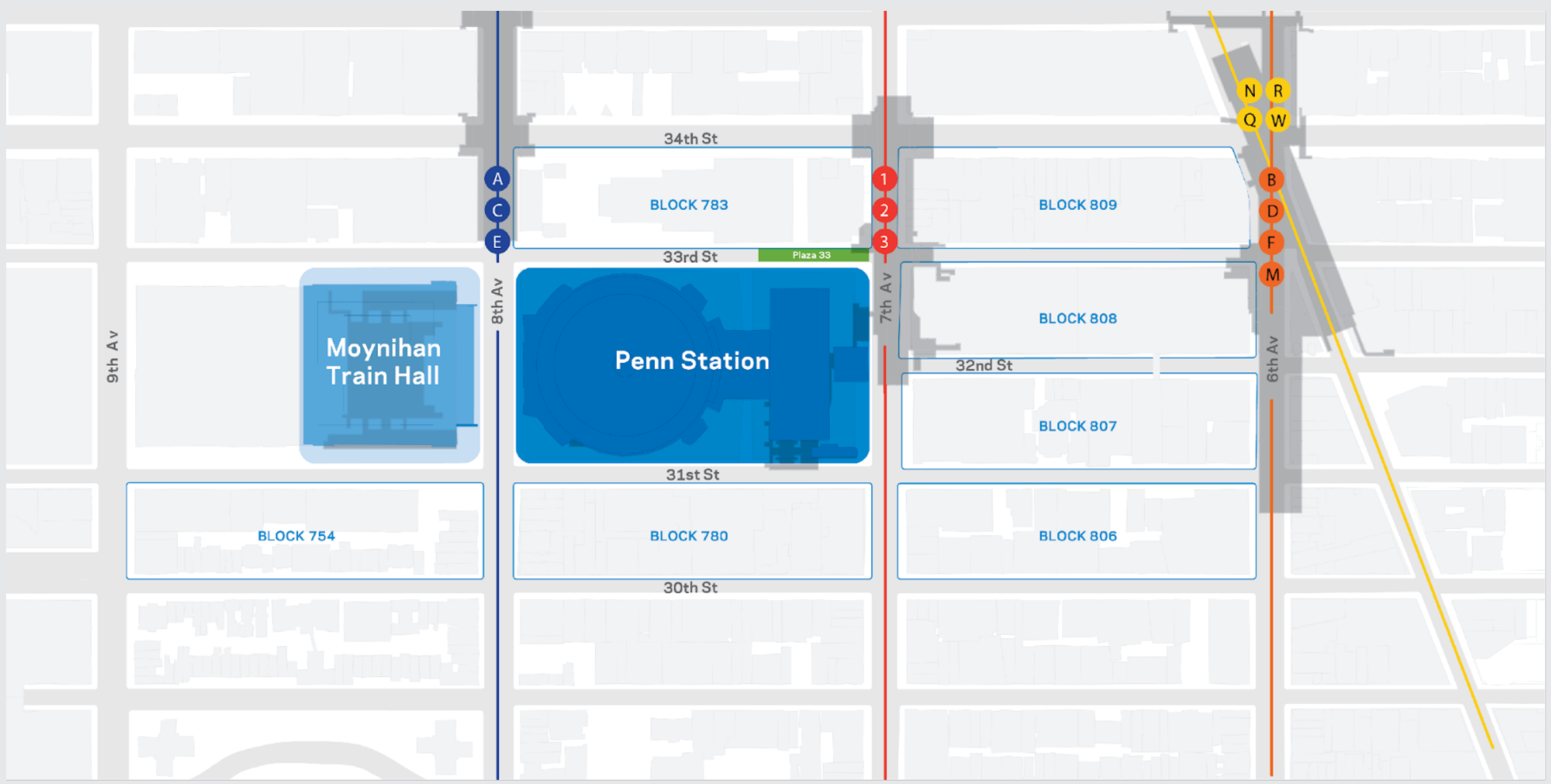
- Reconfigured Track Alignment
- Existing Track Alignment
- Reconfigured Station Platforms

Section 1.3

Existing Conditions

Amtrak owns Penn Station. Amtrak, the LIRR, and NJ TRANSIT operate within the station, and plans to introduce Metro-North Railroad operations are underway. Passenger connections are available within Penn Station to NYCT subway lines.

Figure 1-5
Penn Station Area



In 1910, the prosperous Pennsylvania Railroad built Penn Station as a grand, spacious, daylit train hall to accommodate rail, the then-dominant mode of intercity travel. In the 1960s, with the subsequent rise of auto, air, and commuter rail travel and corresponding decline in intercity train travel, the cash-strapped Pennsylvania Railroad was forced to reconfigure the station as two basement levels to allow it to lease space above for Madison Square Garden and Two Penn Plaza as it tried unsuccessfully to stave off insolvency. The reconfigured station was designed to handle 200,000 daily passenger trips on a typical day. Figure 1-5 shows the station area, connecting subway service, and surrounding city blocks.

Today, Penn Station is the most heavily used and most crowded rail passenger station in the United States, handling 455,000 weekday rail passenger trips in 2019, pre-COVID. The station complex, including Moynihan Train Hall (Amtrak's main passenger facility at the station) and the Seventh and Eighth Avenue subway stations, serves an estimated 600,000 daily pedestrian trips, including subway users, office building workers, Madison Square Garden patrons, and other pedestrians who are not railroad riders. The station serves as both New York's intercity rail terminal for Amtrak and the sole Manhattan rail terminal where Amtrak, NJ TRANSIT, and LIRR all connect. The bulk of the riders on the latter two carriers are commuters from the suburbs to workplaces in the Manhattan central business district (although ridership to and from area airports has steadily increased). Because of this, usage of the station is heavily peaked in the early morning and early evening hours.

The station operates 24 hours a day, 365 days per year, and the "train shed" covers four full city blocks. The station platforms are accessed directly either from the lower level (one story above, also called Level A) or the upper level (two stories above, also called Level B). Subway connections to the station are at the avenues, on the lower level, while street-level access varies depending on area of the station.

Physical Constraints

Penn Station sits amid a complex network of rail and municipal infrastructure, which constrains reasonable alternatives for doubling the station's trans-Hudson rail capacity within its existing footprint. The station is connected to three sets of rail tunnels — the North River Tunnel and Empire Tunnel to the west and East River Tunnel to the east — that carry Amtrak, NJ TRANSIT, and LIRR trains to and from the station. Amtrak has also constructed the first two segments of the Hudson Yards Concrete Casing beneath the Hudson Yards Development and LIRR's West Side Storage Yard to preserve the right-of-way for the future Hudson Tunnel Project (HTP) alignment between Tenth Avenue and Eleventh Avenue to provide connectivity between the new Hudson River Tunnel and Penn Station. An additional segment of concrete casing between Eleventh Avenue and West 30th Street was approved by the FRA in a November 2014 Finding of No Significant Impact (FONSI) for Supplemental Environmental Assessment and in a November 2021 ROD for the Western Rail Yard Infrastructure Project, as well as by the Federal Transit Administration (FTA) in a November 2019 Categorical Exclusion (CE). Construction of the additional concrete casing segment, called Hudson Yards Concrete Casing Section 3 (HYCC-3), began in 2023. Any alternative for expanding trans-Hudson rail capacity at Penn Station must maintain this existing and planned infrastructure.

Other existing underground infrastructure surrounding the station includes several Amtrak and MTA facilities, including the East River Tunnel, the NYCT No. 7 Line subway tunnels that pass beneath the North River Tunnel and Empire Tunnel at Eleventh Avenue, and the Eighth Avenue IND and Seventh Avenue IRT subway lines that pass above Penn Station's track level. The NYCT Herald Square Station Complex is located east of Penn Station, above and adjacent to the East River Tunnel, at Broadway and Sixth Avenue (Figure 1-6). All alternatives for maximizing the rail capacity of Penn Station identified in this report must maintain the functionality of these structures.

Several major utilities are located in the vicinity of Penn Station and Moynihan Train Hall. A New York City Department of Environmental Protection (NYCDEP) combined sewer tunnel runs under the West 30th Street right-of-way, and NYCDEP's City Water Tunnel No. 1, which supplies water to Lower Manhattan, is located below Sixth Avenue as it crosses West 34th Street, then continues south beneath Broadway. Within the Penn Station footprint itself, a series of below-track utility tunnels carry various utilities and other systems between Penn Station and off-site, ancillary facilities like the Penn Station Service Building, Penn Station Control Center, and fan plants on First Avenue and in Weehawken, New Jersey.

Section 4.1 describes each structure in greater detail.

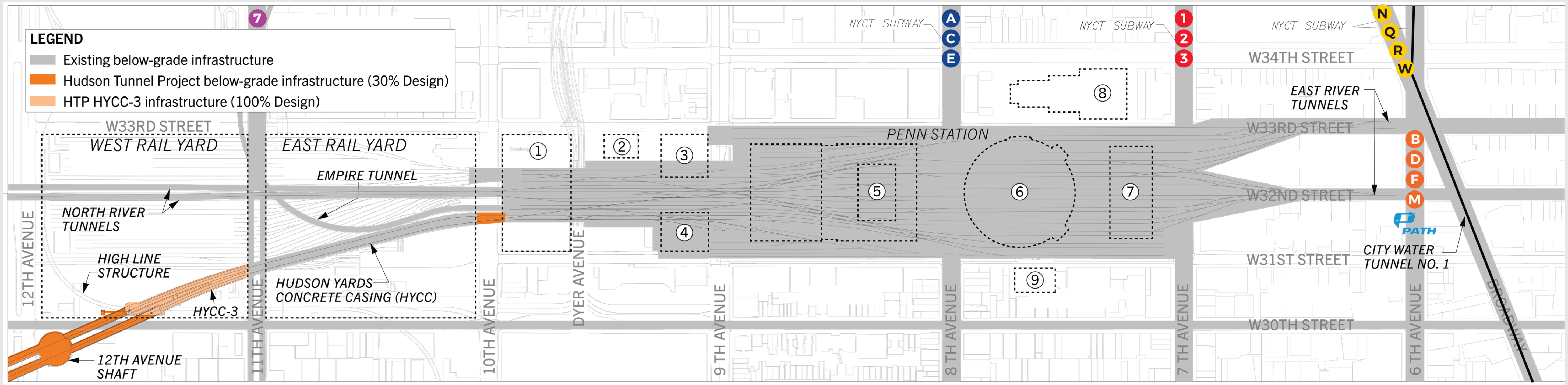
The above-ground station area is equally complex, as a densely developed part of Midtown Manhattan with large buildings, including on platforms above railroad tracks and infrastructure, and a number of historically significant buildings. Immediately west of and connected to the main Penn Station structure is the Moynihan Train Hall, opened in 2021 in the renovated former James A. Farley Post Office Building. Moynihan now functions as Amtrak's main passenger facility at the Penn Station Complex and also serves LIRR trains.

The Hudson Yards Development is a two-phase overbuild development over LIRR's West Side Storage Yard between Tenth and Eleventh Avenues. The first phase over the East Rail Yard, completed and opened in 2019, consists of a public green space and multiple structures. The second phase over the West Rail Yard has not yet started construction.

Manhattan West between Ninth and Tenth Avenues — another overbuild development constructed above the tracks immediately west of the existing Penn Station complex — features two new glass office towers, One and Two Manhattan West, along with several residential towers and a hotel. In addition to the new structures, two former industrial buildings — Five Manhattan West and the 1913 Lofts building — have also been renovated and adaptively reused for office space.

The station area beyond these new developments is composed of buildings of varying heights, forms, and ages (the most recent of which are PENN 1 and PENN 2, completed approximately 50 years ago). The buildings include mid-rise buildings such as Madison Square Garden, the Macy's Herald Square flagship store, and the largely vacant Manhattan Mall; towers surrounded by elevated plazas; large-scale asymmetrically built hotels constructed in the early 20th century; manufacturing and commercial loft buildings; and residential row house buildings.

Figure 1-6
Physical Constraints



1 Five Manhattan West
2 Lofts Building
3 One Manhattan West
4 Two Manhattan West
5 Moynihan Train Hall
6 Madison Square Garden
7 PENN 2
8 PENN 1
9 Penn Station Service Building

Tie-In to Hudson Tunnel Project

In addition to these existing structures, design concepts for the expansion of trans-Hudson rail capacity at Penn Station will connect into the alignment for the Hudson Tunnel Project, which was formally adopted by the FRA in its May 2021 ROD. Like the Penn Station Capacity Expansion Project, the Hudson Tunnel Project is one of the component projects of the Gateway Program (Figure 1-7), a series of rail infrastructure projects that will increase resiliency and capacity along the ten-mile stretch of the NEC between Newark, New Jersey, and New York Penn Station as a part of NEC FUTURE.

The Hudson Tunnel Project consists of a new two-track tunnel (called the Hudson River Tunnel) and the rehabilitation of the existing North River Tunnel. The new Hudson River Tunnel alignment will have two new tracks running parallel to, and south of, the existing NEC from Secaucus, New Jersey, beneath the New Jersey Palisades and the Hoboken/Weehawken waterfront area, and under the Hudson River to connect to the existing tracks in Penn Station. Upon completion of the Hudson Tunnel Project, the NEC would have four tracks (two in the new Hudson River Tunnel and two in the existing North River Tunnel) between New Jersey and New York under the Hudson River, which would provide operational flexibility and redundancy for Amtrak and NJ TRANSIT rail operations.

In Manhattan, the new tunnel will run below Hudson River Park, Twelfth Avenue (New York State Route 9A); the block between West 29th and West 30th Streets on the east side of Twelfth Avenue (Block 675); and West 30th Street. On the north side of West 30th Street, the alignment will meet the underground HYCC-3, which began construction in 2023, and the existing Hudson Yards Concrete Casing (between Eleventh and Tenth Avenues) that preserves the future Hudson Tunnel Project right-of-way. From the eastern end of the existing Hudson Yards Concrete Casing, the new alignment will continue under Tenth Avenue to a tunnel portal east of Tenth Avenue, within the complex of tracks located beneath the existing building that spans the tracks on the east side of Tenth Avenue (450 West 33rd Street) within A-Yard and finally connect to the existing Penn Station approach tracks near Ninth Avenue. HYCC-3 is a key structural element for providing a connection between any Penn Capacity Expansion alternative alignment and the Hudson Tunnel Project alignment and structures in the area of the Twelfth Avenue Shaft and the crossing below West 30th Street.

The FTA signed a Full Funding Grant Agreement with the Gateway Development Corporation on July 8, 2024, which commits the final piece of funding for the Hudson Tunnel Project and enables construction to begin.

Figure 1-7
Hudson Tunnel Project — Manhattan Tunnels

Other Surrounding Projects

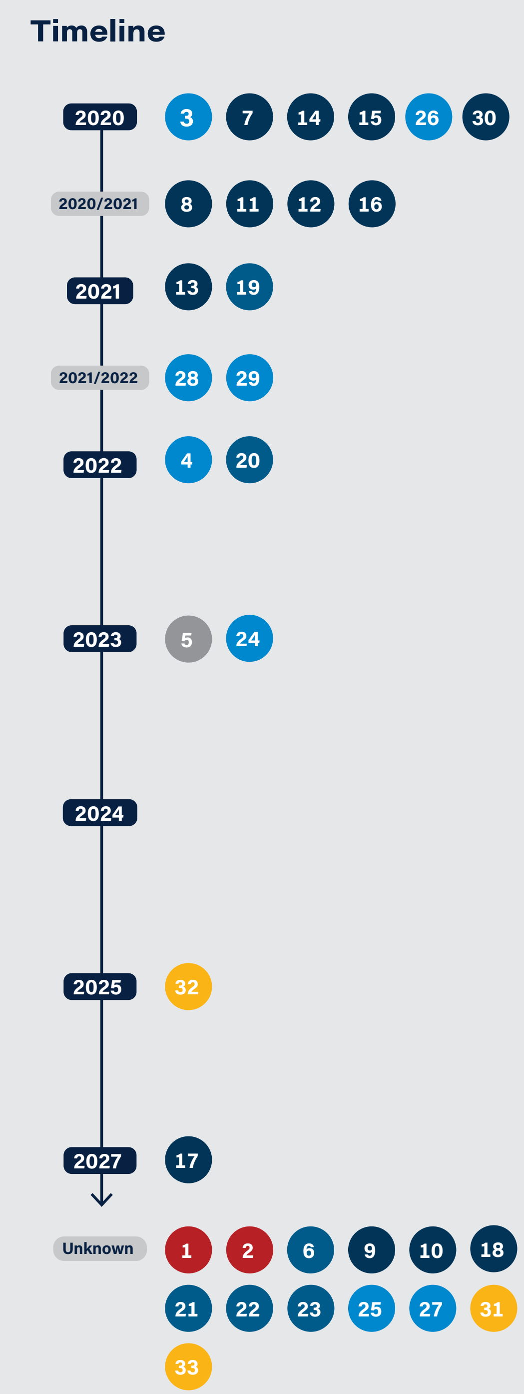
In addition to the Hudson Tunnel Project and other work associated with the NEC FUTURE/Gateway program that would affect the Penn Station Capacity Expansion Project, the following projects have been recently completed, are already underway, or are being planned:

- The transformation of the Farley Post Office Building into the Moynihan Train Hall, a new facility connected to Penn Station, and serving Amtrak and LIRR. (Opened in 2021)
- The renovation and expansion of the LIRR Concourse under West 33rd Street, including the creation of a new entrance at West 33rd Street and Seventh Avenue. (Opened in 2021)
- The renovated station entrance at Seventh Avenue and 32nd Street, the station's busiest entrance. (Opened in 2023)
- The ongoing upgrade of NYCT subway entrances at the Seventh and Eighth Avenue ends of the LIRR Concourse. (Ongoing)
- Penn Station Access, a plan to bring Metro-North service to Penn Station via the Hell Gate Line with new stations in the Bronx. (Expected to open in 2027)
- East Side Access (also called Grand Central Madison), which creates a new terminal beneath Grand Central Terminal for LIRR service. (Opened January 2023)
- Penn Station Reconstruction, which focuses on safety, accessibility, railroad operations, and customer experience improvements within the existing facility.
- Additional Metro-North service directly down the Hudson Line into Penn Station. (In planning)
- Additional NYCT upgrades to the subways and subway concourses, including a below-grade link to Herald Square Station. (In planning)
- Various Amtrak station facility projects, including back-of-house improvements; Ticketed Waiting Room renovations; platform-level improvements to signage, lighting, and finishes; and vertical circulation improvements.
- Various NJ TRANSIT station facility projects, including vertical circulation, signage, and HVAC improvements, as well as the extension of Platforms 1 and 2.
- Various LIRR station facility projects, including the replacement of the LIRR substation north of Platform 21; vertical circulation and HVAC improvements; platform-level improvements to signage, lighting, and finishes; and upgrades to the Station Master's Office.
- Vornado improvements at PENN 1 and PENN 2. (Under construction)

Figure 1-8 presents a full list of station and other related projects, along with their anticipated timelines.

Figure 1-8
Other Surrounding Projects

#	Project Owner	Project Name	Expected Year of Completion
1	Vornado	One Penn Plaza – 34th Street Entrance	Unknown
2	Vornado	Two Penn Plaza Bustle Addition	Unknown
3	LIRR	New 33rd Street / 7th Avenue Entrance	2021
4	LIRR	Expansion of the LIRR 33rd Street Concourse	2023
5	Amtrak, Vornado	7th Avenue and 32nd Street Entrance Renovation	2023
6	NJ Transit	Entry Corridor Extension / Central Concourse	Unknown
7	Amtrak	Club Acela & Ticketed Waiting Room Renovations	2020
8	Amtrak	Vertical Transportation Improvements	2020/2021
9	Amtrak	Back of House Police Department	Unknown
10	Amtrak	NY Penn Interim Improvements Plan	Unknown
11	Amtrak	Platform Improvements (Wayfinding/Lighting/Finishes)	2020/2021
12	Amtrak	Penn Station to Moynihan Train Hall Signage Replacements (Lower and Upper Levels)	2020/2021
13	Amtrak	Taxiway and 8th Avenue Entrance Renovations	2021
14	Amtrak	Back of House Door Replacements (Security)	2020
15	Amtrak	Back of House Sub-Basement Lighting and Communication Upgrades	2020
16	Amtrak	Building State of Good Repair Assessment	2020/2021
17	Amtrak	East River Tunnel Rehab Project	2027
18	NYC EDC	Hudson Park & Blvd Block 5 & 6 Overbuild	Unknown
19	NJ Transit	Track 7/8 Escalator Replacement with Stairs	2021
20	NJ Transit	Artwork removal (Lower Level) and Bathroom Expansion (Upper Level)	2022
21	NJ Transit	Signage Replacement - NJ Transit Concourse	Unknown
22	NJ Transit	HVAC Upgrades	Unknown
23	NJ Transit	Extension of Platforms 1 and 2	Unknown
24	LIRR	Replacement of LIRR Substation North of Track 21	2023
25	LIRR	Replacement of HVAC on Lower Level	Unknown
26	LIRR	Elevator/Escalator Renewal	2020
27	LIRR	Staircase Replacement / Renewal (Anticipated)	Unknown
28	LIRR	Platform Improvements Wayfinding/Lighting/Finishes (Anticipated)	2020/2021
29	LIRR	Station Masters Office	2020/2021
30	Amtrak	Moynihan Train Hall	2021
31	MTA	NYCT subway connections	Unknown
32	MTA	Penn Station Access (PSA) project	2027
33	MTA	Penn Station Reconstruction	Unknown



2 Planning for Regional Connectivity

Two imperatives drive the need for major investment at Penn Station:

1. The need for capacity to support future increases in rail traffic as the Gateway Program is implemented.
2. The opportunity to lay the groundwork for the future implementation of cross-regional service if the railroads and planning bodies determine that there is market demand for this type of service.

The existing station is not equipped to meet either need.

Other global cities have faced the same imperatives and have successfully implemented major investment programs to re-shape their rail networks to better serve regional travel demand and greatly increase the capacity of existing urban core stations. Case studies from Paris, London, Munich, Toronto, and Philadelphia are presented in this chapter and offer insights and guidance for the planning of similar investments at Penn Station.

In each of these example cities, new, purpose-built rail infrastructure was (or will be) created in the urban core and major core stations were (or will be) expanded to introduce what is typically referred to as regional metro service in a targeted portion of the region. This new service model in each city leverages a different combination of new routes and legacy rail lines, modified to be interoperable.

When designed well, dedicated facilities in the urban/suburban core of a metropolitan area, coupled with appropriate rolling stock, allow regional metro service to operate like transit, with uniform train performance and smooth train flow. Platforms in urban core station expansions can be designed with ample space and circulation capacity to permit rapid unloading and loading of trains. Shorter regional branch lines can be entirely converted to this type of service. Longer branch lines need to be configured to accommodate this new service type close to the urban core while still maintaining traditional commuter service from farther out on those routes to the city center. Intercity and international train service must be maintained as well.

Amtrak, MTA, and NJ TRANSIT have long understood the benefits of cross-regional rail service and support its development. All parties recognize the potential for bringing to the New York region the kind of cross-regional service that the passenger rail networks provide in Paris, London, Berlin, Munich, Leipzig, Madrid, Stockholm, Sydney, and elsewhere.

A solution that has been proposed by advocacy groups to both increase capacity and enable cross-regional service is an all-through-running regime at Penn Station. Responding to this suggestion, two variations of an alternative along those lines have been evaluated in this study.

Intercity and international (Canada) rail service will need to remain at Penn Station, as will long-distance suburban commuter services. The key to achieving smooth, high-capacity operations at Penn Station in the future is to keep regional metro services separate from legacy commuter and intercity rail services through the urban core. These different train types have very different performance characteristics and do not mix well on shared tracks. If the services were mixed on the same tracks, the regional metro service would not be able to achieve the transit-style close spacing (short headways) and high level of reliability that make it successful in the case studies in this chapter.

This chapter summarizes potential through-running regimes and a regional metro service model that best leverages the benefits of through-running at Penn Station. It considers the characteristics of the New York regional rail network and international best practices to paint a picture of what through-running regional metro service could look like in the New York metropolitan region.

Section 2.1

Key Terms and Concepts

The following key terms used in this document clarify the concepts that have been analyzed and evaluated:

Timetable-based Service

Timetable-based service is an operational regime where trains operate on a fixed schedule, with specified arrival and departure times. Timetable-based service generally is used on routes with longer intervals between trains than is typical on rail transit systems, such as intercity and commuter systems. Longer commuter and intercity routes operate on timetables and require longer dwell times at stations, especially major hub stations, because the dwell time incorporates recovery time allowances so that trains can usually depart on time, even if the train arrives at the station behind schedule. Current Amtrak, NJ TRANSIT, and LIRR service at Penn Station is entirely timetable-based.

Headway-based Service

Headway-based service is an operational regime where service is frequent enough, to regular destinations, that passengers do not need to consult a timetable in advance of traveling — they can just show up and catch the next train. The frequency is governed by the time (headway) between trains, similar to the service provided by the New York City subways or PATH. Systems with this service model typically have a limited number of routes and similar train stopping patterns, resulting in short dwell times at stations, without the need to build scheduled recovery time into timetables.

Dwell Time

The time spent by a train stationed at the platform is referred to as dwell time. It is controlled by a number of factors including:

- The time it takes for passengers to alight and/or board the rail cars (which itself depends on how many doors each car has, how wide the doors are, and how long it takes passengers to reach the doors from their seats, or vice-versa);
- Time required for the platform to clear, before it is safe to move the train out of the station;
- Time required for train support services such as crew changes, replenishment of food service cars, and baggage handling; and
- Recovery time that allows a train to leave on schedule if it arrives somewhat behind schedule.

Different types of service have different controlling factors and therefore require different dwell times.

Platform Reoccupation Time

The time that elapses between when a train arrives at a station track and the time that the next train arrives at the same platform track is referred to as platform reoccupation time. It is the sum of the dwell time, the time it takes the train to move through switches or interlockings on either or both ends of the station, the time required to throw switches to line a train up with its route through the station complex, plus a buffer time to ensure safe and reliable operations. The peak hour throughput capacity of a station is a function of the number of station tracks and the platform reoccupation time on each track.

Turnback Operation

Turnback service is an operational regime where trains reverse direction in the station and return in the direction from which they arrived. This operational regime is how a terminal station operates because all trains end their routes at the station. Turning at the station causes conflicts when incoming and out-going trains have to cross paths, reducing the number of trains that can use the station during a given peak period (throughput). Trains that turn back typically need a longer time on a platform track.

Intercity Rail

Intercity rail is the service currently provided by Amtrak at Penn Station. Trains cover longer distances, often several hundred miles, and operate on a fixed timetable. Passengers can include regular travelers but often include people less familiar with the station and train service than regular commuters. Amtrak actually operates three types of intercity service, each with different train-equipment and operational characteristics. Acela trains provide a premium fast service in the NEC. Northeast Regional, Keystone Corridor, and Empire Corridor trains offer regular service, and a handful of long-distance trains provide overnight service to the southern United States and Chicago and daytime service to Canada.

Commuter Rail

Commuter rail is the type of train service that the Long Island Rail Road and NJ TRANSIT operate to and from Penn Station. This service focuses on weekday peak travel between suburbs and the Manhattan central business district. Rail service is provided in both directions of travel, but the peak service patterns, fleets of train equipment, and station and yard facilities are all highly customized to maximize the number of passengers and trains that can be delivered to Penn Station during the weekday morning peak period and from Penn Station during the weekday evening peak period.

Cross-Regional Rail

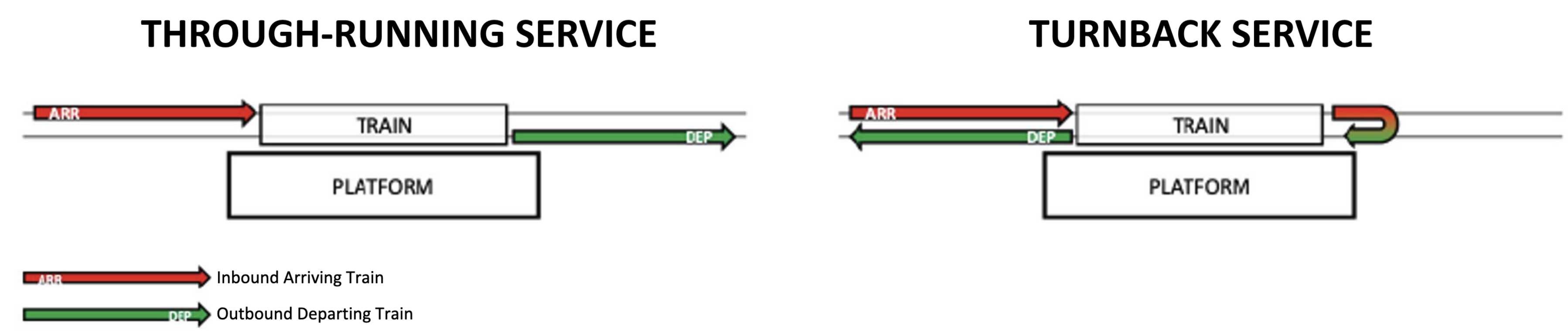
Cross-regional rail is a general term for any system providing service that connects communities and business centers to an urban center and to each other in a greater metropolitan region. Its focus is on providing regular, all-day bidirectional service among multiple origins and destinations, serving multiple travel purposes. Trains operate in highly predictable patterns at regular, repeating intervals, either timetable-based or headway-based. While cross-regional rail can provide more service during the weekday peak periods and can support the type of limited-stop express service that is common in the New York region, this peak service is not provided at the expense of the regular service patterns. Implementing cross-regional rail in the New York metropolitan region implies a greater level of service integration and coordination among the three existing commuter rail operators (LIRR, NJ TRANSIT, and Metro-North) and with Amtrak, but it does not necessarily require the merging of the railroads.

Regional Metro

Regional metro is a specific service concept for cross-regional rail. It is characterized by frequent, transit-style service (headways of 15 minutes or less) connecting urban and inner-suburban communities to each other, as well as to a city center. Regional metro systems rely on running trains through major stations in urban centers to connect communities on opposite sides of the urban center to each other. This type of service supplements conventional intercity and commuter service on an inner portion of a regional rail network that is configured to accommodate it, and where markets can support it, but does not replace the conventional intercity and commuter services that are so essential to their regional economies.

It entails the provision of subway-like service covering areas along existing railroad lines that are beyond the reach of the subway. Service is generally headway-based as opposed to timetable-based. As examples, existing commuter rail in the New York region is timetable-based, while subway service is headway-based.

Regional metro most often comprises a system of one or more trunk lines, fed at each end by multiple short-haul branch lines that feed into the trunk line. Generally, all trains operating along a regional metro trunk line make all local stops along the line, resulting in uniform and relatively simple operating patterns.



Suburban Rail Service

Suburban rail service serves longer-distance travel markets, for trips generally greater than 25 miles, on the rail network surrounding a large central city. These trains connect suburban and exurban communities with the central business district, and the largest volumes of passengers tend to be weekday commuters. Service frequency typically is less than regional metro, with trains operating on fixed timetables rather than headway-based. During peak periods, limited-stop express service may be offered in urban core areas with four-track systems where demand is sufficient, to provide faster trip times than can be achieved with all-stop local service.

Suburban service complements regional metro service. Regional metro and suburban service together could serve as a future replacement for traditional commuter rail in a future vision for a cross-regional rail network.

Through-running Operation

Although through-running is often used as a catch-all name for cross-regional service, it is actually an operational regime rather than a service type. It relates to the way trains move through a major station and the length of time they require when occupying platform tracks at the station. Through-running trains maintain their direction of movement through the station. It can be as simple as arriving at a major station in a city center in revenue service, dropping off their passengers, then running through in non-revenue service (without passengers) to a storage yard on the opposite side of the station, where it lays up until it is needed for the reverse movement back to its station of origin. This is called revenue-to-non-revenue or drop-and-go operation. Its main advantage is increasing train throughput capacity (i.e., the number of trains that can use the station in a given peak period). Alternatively, through-running can be used to connect destinations on opposite sides of the station to each other (revenue-to-revenue service), as well as increasing throughput. The term is generally applied to major stations that deliver high-density service, where the station tracks are connected to the rail network at both ends.

There are several potential benefits of through-running service:

- Improving the efficiency and reliability of train operations.
- Enabling growth in the volume of train movements that the station can serve during peak periods.
- Providing service to potential ridership markets beyond traditional journey-to-work commuting from suburbs to the central business district.
- Enabling a type of rail service and mode of train operation that has proven to be successful in many cities around the world, including London, Paris, and Munich.

Section 2.2

Existing Operations and Service at Penn Station

Regional Rail Network and Service Characteristics

The network of passenger rail lines feeding New York City is sprawling and extensive. Passenger service is provided on a total of nine branch lines in northern and mid-New Jersey, of which six currently offer some amount of direct service to Penn Station. When the Gateway Program is completed, direct service will be provided to all nine branches. The LIRR operates service to Penn Station from ten branch lines. During peak periods, express train service is offered from both New Jersey and Long Island from groups of stations along the major routes and branch lines, significantly increasing the number of discrete service patterns operated to and from Penn Station. Table 2-1 summarizes existing branches, route lengths, and number of stations served on each branch in the existing regional network.

The major commuter rail lines in the greater New York region extend 40 to 60 miles from Penn Station in Manhattan, to places such as Trenton, Long Branch, and Dover in New Jersey and Ronkonkoma, Port Jefferson, and Babylon on Long Island. Several branch lines, however, extend for 100 miles or longer, to places like Montauk and Greenport on Long Island and Port Jervis on the west side of the Hudson River.

The Amtrak NEC Line operates as an integral part of the New York metropolitan region network, with intercity trains sharing tracks with commuter trains at Penn Station and along virtually the entire length of the corridor in New Jersey, New York, and Connecticut. The Amtrak Empire Corridor that runs along the east bank of the Hudson River also terminates at Penn Station and hosts Amtrak service to upstate New York and Vermont and daily long-distance trains to Chicago, Toronto, and Montreal. The degree of overlap between intercity and commuter tracks and infrastructure is also greater than that found in most regional rail networks around the world.

Amtrak operates three different types of trains on the NEC, each with different operational characteristics:

- Acela premium express service
- Regular intercity service, including Northeast Regional trains to Boston, Springfield, MA, Washington, D.C., and Virginia, as well as service to Vermont, North Carolina, Harrisburg, PA, and western Pennsylvania
- Long-distance service, including overnight trains to Florida, New Orleans, and Chicago

Travel demand patterns and travel markets in the greater New York region include local travel within New York City and the close-in suburbs, suburb-to-city travel markets, suburb-to-suburb travel markets (which are very small in magnitude compared with commuting to Manhattan), and intercity travel markets.

Table 2-1

Commuter Rail Network Feeding Penn Station

Existing Services

Railroad	Branch	Terminal Station	Distance from Penn Station (Miles)	Total Number of Stations on Route	Number of Stations on Branch
NJ TRANSIT	Northeast Corridor	Trenton	58	16	16
	North Jersey Coast Line	Bay Head	66	27	20
	Morris & Essex Line	Dover	43	20	19
	Gladstone Branch	Gladstone	45	24	12
	Montclair-Boonton Line	Montclair State Univ.	17	12	10
LIRR	Main Line	Ronkonkoma	47	24	8
	Port Washington Branch	Port Washington	20	14	12
	Port Jefferson Branch	Port Jefferson	59	26	10
	Babylon Branch	Babylon	39	23	13
	Montauk Branch	Montauk	121	34	16
	Oyster Bay Branch	Oyster Bay	35	23	10
	Hempstead Branch	Hempstead	21	15	5
	West Hempstead Branch	West Hempstead	23	12	5
	Long Beach Branch	Long Beach	25	15	6
	Far Rockaway Branch	Far Rockaway	23	16	7

Potential Future Services at Penn Station

Railroad	Branch	Terminal Station	Distance from Penn Station (Miles)	Total Number of Stations on Route	Number of Stations on Branch
NJ TRANSIT	Raritan Valley Line	High Bridge	56	20	18
	Montclair-Boonton Line	Hackettstown	62	26	14
	Main Line	Suffern	32	17	16
	Bergen County Line	Suffern	31	16	15
	Pascack Valley Line	Spring Valley	36	17	16
	Port Jervis Line	Port Jervis	96	24	8
LIRR	Main Line East	Greenport	97	30	14
	Rockaway Beach Branch	JFK Airport	14	7	5
Metro-North	New Haven Line	New Haven	75	31	31
	Hudson Line	Croton-Harmon	33	14	14

Hybrid Through-Running and Turnback Operations

Penn Station supports both through-running and turnback service. The station operates in a hybrid mode, with some trains running through the station and others turning (reversing direction) at the platform. Amtrak trains generally run through the station. Acela and Northeast Regional trains that run between Boston and Washington drop off and pick up passengers at Penn Station. Amtrak trains that originate or terminate in New York also operate through the station, since these trains generally serve the Northeast Corridor to the south of New York or the Empire Corridor, but the trains are stored and serviced at Amtrak's Sunnyside Yard in Queens.

Some LIRR and NJ TRANSIT trains drop-and-go at Penn Station (a form of through-running), with LIRR trains continuing through to the west side storage yard in Manhattan and NJ TRANSIT trains continuing through the East River Tunnel to Sunnyside Yard in Queens. Other LIRR and NJ TRANSIT trains turn back at the Penn Station platforms.

The existing hybrid operation is depicted in Figure 2-1. Roughly 52 percent of all peak period trains run through the station in revenue-to-revenue service (Amtrak NEC service) or drop-and-go service (LIRR, NJ TRANSIT and Amtrak originating/terminating trains). The remainder of peak period trains engage in turnback operations at the station (LIRR and NJ TRANSIT).

Turning at the station causes conflicts when inbound and outbound trains must cross paths, reducing the number of trains that can use the station during a given peak period (throughput). Through-running decreases these conflicts, potentially increasing the throughput of the station. A train running through a station generally needs less time at the platform (dwell time) than a turning train, also potentially increasing throughput.

All Amtrak, NJ TRANSIT, and LIRR service at Penn Station operates on a fixed timetable. Given the complexity of the rail network feeding Penn Station and relatively long distances traversed by both intercity and suburban services, extra time is built into scheduled train dwell times at Penn Station to allow for recovery from modest delays to arriving trains — increasing the likelihood that departing trains leave the station on time, even in cases where the inbound train has been delayed. These recovery time allowances lengthen train dwell times and consume train throughput capacity — one of the factors constraining the overall capacity of the station complex.

Penn Station also hosts multiple types and styles of train service, with variable train operating and passenger behavior characteristics based on the type of service. This includes all three types of Amtrak intercity service, plus commuter rail service to both New Jersey and Long Island. (It also will include Metro-North commuter rail service to the East Bronx, Westchester, and Connecticut in the future.)

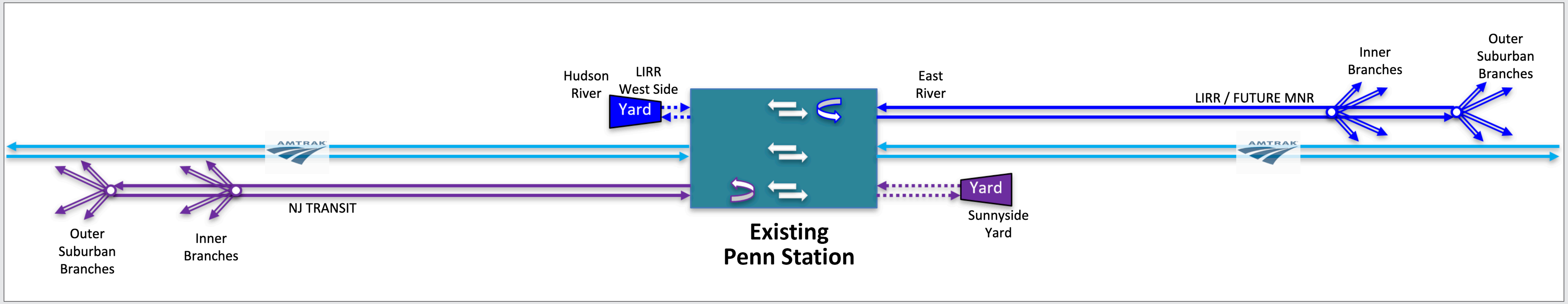
Amtrak trains tend to occupy the platforms at Penn Station for longer periods of time than commuter trains, due to allowing recovery time, a variety of train-servicing and passenger-handling functions that occur at the station, and the physical characteristics of the coaches and platforms. Most Amtrak trains offer food and beverage service, and the food service cars are re-stocked while the train is stopped at the platform in New York. In addition, the train crews change at New York for most Amtrak trains that run through the station, because of the length of the trips that these trains take. A new engineer and conductors typically board the train once it arrives and must run through a set of procedures to prepare the train for departure. Amtrak long-distance trains offer sleeping and dining car service and offer checked baggage service, so baggage needs to be unloaded and loaded onto these trains while they sit at the platform. Amtrak Intercity coaches are not configured for rapid alighting and boarding, with only two door locations at the ends of the coaches that are shared with the adjacent coaches.

Amtrak Acela trains are faster than Amtrak Regional trains, so they overtake Regional trains on a regular schedule. These overtakes are accommodated at Penn Station, the mid-point of the NEC, as well as at Philadelphia and New Haven, the quarter-points. Regional trains arrive at Penn Station first, followed by Acelas. The Regional trains are held in the station until the Acela has boarded and alighted passengers, handled baggage, re-stocked the cafe car, changed crews, and continued on. These overtakes will occur twice an hour during peak travel periods once Gateway is complete, consuming considerable time at four platforms, since the overtakes occur roughly simultaneously in both directions.

Finally, the platforms at Penn Station are too narrow to accommodate alighting and boarding passengers simultaneously, so boarding passengers are held in the station concourses until alighting passengers have cleared the platforms. These factors combine to generate relatively long dwell times for Amtrak trains at Penn Station.

Figure 2-1

Current Hybrid Operations at Penn Station



Penn Station does not operate as a monolithic station with universal access to every station track from all tunnel tracks. It operates instead as a system of zones, where groups of platform tracks are served by various combinations of routes to and from the tunnels feeding the station. These platform track groupings change by time of day, based on the specific schedules for each train operator and the types of trains that are operated. The following operational zones and their associated station- and tunnel-track connections, shown in **Figure 2-2**, indicate how Penn Station is used during weekday peak periods:

- East River Tunnel Line No. 3 and No. 4 — feeding station Tracks 16 through 21 (exclusively LIRR)
- East River Tunnel Line No. 1 and No. 2 connected to existing North River Tunnel — via station Tracks 5 through 16 (Amtrak trains and NJ TRANSIT trains running to or from midday storage at Sunnyside Yard in Queens; also includes LIRR trains during weekday peak periods)
- North River Tunnel — feeding stub-ended Tracks 1 through 4 (NJ TRANSIT turnback operations)
- Empire Tunnel — feeding Tracks 1 through 9 (Amtrak Empire Corridor service)
- West Side Yard — feeding station Tracks 13 through 21 (LIRR trains that run through to/from West Side Yard storage)

The station complex includes several major and minor storage yards and maintenance facilities, also identified in **Figure 2-2**:

- West Side Yard — LIRR
- Sunnyside Yard — Amtrak and NJ TRANSIT
- Penn Station Yards A, C, D, and E — in the southwest and northwest quadrants of the station superblock

Penn Station, therefore, has both a mix of train types with a wide range of performance characteristics, and a complicated operation that mixes these different types of trains together in different ways at different times of day.

Regional Metro Concept Overview

Regional metro service provides subway-like service over portions of the regional railroad network — effectively extending the reach of the rapid transit network to outer portions of the city and the inner suburbs. It provides high-quality transit-style service on a compact network that is relatively simple in design and reliable in operation. Key network characteristics include:

- All-stop service
- Limited number of branches
- Limited branch length

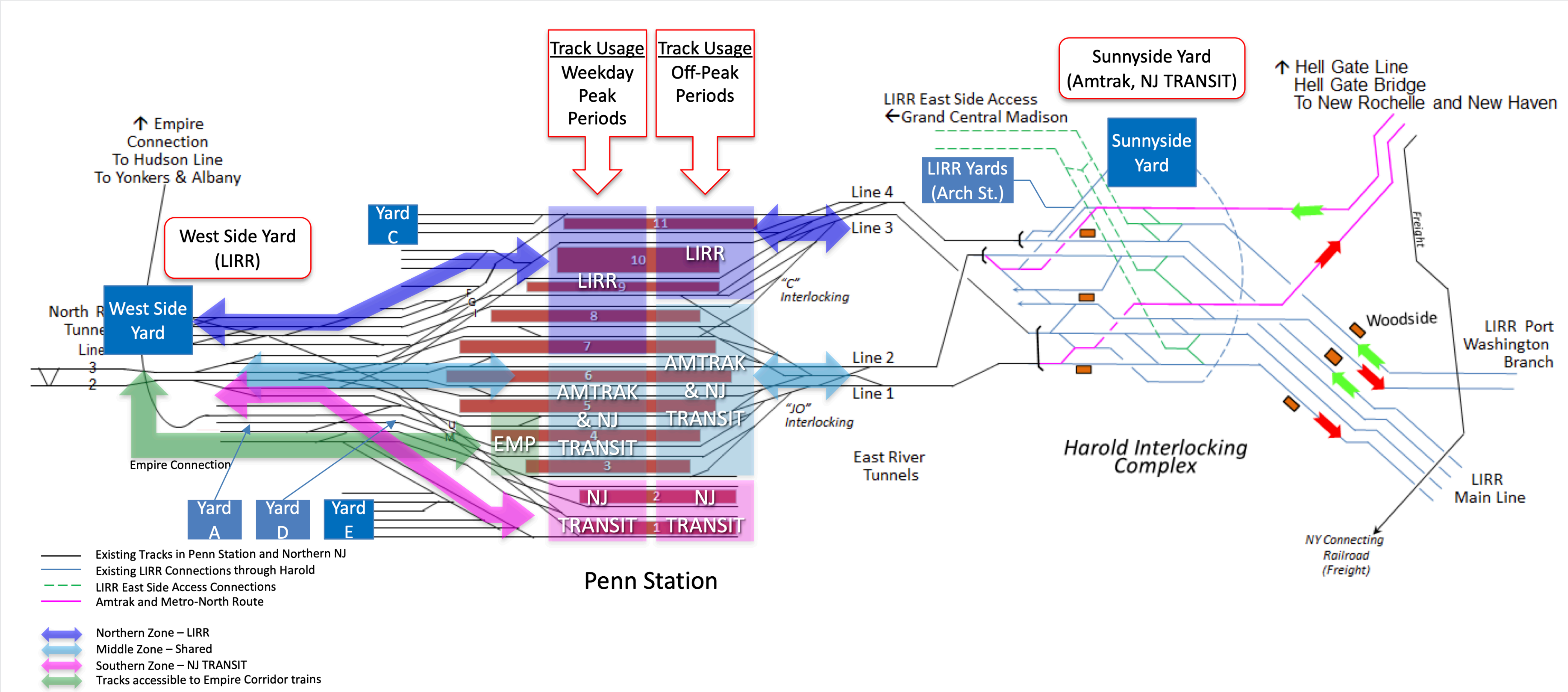
Regional metro service is headway-based, so that passengers do not need to consult timetables to ride the service. This also enables shorter dwell times at line stations since schedule recovery time generally is not needed. A typical regional metro service might include branch lines operating on 15-minute peak headways on each branch, with a total of six branches feeding a common trunk line operating at 24 tph. Or the network could comprise four branches feeding the trunk line, with ten-minute peak headways on each branch, delivering the same 24 tph on the trunk line.

Regional metro service works best with train equipment of uniform or similar performance characteristics, including similar acceleration and deceleration rates and interior layouts with large doors and vestibules for rapid alighting and boarding.

This type of service requires through-running on a central trunk line. At Penn Station, this potentially could be accomplished by either converting the existing station to through-running or expanding the station in a configuration that supports future through-running (the feasibility of which is documented in this report).

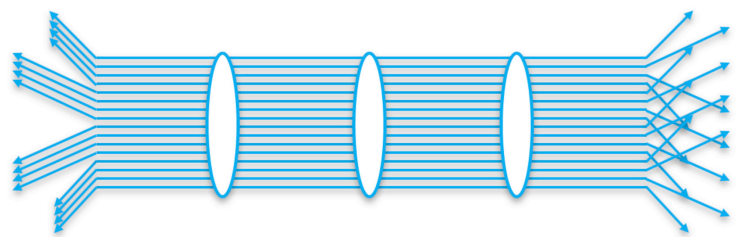
Figure 2-2

Penn Station Operational Zones and Yard Locations



Section 2.3

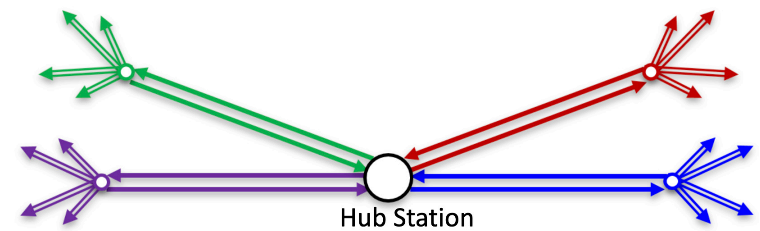
Types of Cross-Regional Rail Service



Everywhere-to-Anywhere Service

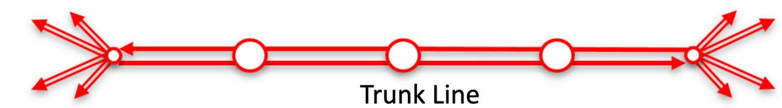
Cross-regional service is sometimes mistakenly assumed to offer passengers a one-seat ride from everywhere to anywhere. This concept only works where the number of network branches is very small, and there are few examples of this type of service. The reason is simple mathematics.

The combination of the two existing North River Tunnel tracks and the two new Hudson River Tunnel tracks can process a total of 48 tph in each direction. Currently, there are ten commuter service zones (serving 9 branches) on the NJ side and 18 service zones (serving ten branches) on the NY side, generating 180 unique service patterns if every zone were connected to every other zone on the other side of the region. Given the combined tunnel capacity, and allowing for Amtrak service, each pair of service zones could be served by a single train once every four hours. This clearly would be an unacceptable way to operate rail service, but it demonstrates why one-seat everywhere-to-anywhere service is a mathematical impossibility.



Hub-and-Spoke

The most common service model for airlines, the hub-and-spoke concept has multiple lines and services converging on a central hub station. Cross-regional rail would be achieved with passenger transfers, which would be available among all rail services at the hub station. If service is frequent enough, or if service schedules are coordinated, transfers between routes at the hub station can be convenient and relatively quick. The hub station ideally would be configured to make those transfers as quick and convenient as possible. U.S. examples include Chicago Union Station, Washington Union Station, and the LIRR's Jamaica Station. Most traditional stub-ended rail terminals, such as Grand Central Terminal, Boston South Station, or Los Angeles Union Station, best support hub-and-spoke service. The existing Penn Station operates partially as a hub-and-spoke terminal in that commuters can transfer to Amtrak routes (e.g., from an LIRR train to Amtrak Empire service) or between LIRR and NJ TRANSIT routes.



Trunk-and-Branch

In this route configuration for cross-regional rail, multiple branch lines feed a trunk line that runs through the city center, serving multiple stations. Stations along the trunk line route can become major hubs and economic activity nodes, since direct one-seat-ride rail service is available to all branches from the trunk line stations. For stations on branches beyond the trunk line, direct one-seat service is provided to only one branch on the far side of the trunk line. A transfer somewhere along the trunk line is required to reach the other far-side branches. Generally, these transfers involve passengers disembarking and waiting on the same platform for a subsequent train that runs to their desired destination.

Paris, London, and Munich are examples of major cities that have implemented trunk-and-branch networks for regional metro service. Paris and London have created robust networks with multiple regional rail trunk lines. Philadelphia's Center City Connector was built to create a trunk-and-branch regional rail network. The trunk-and-branch model appears to be the most applicable to the New York region and the rail corridor that runs across Manhattan through Penn Station.

Section 2.4

Worldwide Examples and Best Practices

Numerous examples of regional rail from around the world demonstrate where legacy rail lines have been connected through the city center and where transit-style, through-running service is operated. Three successful international examples of implementing through-running service in an urban core tied to existing legacy rail networks and train stations, which offer guidance for regional metro service implementation in the New York region, include:

- Paris RER Lines B and D
- Munich S-Bahn
- London Elizabeth Line (Crossrail) and Thameslink

Philadelphia began the same process 40 years ago with the construction of a four-track trunk line under Center City with three trunk line stations. It offers an instructive example of both the potential for and challenges of re-imagining cross-regional rail service. Toronto is in the process of converting its commuter rail system into a mixed regional metro and commuter network, applying best practices from the successful European examples, and offers perhaps the most relevant guidance for the NY/NJ region.

All of these systems have similar operational, station infrastructure, and rail network characteristics, and all of them were created by constructing purpose-built, new infrastructure that supports through-running operations through the city center and at the major rail stations. They leverage existing legacy rail networks that serve a region beyond the reach of the urban rail transit network. These are not the only cities that have implemented regional metro and invested in new, dedicated, purpose-built infrastructure at major train stations to support the service. Other examples in Europe include Stockholm, Sweden, Zurich, Switzerland and Leipzig, Germany.

Several major train stations on these networks provide useful examples of how station infrastructure was modified and supplemented to support regional metro service and are discussed in the case studies:

- Gare du Nord — Paris (RER)
- Hauptbahnhof — Munich (S-Bahn)
- Ostbahnhof — Munich (S-Bahn)
- Liverpool Street Station — London (Elizabeth Line/Crossrail)
- Paddington Station — London (Elizabeth Line/Crossrail)
- St. Pancras International Station — London (Thameslink)
- Toronto Union Station

Paris RER

The Paris RER network comprises five train lines (designated A, B, C, D, and E) that link the Paris city center to its surrounding suburbs (Figure 2-3). The RER operates in a trunk-and-branch configuration with four different trunk lines through the city center, and with several hub stations where the trunk lines interconnect. Lines A, B, C, and D run through the city center trunk lines, connecting communities and destinations on opposite sides of the city center to each other, while the E line terminates at a station in the city center, but also provides transit-style frequent service. Less than one-third of the regional rail network in the province of Ile-de-France around Paris was reformatted to create the RER system, taking over 30 years to complete. The RER includes 33 stations within the city of Paris, that are spaced farther apart than the Paris Metro, so the RER acts as an express service through the city center. Beyond the Paris city center, the RER operates along legacy rail lines, connecting outlying suburbs and popular destinations such as Charles de Gaulle Airport (RER B Line), Disneyland Paris (RER A Line), and Versailles (RER C Line) to central Paris. The network comprises 365 route-miles, 47.5 route-miles of which is underground tunnel. The RER routes extend an average of 37 miles out from the center of Paris. Passengers transfer at hub stations such as Chatelet-Les-Halles between trunk lines or to reach suburban destinations on the far side of the city center beyond the reach of the regional metro service.

The two RER lines that are most comparable to conditions in the New York region are the B and D Lines. Line B opened in 1977 and comprises 50 route miles and 47 stations. Line D opened in stages between 1987 and 1996 and includes 59 stations over 118 route miles. Line D has the greatest overlap with legacy rail lines over the longest distances. It also offers less-frequent service than Line B but also has been described as having a lower level of on-time performance, due to its greater degree of interaction with the legacy rail network.

Between Châtelet-Les Halles and Gare du Nord, the RER B and D Lines share a two-track tunnel alignment. This trunk line segment governs the capacity of the two lines. The major stations along the trunk line, however, have dedicated platform tracks for each service. This benefits passenger wayfinding and allows for shorter headways in the tunnel since the station tracks can be fed by alternating

- Regional metro operates on four trunk links through central Paris
- Trunk lines used exclusively by regional metro trains
- Regional metro service merges with suburban and intercity traffic beyond the major stations
- Regional metro tracks and platforms separate from other rail services at major stations (Gare du Nord, Gare de Lyon, Gare de l'Est)

train services. The alternating feed to multiple station platforms from the single trunk line track allows for very close train spacing (2 minutes or less) on the trunk line and sufficient dwell times at the station for passenger alighting and boarding.

The RER B and D Lines provide regional metro service (Figure 2-4). During peak periods, the B Line operates 20 tph (3-minute headway), and the D Line operates 12 tph (5-minute headway). The B Line has two branches to the south and two branches to the north. The D Line has a single branch to the north and three principal branches to the south. The northern end of the B Line operates two services at 10 tph each (6-minute headway). The southern end of the B Line operates four services at 5 tph each, including one local service on the Robinson Branch and three zone express services on the Saint-Rémy-lès-Chevreuse Branch. Line D operates three separate services at 4 tph each (15-minute headway on outer branches).

These RER lines operate with both single- and bi-level rolling stock. The trains are also equipped for dual-power electrified operations (supporting 1.5kv DC traction power on the south side of Paris and 25kv AC power on the north side).

Gare du Nord is the major rail terminal serving trains running to the north of Paris, including international services to Belgium, the Netherlands, and the United Kingdom via the Channel Tunnel. It is a stub-end terminal, used by long-distance trains as well as suburban commuter trains. All tracks in the existing rail terminal are used for intercity and suburban turnback operations. The station has been expanded several times to accommodate increased service, most recently with a modern expansion to accommodate Eurostar service to London. An entirely separate lower-level shoulder station was constructed for RER service, as shown in Figure 2-5, with four tracks and two island platforms. The RER station, which opened in 1982, is connected to the existing station concourse with escalators and elevators. The RER tracks join the railroad right-of-way to the north of the existing station throat, keeping RER operations separate from other train movements at Gare du Nord. The RER service also operates on its own tracks within the existing rail right-of-way as it heads north from central Paris.

Figure 2-3
Paris RER Regional Metro Network

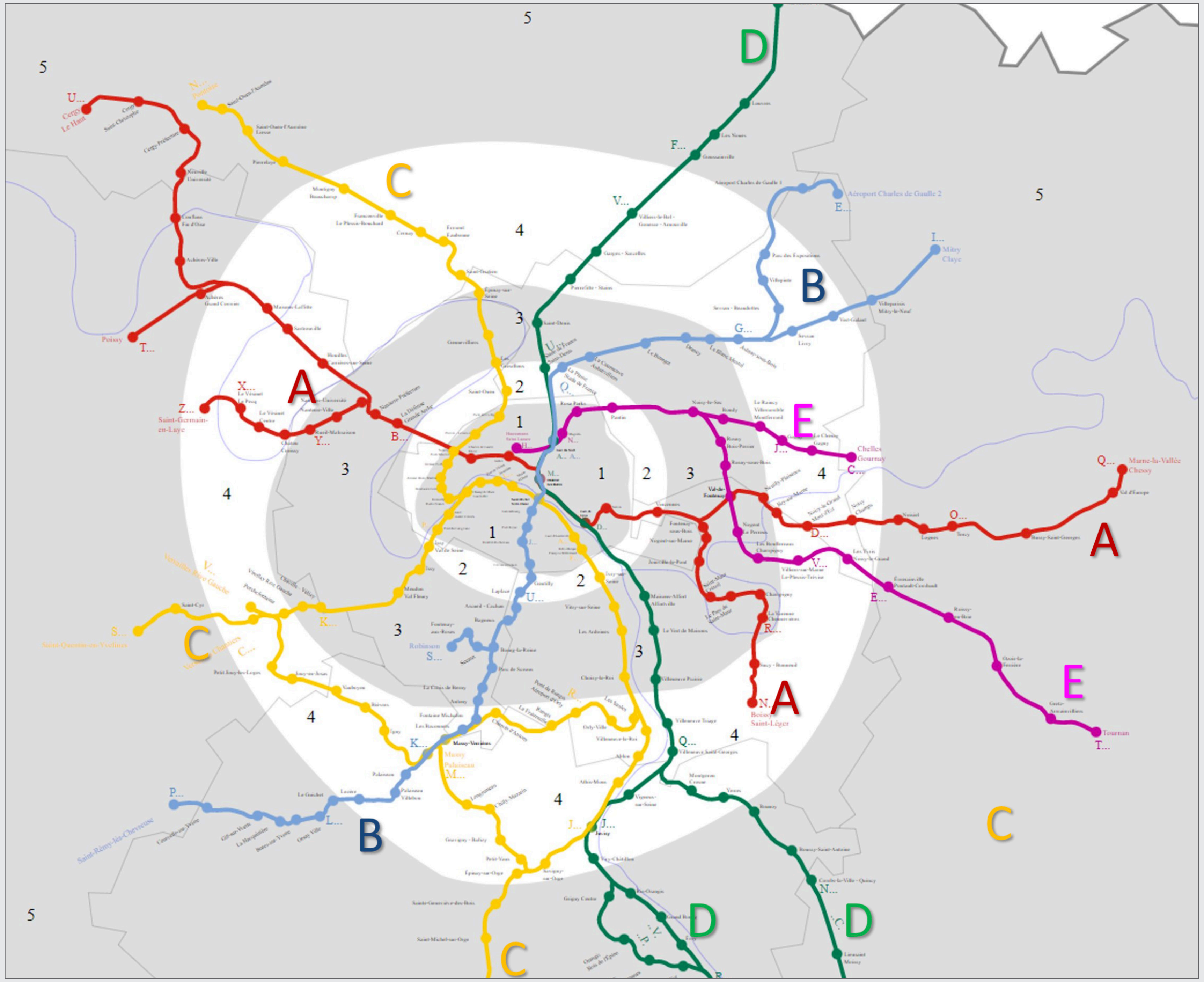


Figure 2-4

RER B and D Lines

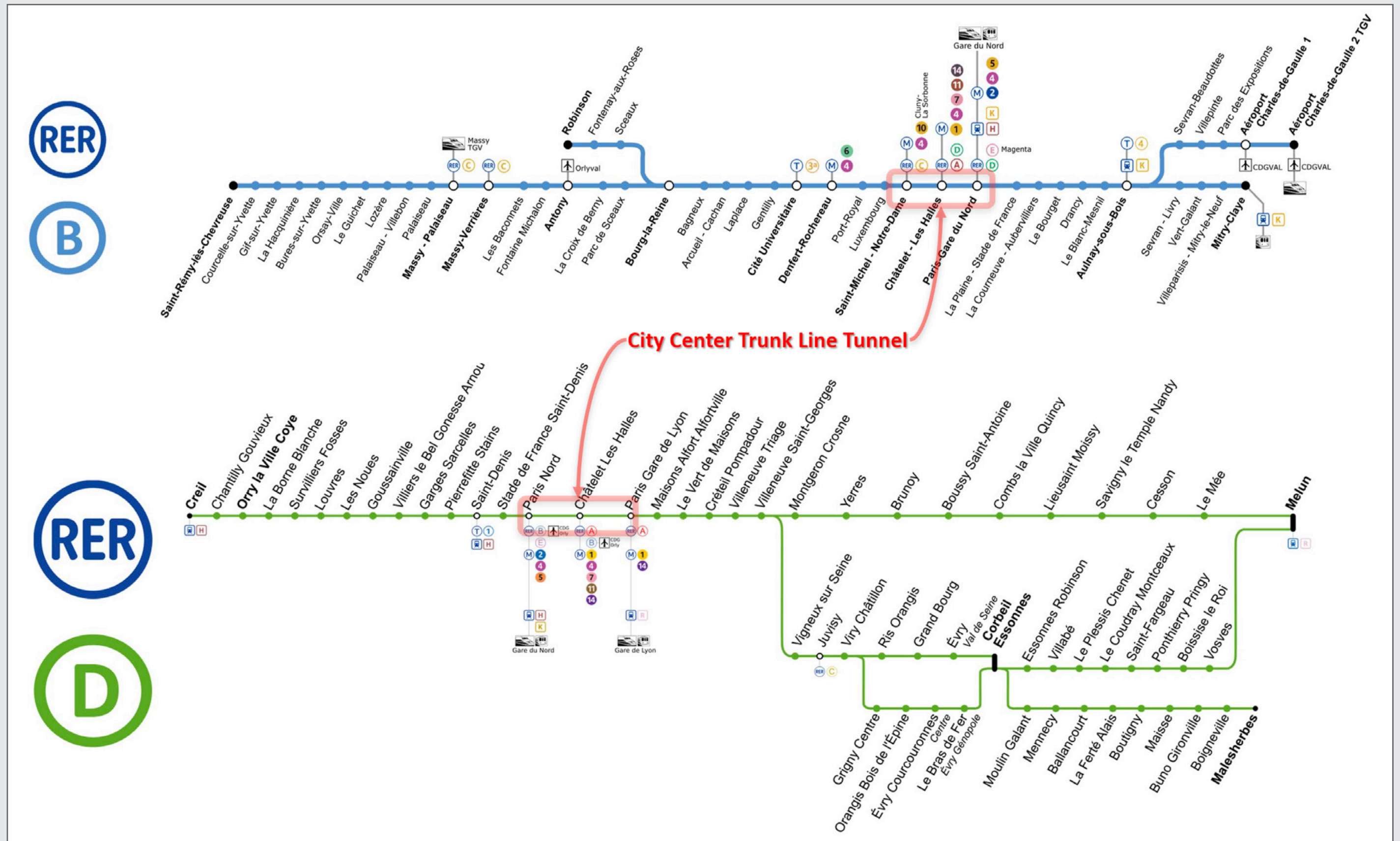
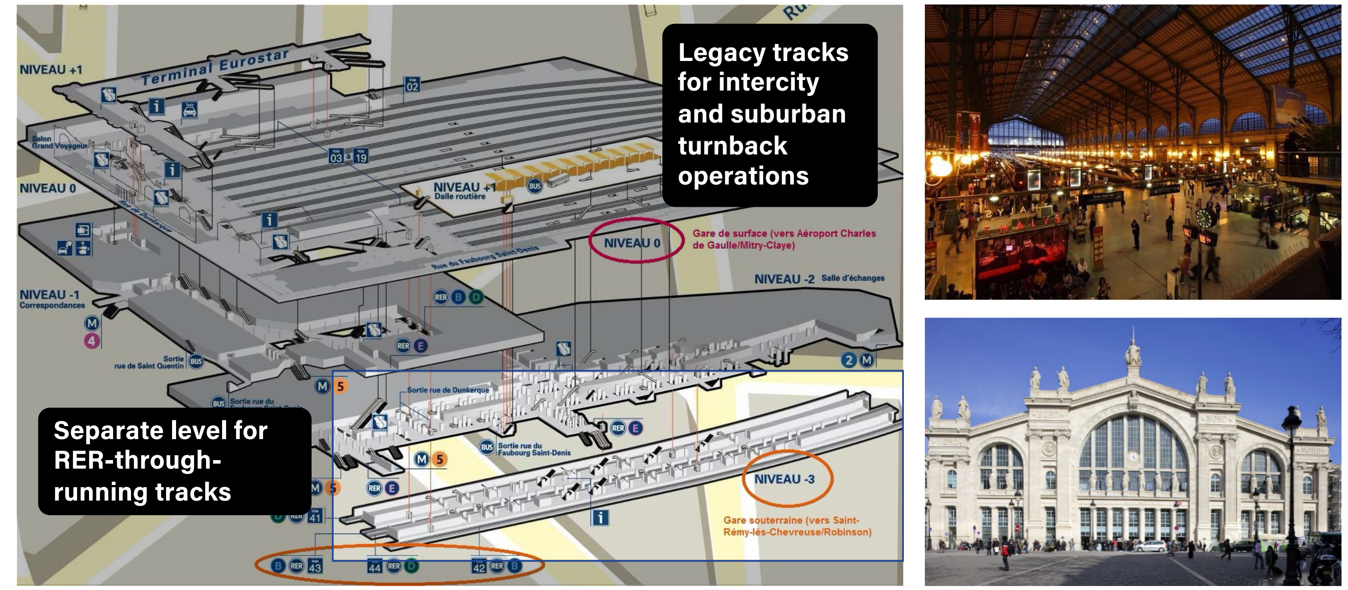


Figure 2-5

Gare du Nord - Paris



Munich S-Bahn

Munich, Germany has a well-developed regional rail network that provides extensive coverage of the region surrounding the city in the state of Bavaria. Munich has a single 7-mile-long trunk line constructed in tunnel through the city center with 10 stations, including Munich's two primary railway stations, the Hauptbahnhof (main station) and Ostbahnhof (east station). The network has eight branch lines to the west and five branch lines to the east, as shown in Figure 2-6. The S-Bahn branch lines extend an average of 35 miles out from the city center, with the shortest branch only 10 miles in length. These branch line distances are significantly shorter than the commuter rail branch lines in New York, reflecting Munich's smaller regional population of 2.7 million. The various branches were reformatted to create the S-Bahn in several stages spread out over a total of 46 years.

- Regional metro service in trunk and branch configuration
- Trunk line used exclusively by regional metro trains
- Regional metro service merges with suburban and intercity traffic beyond the major stations
- Regional metro tracks and platforms separate from other rail services at major stations (Munich Hauptbahnhof and Ostbahnhof)

The Munich S-Bahn is a classic regional metro service. The base service headway on each S-Bahn route is 20 minutes (3 tph) on each branch, which generates 2½-minute headways (24 tph) on the trunk line during peak periods. All trains operate as all-stop local trains through the trunk line. Peak express service is offered on selected branches outside the urban core. Off-peak trains run with the same service patterns and in the same schedule slots as peak trains, with selected trains deleted from the off-peak schedule. This results in a highly predictable operation and simplifies train merging and diverging movements at the S-Bahn's many junctions. Passengers originating or destined for locations along the central trunk line can catch trains directly to and from every branch line in the network. Most passengers traveling between suburban locations transfer between routes at stations along the trunk line.

The relationship of the S-Bahn to other rail services at the two major stations closely resembles the configuration of the RER at Gare du Nord, as shown in Figure 2-7 and Figure 2-8. S-Bahn stations are adjacent to but separate from the legacy train stations that predominantly serve other types of trains, including longer-distance suburban and intercity trains, as well as international trains. The S-Bahn station at the Hauptbahnhof was purpose-built for transit-style S-Bahn service. The S-Bahn tracks join the legacy rail lines beyond the limits of the main station platforms and throat area.

In Munich, a new parallel S-Bahn tunnel has been approved and funded, with construction scheduled to begin in 2028. The expanded trunk line capacity would allow for more frequent service on the branch lines, including the expansion of express services.

Figure 2-6
Munich S-Bahn Regional Metro Network

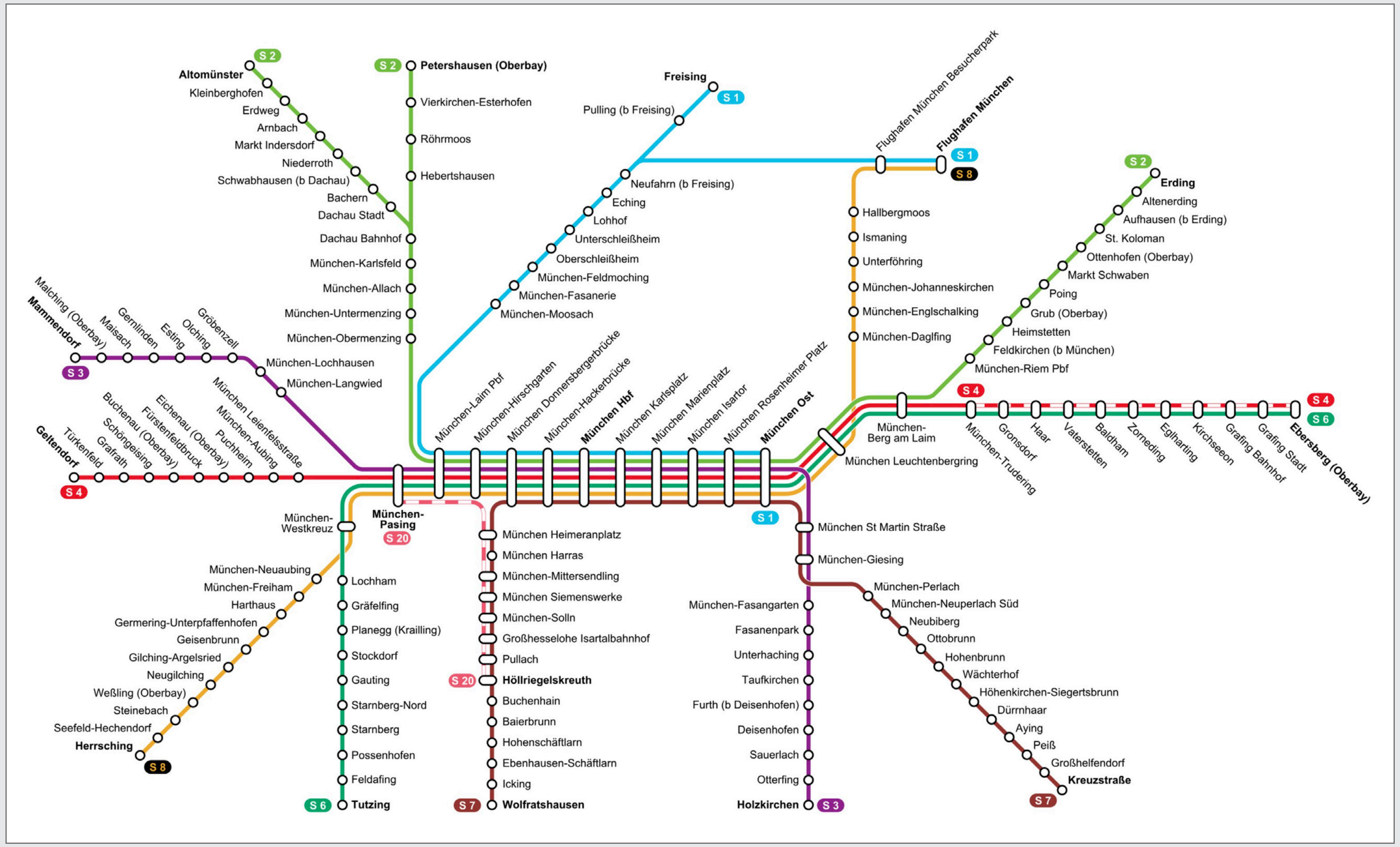


Figure 2-7

Main Train Station - Munich

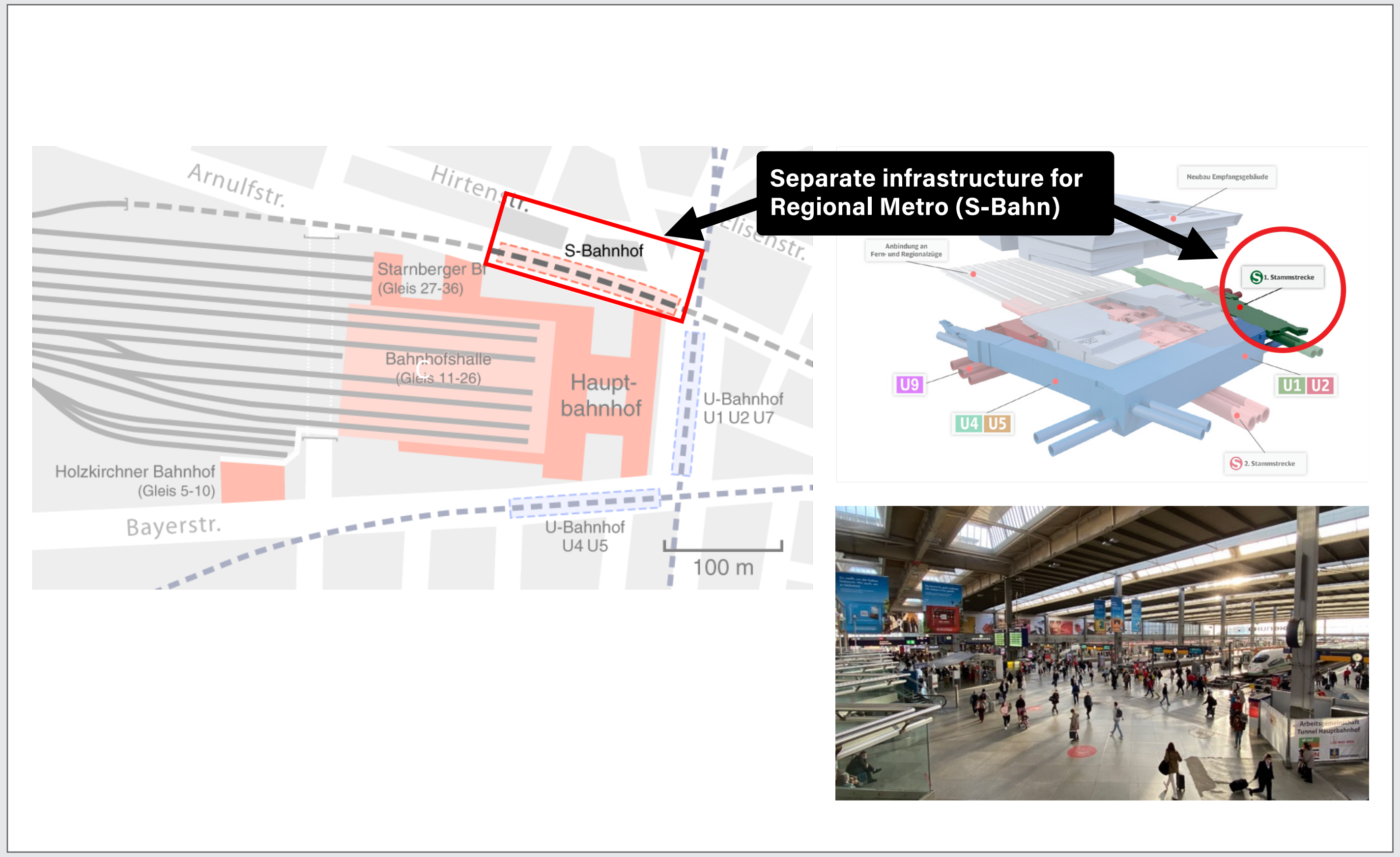
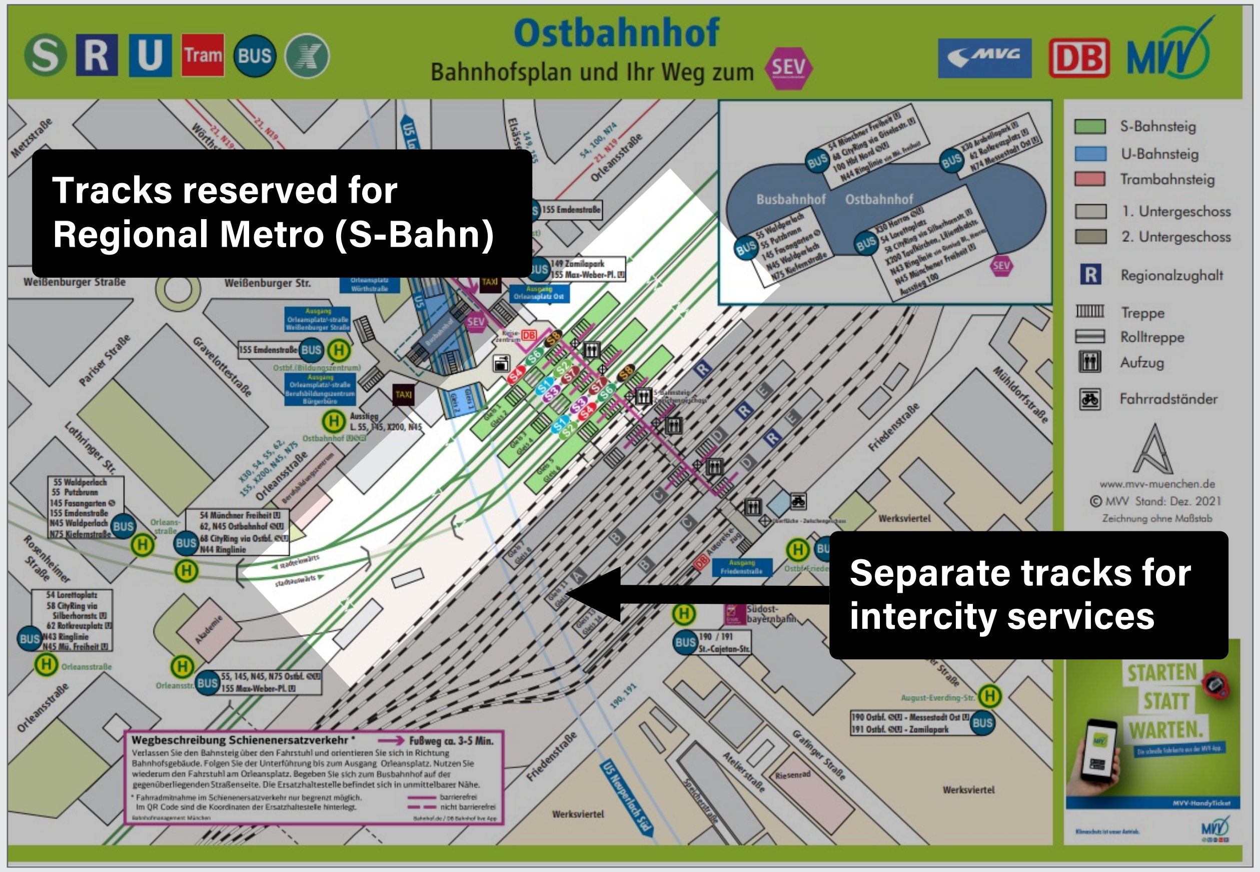


Figure 2-8

East Train Station - Munich



London Elizabeth Line (Crossrail)

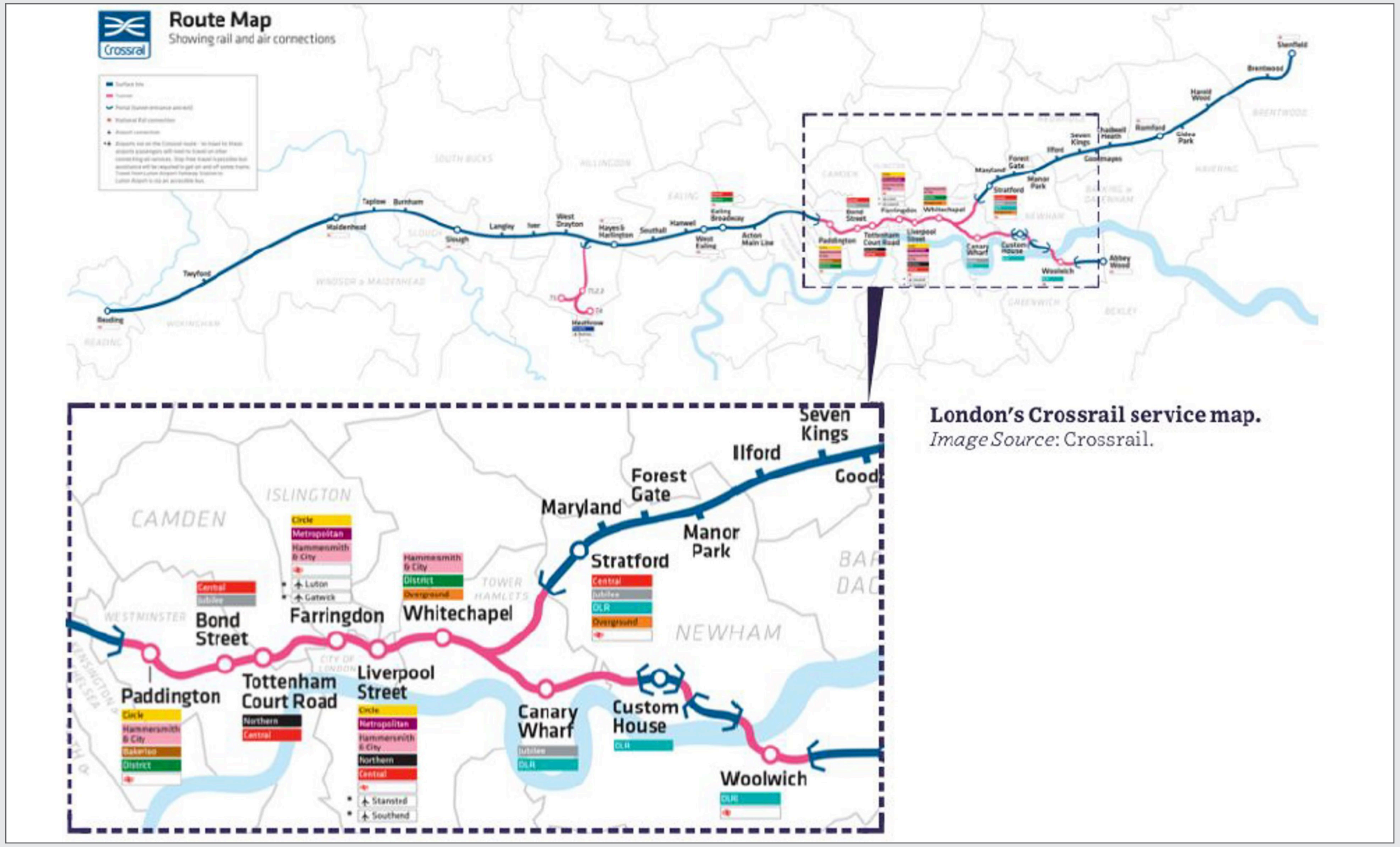
The Elizabeth Line is a regional rail service that operates on a newly opened east-west tunnel alignment through central London (Figure 2-9). Crossrail was the name of the construction program that built the new infrastructure that supports the service. The new central trunk line is used exclusively by Elizabeth Line trains, but the services operate via legacy rail lines to the west and east of central London. Two branches — Reading and Heathrow Airport to the west and Shenfield and Abbey Wood to the east — feed the trunk line on each end. The route distance from Paddington to Reading is 34 miles and from Paddington to Heathrow is 12 miles. The eastern branch distance from Liverpool Street to Shenfield is 19 miles and from Liverpool Street to Abbey Wood is 9 miles. Again, these distances are much shorter than regional commuter routes in the New York metropolitan region. It took a total of 19 years to plan, fund and construct the Elizabeth Line, though the first proposal to fund such a line dates back to 1974.

- Regional metro service in trunk and branch configuration
- Trunk line used exclusively by regional metro trains
- Regional metro tracks and platforms separate from other rail services at major stations (Paddington and Liverpool Street)

The Elizabeth Line provides regional metro service, offering rapid transit (i.e., subway-style) service. The trunk line operates at up to 24 tph during peak periods, which equates to headways averaging 2½ minutes. Several new purpose-built underground stations have been constructed along the trunk line, each with a single platform face for each direction of travel. A single operating entity provides all service, with a single rolling stock type designed for heavy passenger loading and rapid boarding and alighting. All train equipment has the same operational performance characteristics. Several stations serve central London, with multiple opportunities for transfers to and from other underground transit lines.

Figure 2-9

London Elizabeth Line Regional Metro



London's Crossrail service map. *Image Source*: Crossrail.

The interface points with the legacy rail network are at Liverpool Street Station and Paddington Station, both major stub-end rail stations. Figure 2-10 and Figure 2-11 show the relationship of the new Elizabeth Line stations with the existing railway terminals. At each location, the Elizabeth Line right-of-way diverges from the legacy rail corridors before reaching the terminal interlockings and drops into a tunnel. The Elizabeth Line shoulder stations at both Paddington and Liverpool Street are located underground, adjacent to the legacy stations and readily accessible by passengers. The train operations within the Elizabeth Line shoulder stations are totally separate from the legacy train operations at the existing terminal stations. The Elizabeth Line trunk line joins the legacy rail network at junction points beyond the immediate throat of the legacy stations, simplifying operations of both the Elizabeth Line and the rail services using the legacy stations.

Figure 2-10
Liverpool Street Station - London

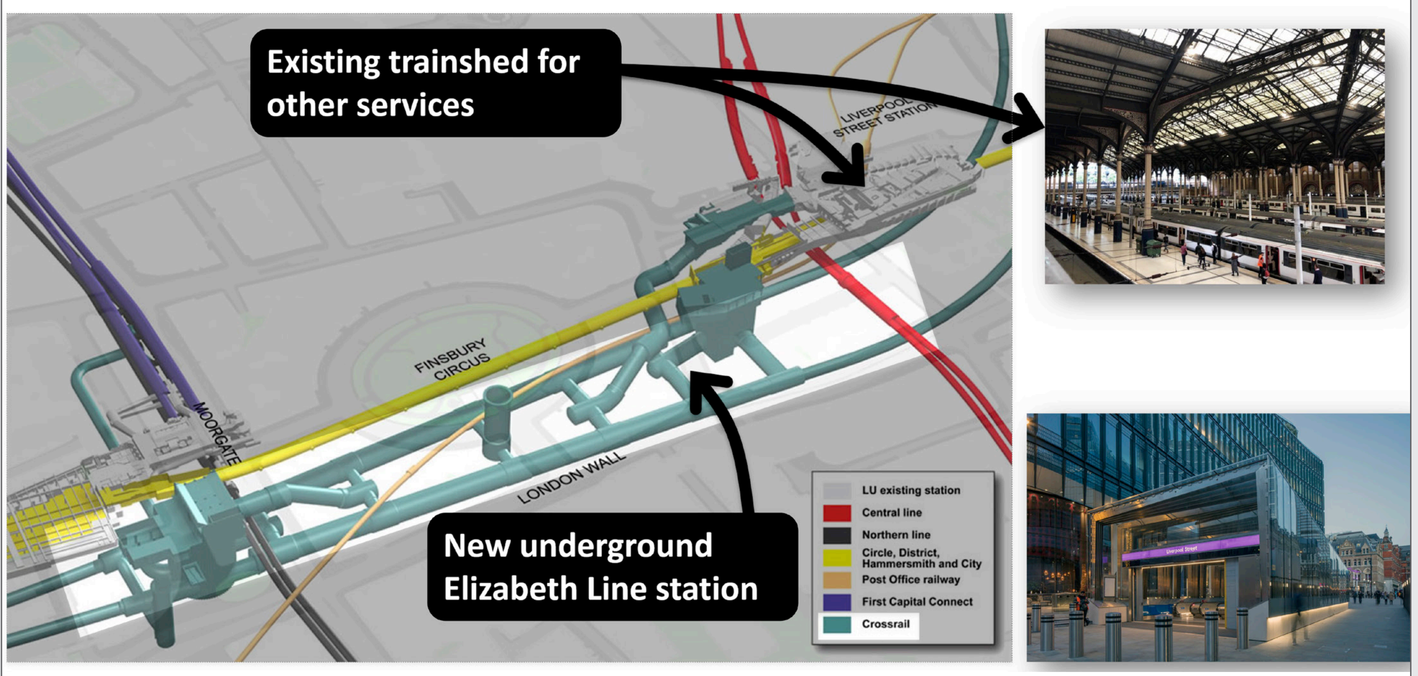
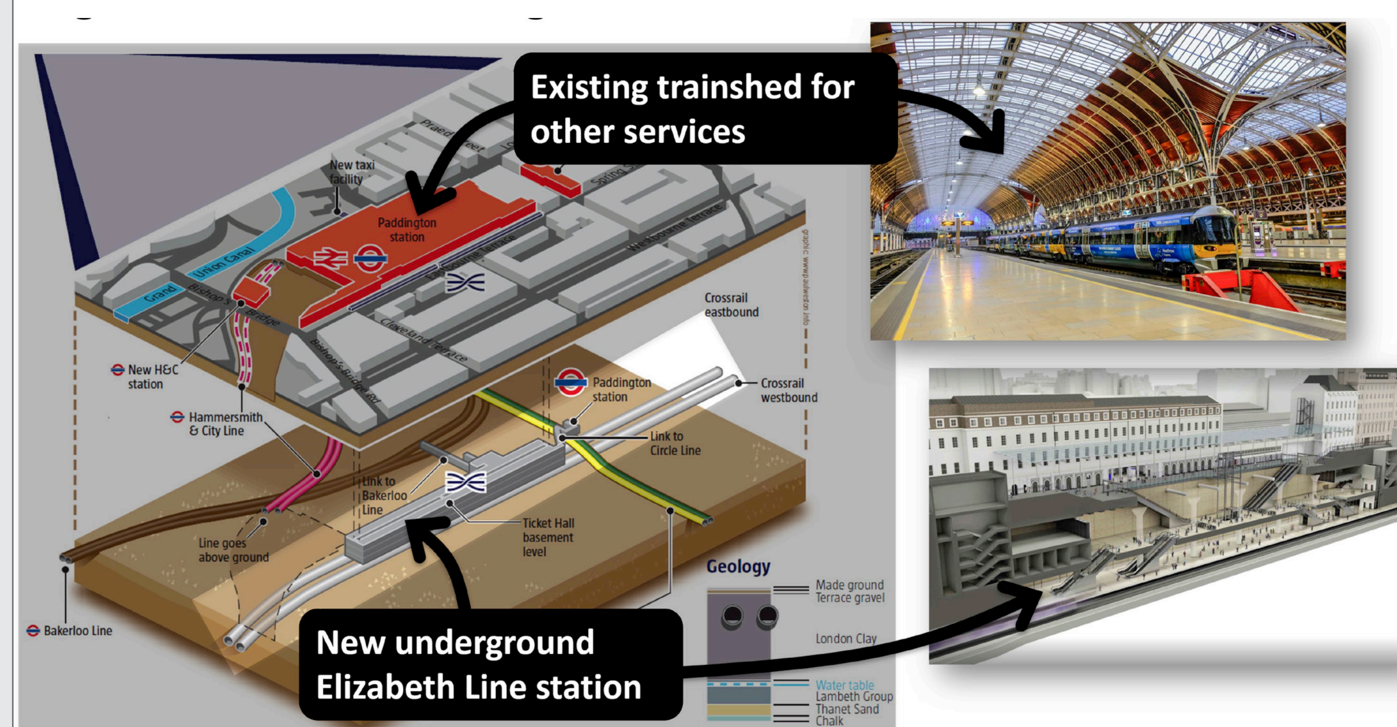


Figure 2-11
Paddington Station - London



London Thameslink

London's Thameslink is another regional north-south rail line that runs through the city center (Figure 2-12). The Thameslink network has some characteristics similar to the rail network feeding Penn Station, which makes it a useful comparison. The Thameslink route is a two-track trunk line in tunnel through central London. The common trunk line has four stations serving central London and is fed by three branch lines from the north and six branch lines from the south.

It took two decades to reformat portions of the regional rail network to create Thameslink, between the 1970s and 1990s. The initial Thamelink line proved inadequate for its ridership, and it took another decade to upgrade it to its current, much improved configuration, completed in 2018.

Less than 20% of the London regional rail network was reformatted to create Thameslink and the Elizabeth line, which intersect at Paddington Station and together form a regional metro network similar in size to those in Paris and Munich.

Thameslink provides regional metro service on the trunk line connecting close-in branch lines on the north and south sides of London. The route also handles longer-distance regional train services, which operate on a timetable at peak headways of 30 minutes.

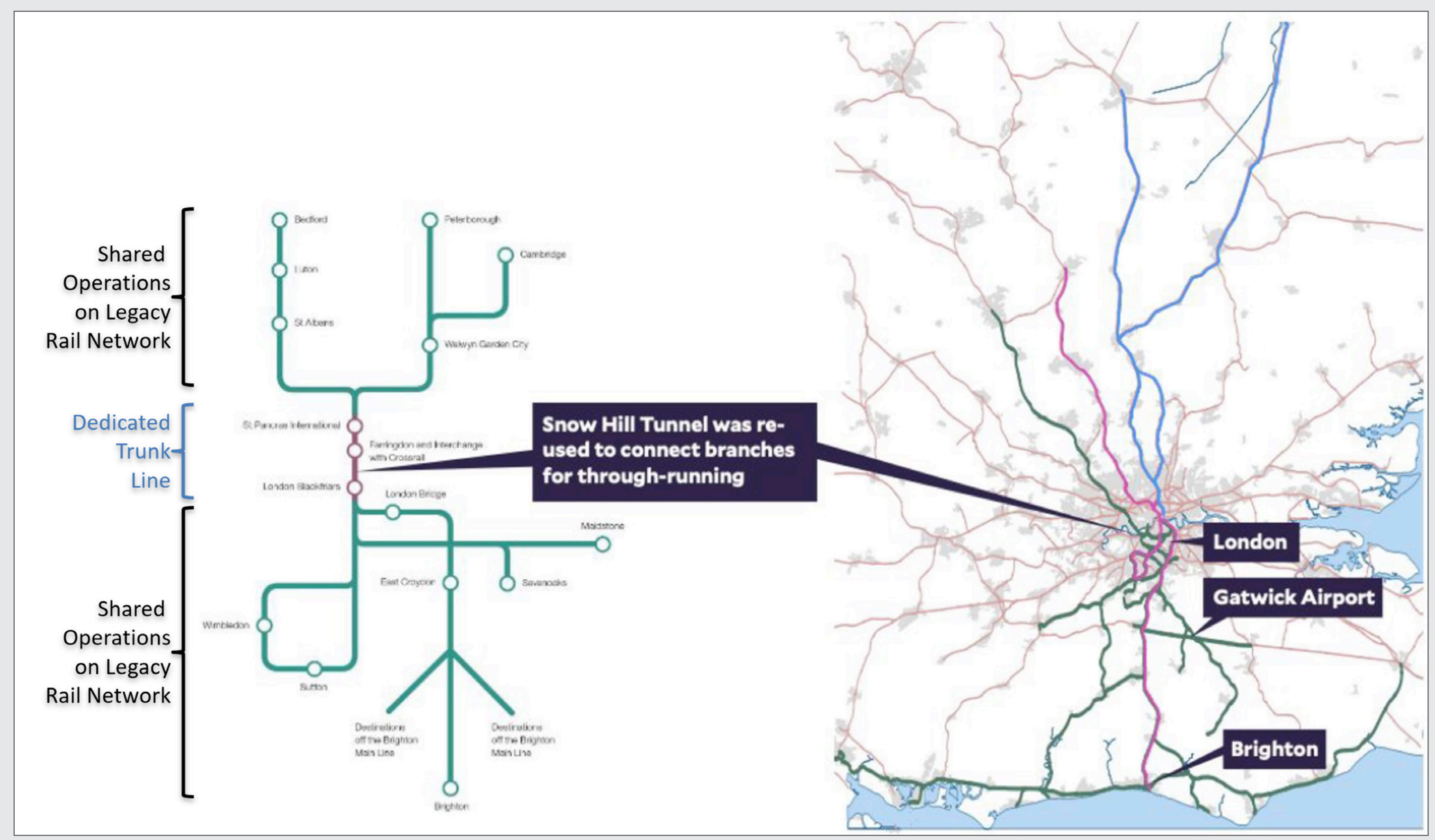
- Regional metro service in trunk and branch configuration
- Regional metro service merges with other suburban and intercity traffic beyond the trunk line
- Regional metro tracks and platforms separate from other rail services at major stations (St. Pancras International and London Bridge)
- Trains operate on timetable, with variable route lengths and frequencies, but trunk line operates like headway-based transit

Trunk line peak capacity is 24 tph. Peak headways on the outer branch lines are 15 to 30 minutes. The service operates with trains scheduled at regular, repeating clockface intervals. Though some trains operate on fixed timetables, the overall service on the common trunk line operates as a headway-based subway-style service. Late trains are either fit into available slots or are cancelled. The Thameslink train schedules do not build schedule recovery time into the dwell times at any of the trunk line stations. All trains operate on the trunk line with uniform performance characteristics, with high-capacity train doors for rapid alighting and boarding, enabling short dwell times at the trunk line stations. The services operate with dual-power rolling stock, operating under third-rail power south of London and with overhead catenary north of London. All trains on the common trunk line are operated by the same operator, which simplifies the operation of the line.

St. Pancras International Station is a major legacy station on the Thameslink trunk line. It is the most recent example of doubling the train capacity of a legacy station, so it is particularly relevant to this feasibility study (see Figure 2-13).

Originally a regional rail terminal with 6 tracks elevated above street level, it now has 15 tracks on two levels in a

Figure 2-12
London Thameslink Network

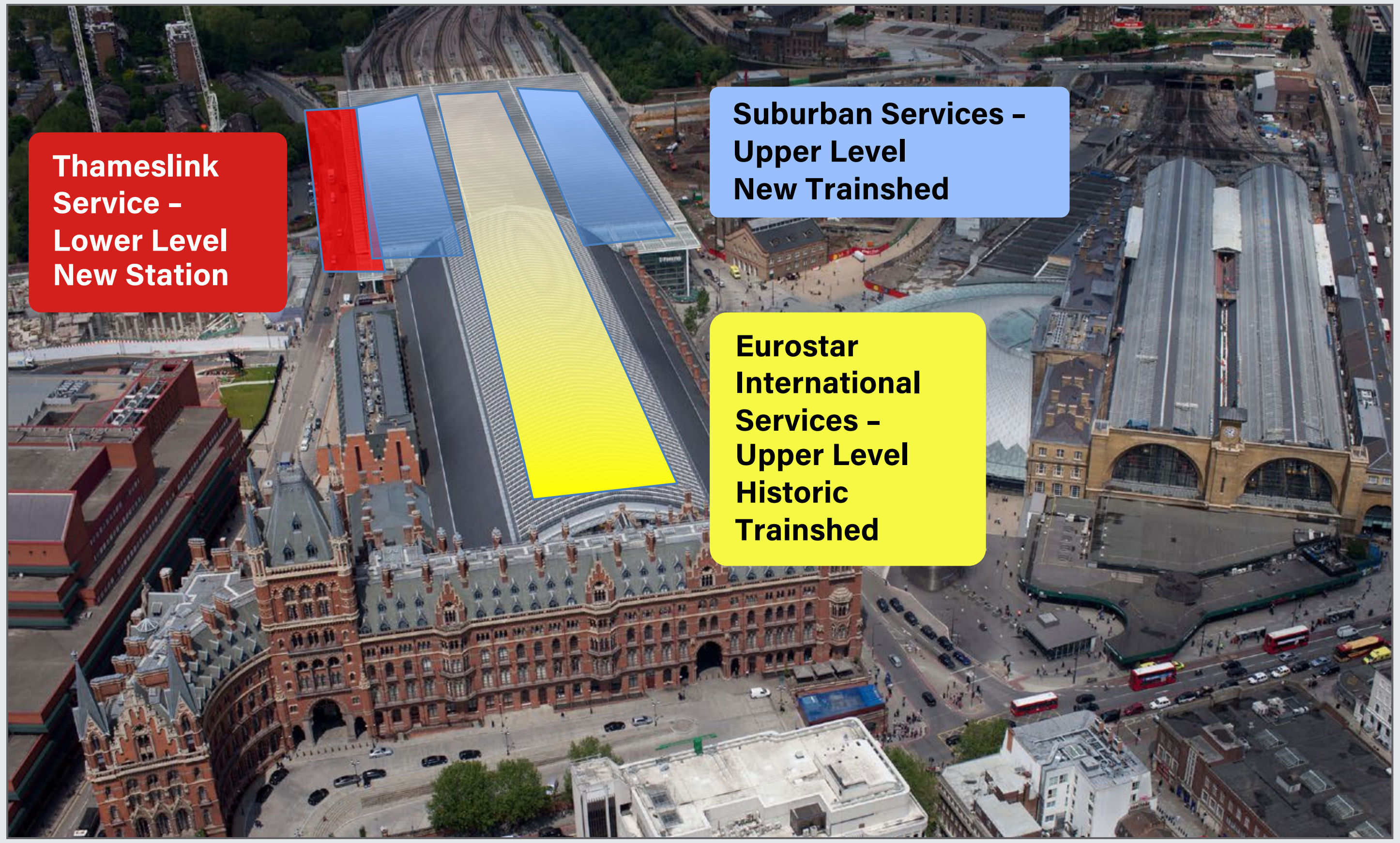


greatly expanded footprint. A modern expansion was built behind the historic train shed, over the original approach tracks, similar to that at Gard-du-Nord in Paris. Within the original train shed, the six tracks were reconstructed and their new platforms lengthened into the expansion to serve the longer Eurostar trains to Paris. The suburban services were relocated to seven new tracks in shoulder stations in the expansion, on either side of the Eurostar approach tracks. Another new shoulder station was purpose-built for Thameslink through-running service underground, below the west suburban shoulder station, bypassing the upper-level interlocking. Transfers between all the services are convenient, and the original train shed was opened to a renovated lower level, formerly station operations space, with customs control for the international trains and extensive retail amenities.

Introducing two new services at St. Pancras — Eurostar and Thameslink — required expanding the station to add more tracks and platforms in conventional terminal service and a new, separate shoulder station for the Thameslink through-running service, with all other services continuing to terminate at the station. The Thameslink route joins the railway main line away from the throat area of the legacy station. At the south end of the Thameslink trunk line, the major through station at London Bridge was rebuilt to provide separate, dedicated tracks for Thameslink service operating through this station.

Figure 2-13

St. Pancras International Station — London Thameslink



Philadelphia Regional Rail

Philadelphia was originally served by two separate commuter rail networks each operating out of their own stub-end terminals in Center City. The Pennsylvania Railroad terminated at Suburban Station, and the Reading Railroad terminated at Reading Terminal. Operation of these regional passenger rail services subsequently passed to SEPTA, a public authority of the Commonwealth of Pennsylvania. These commuter rail services are in addition to Amtrak NEC service, Amtrak Keystone Service to Harrisburg, PA, and NJ TRANSIT's Atlantic City line, all operating out of or through the lower level of what is now Amtrak's 30th Street Station. The Pennsylvania Railroad's Main Line, originally an intercity and freight service and later a passenger operation serving the wealthy suburbs of the city, also terminated at the upper level of 30th Street Station.

SEPTA's Center City Commuter Connection (CCCC) project constructed a 1.7 mile-long, four-track tunnel under Philadelphia Center City, completed in 1984, enabling through-running between the Pennsylvania Railroad and Reading Railroad termini and the upper level of 30th Street Station, and functionally eliminating the stub-end terminals in favor of three trunk line stations. The system was modeled on the German S-Bahn regional metro concept, pairing the six former Pennsylvania Railroad branch lines with the seven former Reading Railroad branch lines, each intended to operate as a single line continuous through the Center City trunk line. The branches extend out an average of 24 miles from Center City, somewhat shorter than the European examples discussed in this chapter.

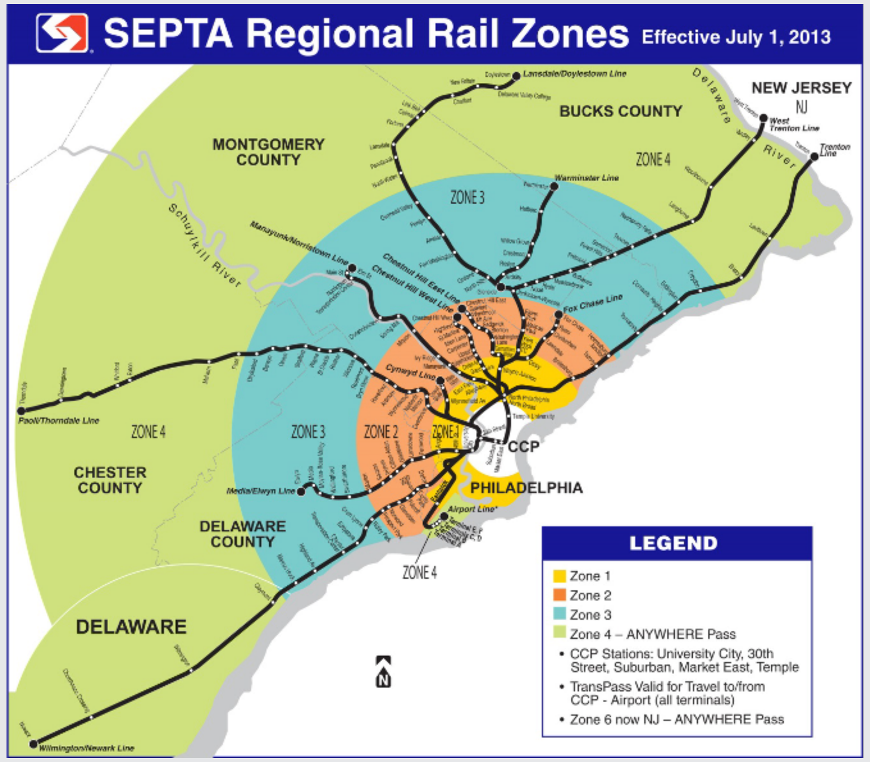
The downtown operation included crew changes at one of the downtown stations, which was accomplished within a three-minute dwell time. The system was designed to operate up to 22 tph on each of the four tracks, with directional capacity of up to 44 tph in the peak hour. Figure 2-14 shows the network of SEPTA regional rail lines.

The CCCC route through Center City is shown in Figure 2-15, serving three main stations in the urban core. A new underground, four-track, through-running station, called Market East Station (now renamed Jefferson Station) replaced the stub-end Reading Terminal. Suburban Station in the heart of Center City was converted from a stub-end terminal to a through-running station. Four of the eight tracks at Suburban Station were connected to the connector tunnel. The remaining stub tracks are used for SEPTA trains that terminate in Center City. The connector tunnel extended west to include the upper level of 30th Street Station.

The Center City Connection project was able to take advantage of the existing railroad configuration at 30th Street Station, where the SEPTA Main Line commuter service was on an upper level of the station and the Amtrak and NJ TRANSIT intercity rail services were on a lower level of the station, on different sets of tracks and platforms. Amtrak's 30th Street Station demonstrates the same separation of regional metro and intercity train operations that is present at the other international stations that were researched as best practice examples. The other two stations on the trunk line handle only regional rail, so the connector is free to operate at high frequency without conflicts with other types of service. Integrating the operations of the two separate regional networks resulted in operational efficiencies and the ability to deploy trains flexibly throughout the system to meet market demand.

- Links all regional branch lines with single trunk line through Center City
- Trunk line serves only regional trains — intercity trains operate to separate station facilities
- Does not currently operate as through-running regional metro
  - Regional network infrastructure investment has been insufficient to support reliable headway-based service across the entire network
  - Limited demand for through service

Figure 2-14
SEPTA Philadelphia Regional Rail Network



On paper, this network was a good candidate for completely converting to regional metro service. The CCCC project was successful in providing new capacity and reliability of rail service through the central trunk line and made it possible for passengers to reach different points in Center City, resulting in an initial increase in ridership.

However, the regional metro vision of 40 years ago still has not been realized. While the shape and scale of the Philadelphia regional rail network would seem to be able to support regional metro service, the ridership market for cross-regional rail service did not materialize in the way that was envisioned. There is strong commuter ridership to the three Center City stations on the trunk line, but there is a wide disparity between peak-direction and reverse-peak-direction ridership, with generally much less demand for suburb-to-suburb travel. Fully 95% of all rider trips originate or terminate in Center City. The capital investment required to provide frequent, reliable, headway-based service over the entire network was never made, so the capacity still does not exist across the network to deliver frequent headway-based rail service on all branches, and lingering state-of-good-repair needs have hampered both line capacity and service reliability. Aligning travel markets with rail service frequencies on both ends of the trunk line has proved difficult, adjusted many times in generally unsuccessful attempts to achieve an economical balance. The paired branch lines have been discontinued in favor of service that is more customized to the demands of each branch line, with inter-line transfers available at any of the three core stations. SEPTA no longer brands the system as a through-running network, but rather as a conventional regional rail network, naming each branch for its outer terminus and even publishing its ridership statistics measured to and from Center City.

Though originally well-conceived, the CCCC project provides an important lesson: creating a productive and successful integrated regional rail network requires system planning and investment across the entire network to provide the necessary capacity and utility that will attract increased ridership. Targeting investment on the core trunk line and stations only will not automatically achieve travel benefits across the full network.

There are some key differences between the Philadelphia Center

Figure 2-15

Philadelphia Center City Commuter Connection

Source: NORTH SOUTH RAIL LINK

City Connection and the rail route through New York's Penn Station. The rail network serving Philadelphia is smaller and less densely-utilized than the network serving New York. Branch lines in Philadelphia are shorter, and the extent of longer-distance suburban service is much more limited. Ridership markets are smaller than New York, with shorter trains and generally lighter passenger loads. Also, the Center City Philadelphia trunk line serving the three core stations is limited exclusively to regional metro trains, which have similar operational characteristics. Intercity trains do not operate on these routes, greatly simplifying operations.

Toronto GO Expansion

The regional transportation agency for greater Toronto, Metrolinx, is investing in a major capital program to convert the regional rail system, formerly known as the Toronto GO system, to a combination of regional metro and traditional commuter service. The new regional metro network was originally called GO-RER, taking inspiration from the Paris RER system, but has now been re-branded as GO Expansion, reflecting a change in emphasis that mirrors the change in emphasis in Philadelphia. Re-evaluating their original premise, Metrolinx's emphasis is now on delivering two-way, all-day service every 15 minutes or less over five of its seven core branches that they now believe can support frequent, bi-directional service. Two branch lines, which have limited capacity for bi-directional operations, will continue to provide service focused on weekday peak travel to downtown Toronto.

- Connects to all regional rail lines
- Regional metro will be implemented using newly-built track and platform infrastructure at Union Station
- Station will continue to serve longer-distance commuter and intercity trains
- System-wide major investment to enable inter-operability and support headway-based regional metro service

Figure 2-16 depicts the network of regional metro lines, which has its focal point at Toronto Union Station, directly serving the Toronto central business district. Union Station is the third busiest rail station in North America after New York Penn Station and Grand Central Terminal, handling about 300,000 daily passenger trips. The future GO Expansion network will connect four branch lines to the west of Union Station and three branch lines to the east. Service on the regional network will be a combination of regional metro and more traditional suburban commuter rail service.

Like Penn Station, the existing Union Station had been originally designed for long-distance train service and was ill-suited for through-running regional metro service, with narrow platforms and limited vertical circulation for passengers to and from the platforms, so the existing station tracks and platforms will be completely reconfigured, and new

Figure 2-16

Toronto — GO Expansion — Regional Metro Network

tracks and platforms are being added adjacent to the existing tracks. The track and platform layout will be customized to support through-running regional metro on dedicated tracks, through-running suburban and intercity service on other tracks, and suburban and regional metro turnback service on dedicated stub-ended tracks. Also like the New York/New Jersey regional rail system, the GO network includes both short and long branch lines. Four branch lines will operate all-day, through-running regional metro service on the inner portions of the line, with traditional commuter trains during peak periods serving the outer portions of each line and running express through the inner zones. One branch line will operate regional metro service that turns back at Union Station. Two branch lines will continue to operate peak-only commuter service to and from Union Station.

The capital program also includes major improvements to the entire rail network, including line electrification, 93 miles of new track capacity, new stations, bridges and tunnels, extending some of the branch lines, grade crossing eliminations, removing capacity bottlenecks and acquiring new rolling stock. The program is expected to take 10 years to construct, estimated to cost $13.5 billion in 2017 Canadian dollars. The GO Expansion is being delivered by an international consortium selected as the Private Partner, in a progressive design, build, operate and maintain format, or DBOM. Progressive means that there is a two-year development phase, which began in 2022, in which the Private Partner, working with Metrolinx, is defining the scope of the project, how the network will operate, and the commercial terms and structure. Certain early tasks such as eliminating grade crossings and work in the train shed at Toronto Union Station have begun during this development phase. The actual cost will be negotiated with the Private Partner during the development phase, including the construction costs and how much the Private Partner will be paid for operating and maintaining the system over an agreed timeframe.

Figure 2-17

Toronto Union Station

As is the case in New York, the future full regional rail network in Toronto will need to serve multiple types of passenger rail service, including:

- Through-running regional metro
- Airport express trains
- Longer distance suburban trains
- Intercity trains
- Long-distance cross-country trains

The GO Expansion project at Union Station includes improvements to the tracks, platforms, interlockings, concourses, and passenger access. It features two new wide platforms and the reconfiguring and widening of tracks and existing narrow platforms in the station. It also includes new and wider concourses, a new lower concourse, new skylights around the perimeter of the building to bring in daylight, and new passenger amenities (Figure 2-17). Frequent bi-directional train service on the five principal branches will be an important feature of future operations at Union Station.

Worldwide Best Practices Summary

Key characteristics of the Paris RER, Munich S-Bahn, and London Crossrail systems are listed in Table 2-2. These successful regional metro systems all share a number of common features:

- A new service type that complements, but does not replace, traditional commuter, intercity, or international service types
- Headway-based operations, with trains running at regular, repeating intervals
- Transit-style service, with all trains making all local stops and with short station dwell times
- Routing around or below existing terminal interlockings
- Uniform rolling stock types and performance
- Limited number of branch lines feeding a central trunk route
- Relatively short branch lines, generally serving urbanized areas
- Regional integrated fare payment systems

Regional metro service using the trunk and branch route configuration represents the standard solution for cross-regional connectivity, as seen in the international examples cited above (Paris, Munich, and London). This type of service operates best along the trunk line as a self-contained transit line, offering high-density, headway-based service with uniform train performance and station dwell time characteristics along corridors that can support high-density through service.

In four-track systems, regional metro trains can run on the local tracks through denser, more urbanized areas closer to the urban center, which permits higher frequency of service, with longer-haul commuter trains running on the express tracks, bypassing the regional metro stations. In two-track systems, regional metro trains must share the tracks with the longer-haul commuter trains, which generally constrains metro service frequency to 15-minute headways and precludes express operations of the commuter trains. If more frequent headways are justified by market demand, then investment in expanding to a four-track system has proven to be necessary and economical.

Multiple metro branch lines feed a trunk line that runs through the city center on headways as short as 2 minutes if reserved for metro trains only, sometimes serving multiple trunkline stations. Stations along the trunk line route can become major hubs and economic activity nodes, since direct rail service is available to all branches that feed the trunk line. The trunk and branch concept does not eliminate the need for transfers for passengers traveling between suburbs beyond the limits of the trunk line or to destinations not served by the metro line they originated on. Major cities such as Paris and London have multiple regional metro trunk lines.

Regional metro service typically does not operate within the original historic train sheds. Serving regional metro and other passenger rail services at separate facilities acknowledges the significant differences that exist in the operational characteristics and passenger behavior characteristics of these service types.

The major legacy rail stations that host regional metro service also have similarities:

- Purpose-built new trackways and station infrastructure to support through-running, generally below and/or adjacent to the legacy train station
- Intercity, long-distance and longer commuter services generally retained at the legacy train station

At major stations within the urban core, regional metro trains operate on a dedicated alignment, bypassing terminal interlockings, with tracks and platforms dedicated to the regional metro service, as illustrated schematically in Figure 2-18. At two example stations — Paddington Station in London on the Elizabeth Line and the Hauptbahnhof (main train station) in Munich — the schematic cross-sections in Figure 2-19 show the relationship of purpose-built regional-metro tracks and platforms with the original traditional portions of the train station used by other suburban and intercity services.

Figure 2-18

International Best Practice Configuration for Regional Metro at Major Rail Stations

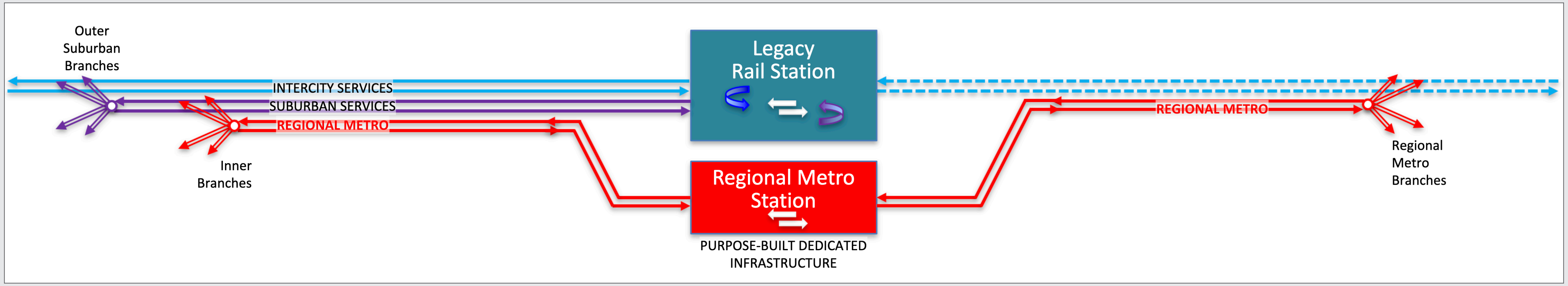


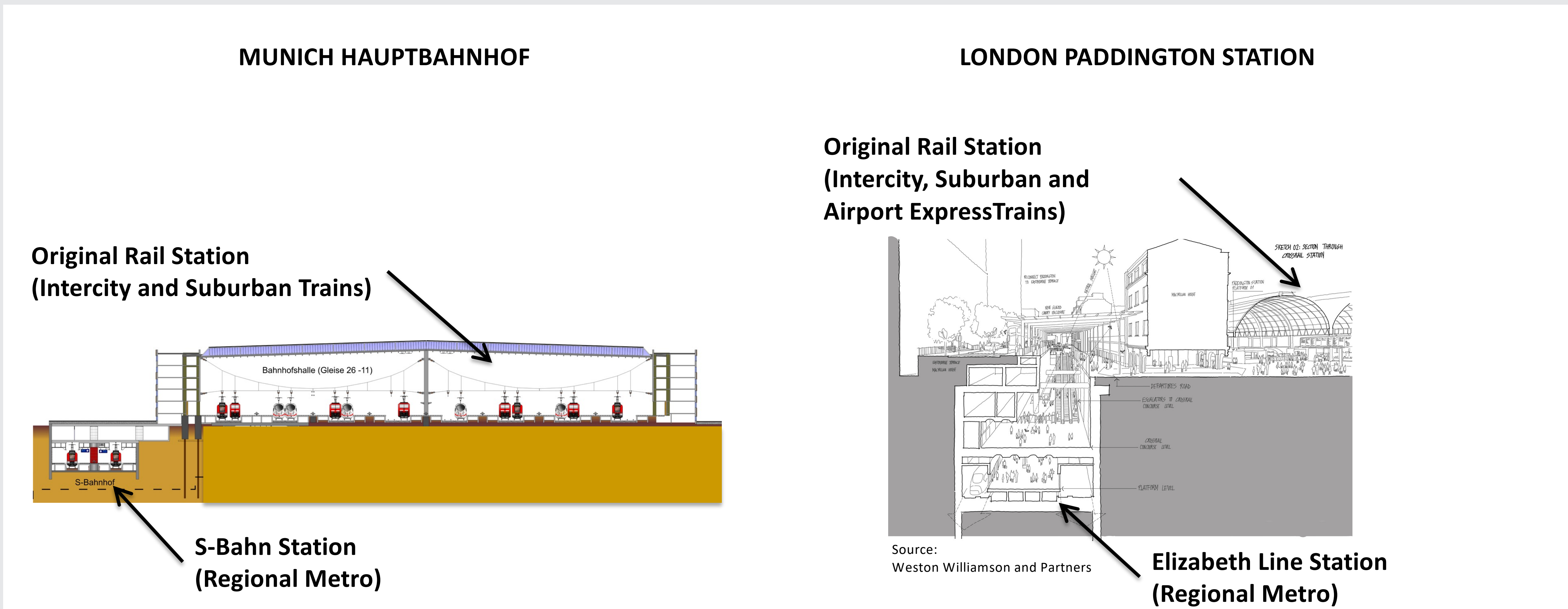
Table 2-2

Key Characteristics of Selected Through-Running Regional Metro Services

Successful examples of Through-Running	London—Crossrail (Paddington & Liverpool Street stations)	Paris—RER Line B/D (Gare du Nord station)	Munich—S-Bahn (Hauptbahnhof & Ostbahnhof stations)
Investment in new tracks and wider platforms in new shoulder stations adjacent to legacy rail terminal to enable through-running	✓	✓	✓
Through-running transit-style service separated from longer-distance legacy service	✓	✓	✓
Network Complexity — Branches on both sides	2 branch lines on West end (20-58 km) and 2 branch lines on east end (up to 80 km)	3 branches to the North end and 4 branches to the South end	7 branches to the West end and 5 branches to the East
Service type (headway- or timetable-based)	Headway-based	Headway-based	Headway-based
Peak-hour average headways in the trunk section	2.5 minutes	1.5-2 minutes	1.5-2 minutes
Peak-hour dwell times	45-60 seconds	50-60 seconds	33-45 seconds
Platform Width sufficient to accommodate arriving and departing passengers simultaneously	✓	✓	✓
Uniform rolling-stock performance	Yes	Yes	Different sets of vehicles
Other non-through-running service at major stations, using legacy platform tracks separate from regional metro	All services by train operators other than Crossrail/Elizabeth Line (suburban and intercity)	Transilien routes H & K (suburban) TER service (regular intercity) TGV service (high-speed rail)	RB (local suburbs & adjacent cities) RE (limited-stop regional express) IC (regular intercity) ICE (high-speed)

Figure 2-19

Major Station Cross-Sections



Application of Worldwide Best Practices to New York Region

The international-standard regional metro model described above would be the most reasonable fit for the New York region, the configuration of the existing rail network, and the regional travel markets that need to be served. Regional metro for the New York metropolitan region could include a central trunk line across Midtown Manhattan in the 30th to 34th Street corridor, serving Penn Station and having multiple branches both west and east of Manhattan. Convenient transfers to other rail and transit services would be available at Penn Station and potentially at other locations along the trunk line. This concept best represents the type of investment and operation seen in the most successful regional rail networks around the world. Table 2-3 presents key statistics for several urban metropolitan areas with rail networks providing or supporting regional metro service and presents comparable statistics for the New York metropolitan region.

Despite some similarities, it is important to note that the extent of the rail service territory served by Penn Station is much larger and the routes are much longer than those covered by the RER in Paris, Crossrail in London, and the Munich S-Bahn. This can be easily appreciated in Figure 2-20, which compares graphically the extent of these three existing regional metro networks with the full New York regional network, at the same scale. Each of the three European cities supports a much larger suburban and intercity rail network than the territory over which through-running regional metro trains operate. The full rail networks feeding the main train stations in Paris, London, and Munich cover distances comparable to those that feed New York Penn Station, but regional metro only covers selected portions of that network, primarily focused on branches close to the city center.

Also, not all branches and service zones in the New York metropolitan region have potential demand sufficient to support the service frequencies required for headway-based service, so the regional rail network cannot be completely converted to regional metro and still be run economically. The potential demand for transit-like service decreases in more distant, less dense suburban markets. Whereas there are numerous markets in the inner, more urbanized metropolitan areas that likely can justify high-frequency service in both directions during peak hours and increased service frequency during off-peak hours, markets farther out cannot. Including more distant markets in such service would result in both peak-direction and reverse-peak direction trains running with too few passengers over much of their routes to be economically viable, a difficulty that SEPTA in Philadelphia has wrestled with for almost 40 years now.

Although market demand for travel within and between the outer counties of the region may be growing, the mode of transportation to serve such markets needs to be right-sized to the market potentials. Frequent service with 12-car trains can be a highly uneconomical modal choice for small markets. Buses, bus rapid transit (systems where traffic signals prioritize buses to obtain higher speeds and shorter travel times), or light rail targeted more specifically to different routings such as circumferential patterns and timed transfers are generally a better match. The Hudson-Bergen Light Rail line in New Jersey, though not complete as planned, is a good example. Another is the Interborough Express, a proposed light rail line between Brooklyn and Queens currently in planning by MTA. Both are local examples of service right-sized to their markets.

Perhaps the foremost example of a right-sized public transportation system in the U.S. is TriMet, which serves the Portland, Oregon metropolitan region, an area with a total population of 2.2 million. This is a region with significantly less traditional commuting than the New York metropolitan region and greater inter-suburban travel. TriMet operates only a single heavy-rail commuter line, with five light-rail lines and 85 bus lines providing service to multiple destinations, serving multiple travel markets. The light rail lines and 17 of the bus lines operate on 15-minute headways or less, with 58 percent of bus trips on the frequent service lines. A total of 17 transit centers facilitate timed-transfers between bus and light rail lines. The success of the TriMet system as a widely distributed network with four different service types reinforces the perspective that heavy rail is not necessarily the best mode to accommodate multi-destination travel markets in more lightly-populated areas.

A robust network of longer-distance suburban routes and expanded Amtrak intercity services, also operating through a major connectivity hub at Penn Station, would complement the regional metro service. Because of their different operating characteristics, Amtrak intercity services cannot be easily blended with frequent, transit-style service, even though all of its peak period trains already run through Penn Station. None of the successful regional metro examples we have studied blends headway-based regional metro with timetable-based suburban and intercity service on shared tracks through major stations with shared platforms. Stations have uniformly been expanded to accommodate the new regional metro service, with legacy commuter and intercity services continuing to use the legacy platforms. Toronto Union Station is a good example of a major rail hub with hybrid rail operations, including both turnback and through-running service and purpose-built infrastructure, where regional metro trains will utilize platforms separate from those used by intercity and suburban trains, but where all three types of service will operate together on the tracks feeding Union Station.

Converting the entire regional rail network to be fully integrated and interoperable would also be prohibitively expensive. A comparison with the cost of the Toronto GO-RER conversion is a useful reference point. The 10-year GO Expansion project to make their regional metro network interoperable and satisfactory for the planned new service model was estimated to cost approximately $13.5 billion. To a rough approximation, the full New York metropolitan regional rail network centered on Penn Station

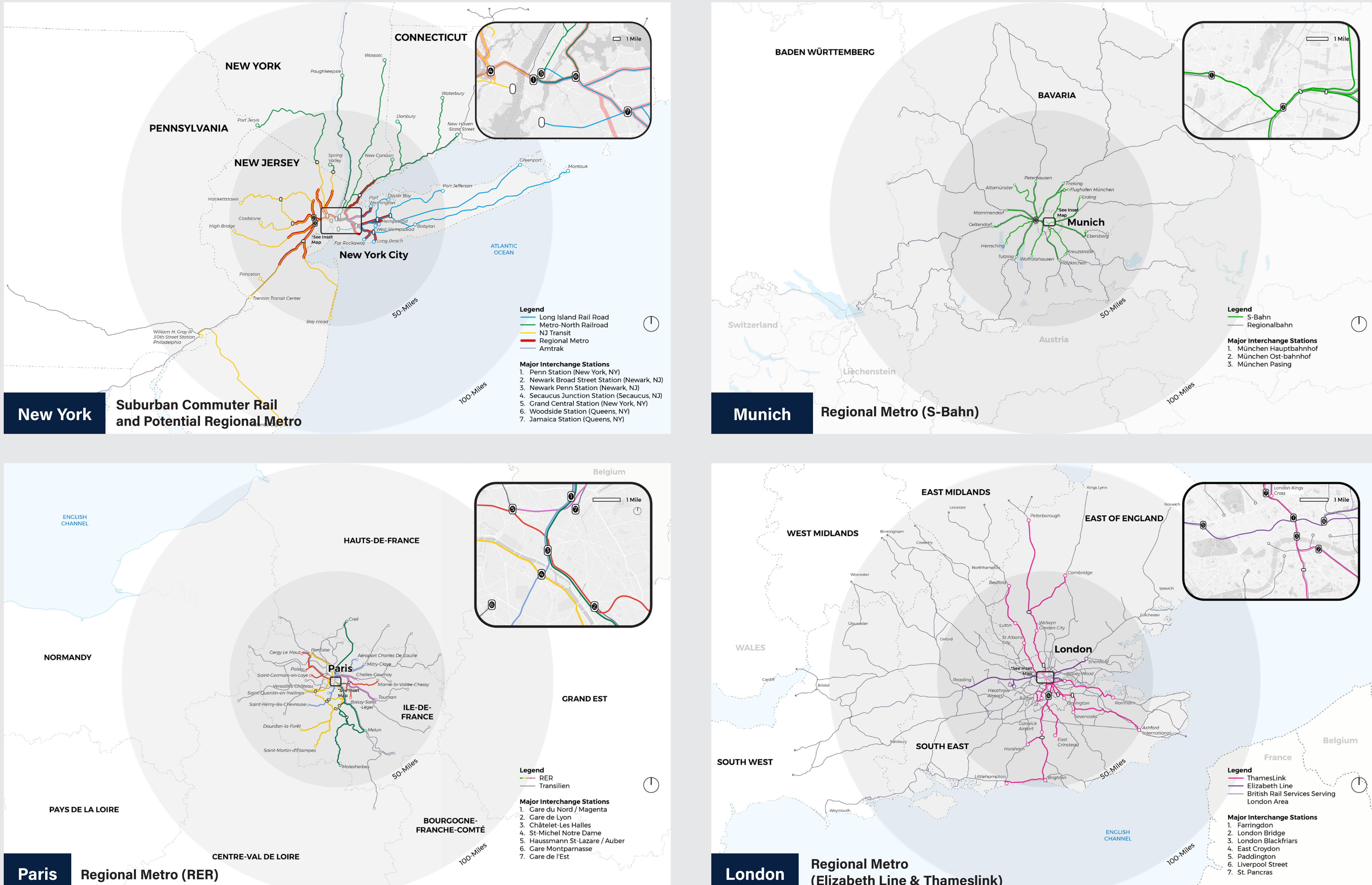
Table 2-3

Comparative Statistics for Metropolitan Areas with Regional Rail Networks

Metropolitan Region Data	Paris Ile de France	London Metropolitan London	Munich Munich Metro Area	Toronto Greater Toronto Area	Philadelphia Philadelphia CSA	New York Metro Region New York MSA
Region Size (square miles)	4,617	3,870	2,074	2,750	4,603	6,685
Population	12,329,432	14,372,596	2,935,114	6,711,985	6,107,906	19,768,458
Employment	5,525,000	7,223,000	1,377,000	3,568,500	5,041,350	16,032,587
Rail Network Data						
Regional Rail Network (through-running)						
Lines Branches	5 22 — RER A, B, C, D, E	2 13 — Elizabeth Line & Thameslink	8 14 — S-Bahn	3 5 — GO-Expansion	8 13 — Regional Rail	N/A
Suburban Network (non-through-running)						
Lines Branches	6 20 — Transilien Service (stub-ended at Paris terminals)	60 — Branch service by other regional operators	14 — RB (local) Routes	1 — Richmond Hill Line 1 — Milton Line 4 — Line extensions	1 — PATCO Line 1 — Atlantic City Line	26 — To Penn Station 18 — To other terminals
Major stations / terminals	6	13	3	1	3	6
Total Branch Line Services	**42**	**73**	**28**	**8**	**15**	**44**
Network Route Data						
	Regional Metro Only	**Regional Metro Only**	**Regional Metro Only**	**Full Network**	**Regional Rail**	**Full Network**
Network Route Mileage	365	456	270	327	223	1,067
Stations	257	195	150	68	155	409
Branch Length — Minimum (miles)	13	12	16	29	6	20
Branch Length — Average (miles)	37	38	35	47	24	54
Branch Length — Maximum (miles)	75	78	46	82	41	118

Figure 2-20

Regional Rail Network Scale Comparison — New York, London, Paris, and Munich



These factors suggest that we should expect a full network conversion in the New York metropolitan region to cost as much as $60 to $70 billion, disrupting rail service for 15 years.

is more than three times the size of the GO network, and far more complex. Implementing a fully-integrated regional rail network would entail extensive infrastructure design and operations analysis, environmental study, reaching cross-operation agreements between the railroads, and securing funding, all processes that are subject to delay — amplified by the scale and complexity of the network. The construction period would be at least 15 years, so the midpoint of construction here would lag behind that in Toronto by at least 10 years, inflating the cost basis by the same amount compared with Toronto's. These factors suggest that we should expect a full network conversion in the New York metropolitan region to cost as much as $60 to $70 billion, disrupting rail service for 15 years.

The incremental benefits of full network integration above the benefits of converting only a portion of the network to support regional metro service would not justify such a high cost. Funding, if it could even be obtained, would have to be spread out over multiple five-year federal and state funding cycles. Disruption of the regional rail system for this long would create hardships for regional travelers. Taken together, these observations highlight the need to right-size a regional metro system while maintaining conventional legacy services, as the successful systems in the European case studies have done.

Based on our review of international best practices, the future cross-regional rail network for the New York metropolitan region, focused on Penn Station, should include three types of rail service:

- Regional metro in a headway-based trunk and branch configuration, serving NYC and the inner suburbs
- Suburban trains covering the full commuter territory with timetable-based service
- Intercity trains providing express, regular and long-distance service

Regional metro ideally should operate through the trunk line and at Penn Station on dedicated tracks, separate from those handling suburban and intercity trains.

3 Evaluation Methodology

To arrive at the potential concepts for maximizing rail capacity at Penn Station by adapting the station within its existing footprint, the WSP/FXC Team took the two alternatives that the Partners identified and developed various design concepts for each. While each alternative conceivably has an infinite number of potential variations, many of those would be similar in physical design, operation, and impact. Therefore, the WSP/FXC Team identified four design concepts that are suitably different from one another and together provide decision-makers with a full picture of the possible ways the station could be adapted to increase capacity and connectivity.

Screening Criteria and Process

The WSP/FXC Team evaluated each of the four design concepts in this report against a set of screening criteria to identify feasible alternatives that will be studied further in a subsequent phase of the Penn Station Capacity Expansion Project. A separate, future analysis will assess the feasibility of design concepts that add rail capacity by expanding the footprint of Penn Station.

To screen alternatives, the WSP/FXC Team developed a list of criteria that were applied to each design concept to determine which of the identified concepts are feasible from a technical perspective and should be studied further. The screening criteria measure characteristics that truly differentiate among the various design concepts. They are different from the design criteria discussed in the next chapter, which are critical to the design of the alternatives but do not distinguish among them; design criteria are conditions that must be met, regardless of the alternative.

The WSP/FXC Team devised a two-step process to screen the design concepts (**Figure 3-1**). First, Step 1 screening criteria were used to evaluate the design concepts based primarily on their ability to meet basic engineering feasibility and minimum operational performance requirements. These Step 1 criteria are pass-fail, used to help identify and eliminate any alternatives with fatal flaws. A classification of "pass" at this stage indicates that no challenges have been identified that prevent the alternative from proceeding for further evaluation. The criteria used during subsequent phases of the Penn Station Capacity Expansion Project will be more expansive than the technical and economic feasibility being evaluated in this report and will further refine feasibility of alternatives.

For the purposes of this report, technical feasibility fatal flaw criteria include the following:

- Can the track geometry function operationally, and can it provide connections to the existing Penn Station, the existing North River Tunnel, the future Hudson River Tunnel, and the East River Tunnel?
- Is the concept **reasonable to construct** from a structural and geotechnical perspective, without untenable impacts to existing train service, passenger flows, network operations, structures, utilities, and systems?
- Can the concept comply with governing regulations for emergency egress and ventilation?
- Can the concept provide total operational capacity sufficient to enable peak trans-Hudson rail service to increase to at least 48 tph in the peak direction (doubling the existing trans-Hudson capacity by enabling at least 24 tph in each direction through the new Hudson River Tunnel) while also maintaining existing levels of bi-directional suburban commuter services?
- Is the concept compatible with the future cross-regional rail vision that includes creating a regional metro network, maintaining longer-distance suburban commuter service, and expanding intercity service?

Under this screening process, a design concept would have to pass on all Step 1 screening criteria to advance to Step 2. Any design concept that failed at least one criterion would be deemed fatally flawed and eliminated from further consideration. Any alternative that passed all Step 1 criteria would advance to Step 2, and order-of-magnitude construction cost estimates and a rough construction schedule would be developed to ascertain the financial feasibility of those concepts.

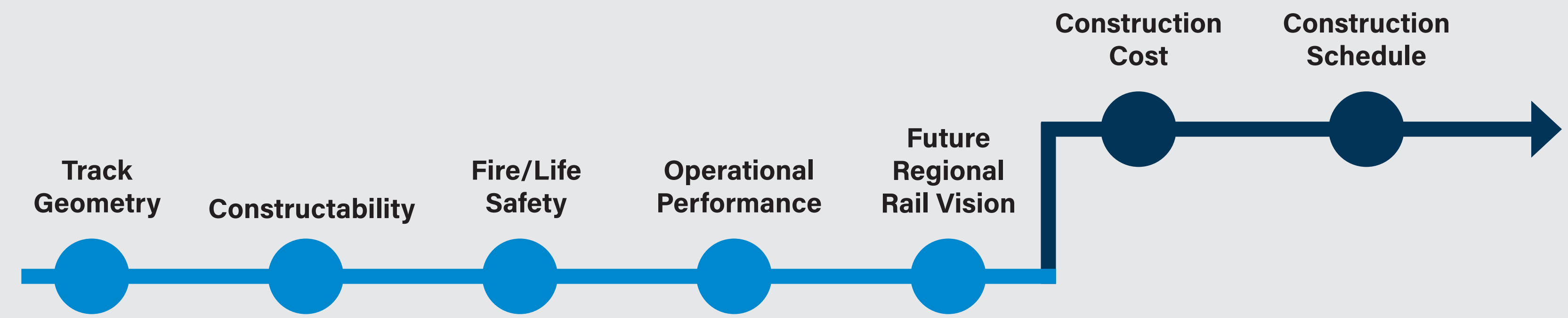
None of the four design concepts evaluated in this report advanced to Step 2.

Any concept passing the technical feasibility criteria in Step 1 and found to be economically feasible in Step 2 would be advanced as part of the reasonable range of alternatives to be considered by the Partners in the next phase of evaluation, which will lead to an environmental impact statement prepared pursuant to NEPA. The EIS will articulate the purpose of and need for the proposed action, identify and describe the reasonable range of alternatives that can accomplish the purpose and need, describe the environment of the area to be affected by the alternative(s) under consideration, discuss the environmental and socioeconomic effects of the action and their significance, and document outreach to and input from the community and other stakeholders.

Environmental and socioeconomic effects typically addressed in an EIS (though some do not apply in the urban context of New York City) include:

- Water resources, including surfaces waters, floodplains, wetlands, and water quality
- Topography, geology, and soils
- Agricultural lands
- Mineral resources
- Solid wastes and hazardous materials
- Air quality
- Noise and vibration
- Energy
- Aesthetics and visual environment
- Biological resources, including land and aquatic wildlife, habitats, and rare, threatened, and endangered species
- Community resources such as neighborhoods, community facilities, and land use, as well as effects on population, employment, and income
- Environmental justice
- Archaeological and aboveground cultural and historic resources
- Parklands, recreational areas, and refuges
- Transportation facilities
- Utilities and related services
- Public health and safety

Figure 3-1
Two-Step Screening Process



4 Technical Background

This chapter provides the technical background that supports the screening and design criteria used to evaluate the alternatives. To understand the technical implications of the various alternatives, this chapter goes into depth on the applicable technical constraints, terms, and construction methodologies. The actual assessment of the Penn Station Capacity Expansion Project alternatives begins in **Chapter 5** of the report.

Section 4.1

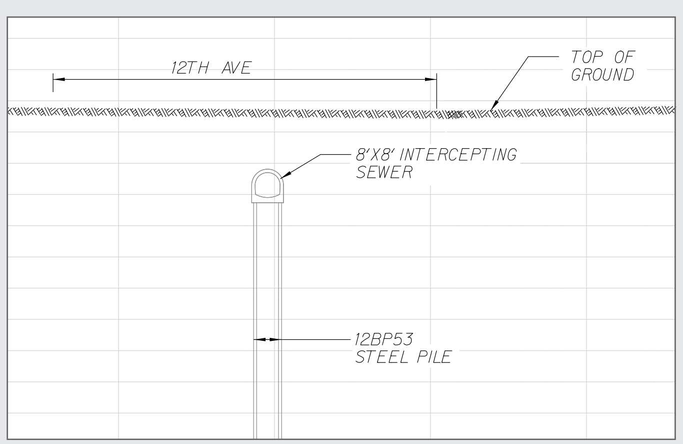
Existing Underground Infrastructure

The construction of new infrastructure for any applicable alternative discussed within this report must consider the physical location and function of the following existing underground structures.

Twelfth Avenue Interceptor Sewer (NYCDEP)

An active interceptor sewer, 8 feet by 8 feet, is located within the northbound lanes of Twelfth Avenue, running north with connectivity to the North River Wastewater Treatment Plant at 137th Street (Figure 4-1). The sewer is supported by a set of steel piles, longitudinally spaced at 5 feet centers.

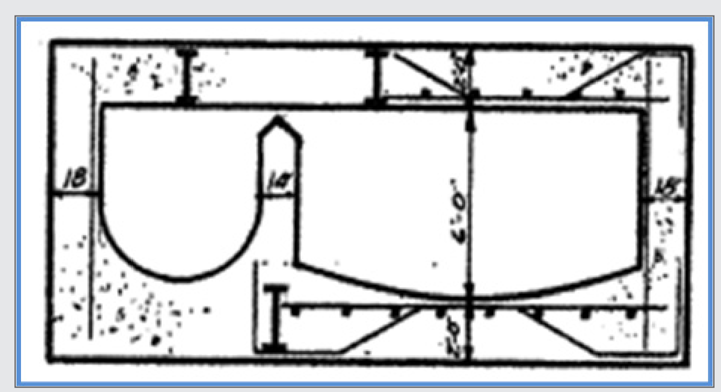
Figure 4-1
Interceptor Sewer Elevation



West 30th Street Combined Sewer (NYCDEP)

An active flat-top reinforced concrete combined sewer/storm drainage containing two tunnel cells is located under the West 30th Street right-of-way, carrying effluent to an interceptor under Twelfth Avenue (Figure 4-2). No known historic documentation of the foundation material or geometry exists; however, based on the year of construction and the poor ground conditions within this area, the foundation is likely to consist of timber piles.

Figure 4-2
Combined Sewer Cross Section



High Line Structure (NYC Parks)

The High Line was built in the 1930s as part of a massive public-private infrastructure project called the West Side Improvement. It lifted freight traffic 30 feet in the air, removing dangerous trains from the streets of Manhattan's largest industrial district. The surface of the High Line was later converted into a park and is owned by the City of New York and operates under a license agreement with NYC Parks. The superstructure and transverse bents consist of steel and span over Eleventh Avenue and the southern portion of Block 676 just north of West 30th Street, before it turns north adjacent to Twelfth Avenue (Figure 4-3). The foundations of the High Line along West 30th Street vary and consist of either circular concrete piers ranging from 5 to 8 feet 6 inches in diameter founded on rock, or clusters of timber piles with a concrete pile cap. The timber pile tip elevations are unknown.

Figure 4-3
High Line in Operation
(Eleventh Avenue and West 30th Street)

Source: Friends of the High Line

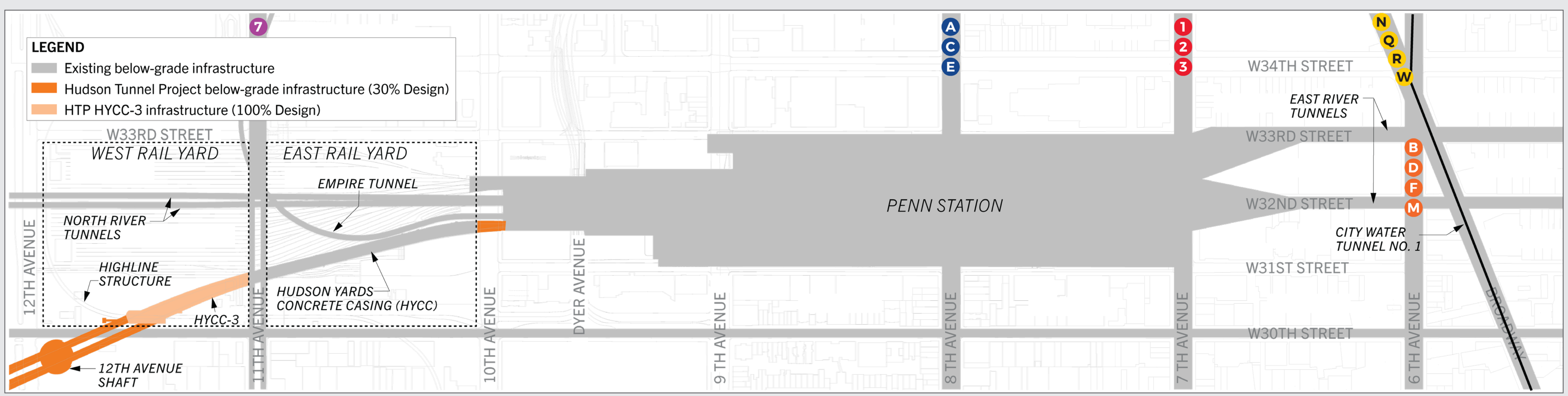
Hudson Yards Development/ Hudson Yards Concrete Casing

The Hudson Yards Development is a two-phase overbuild development over LIRR's West Side Storage Yard and adjacent areas. The first phase over the East Rail Yard was completed and opened in 2019. This first phase consists of a public green space and multiple structures. The second phase over the Western Rail Yard has not yet started construction. Related Companies and Oxford Properties are the primary developers.

Amtrak is constructing the Hudson Yards Concrete Casing, a two-cell reinforced cut-and-cover concrete tunnel, to protect the future alignment beneath the Hudson Yards Development between Tenth Avenue and West 30th Street. Construction began in 2013, and the first two segments, including the tunnel extension below the Eleventh Avenue viaducts, were completed in 2016. The approximate length of the concrete casing is 905 feet long between the west side of Tenth Avenue and the west side of Eleventh Avenue. The roof of the casing supports various overbuild columns supporting the Hudson Yards Development within the East Rail Yard and a reconstructed pier of the Eleventh Avenue viaduct. The casing is capped off at both sides with reinforced concrete endwalls, which would eventually be demolished once the tunnel is extended to the east into Penn Station and west toward the Hudson River.

Construction of the final segment of the concrete casing, known as HYCC-3, began in 2023. HYCC-3 will extend from the existing tunnel endwall at the west side of Eleventh Avenue diagonally and terminate along the north side of West 30th Street (Figure 4-4). Similar to the built HYCC structure, HYCC-3 is being excavated by cut-and-cover and will consist of two-cell reinforced concrete supporting the future overbuild columns for the Hudson Yard Development within the Western Rail Yard. This design requires temporary underpinning of the existing NYC Parks High Line Structure. The HYCC-3 tunnel roof will permanently support various High Line columns. A tunnel interface is designed at the southern limit of the HYCC-3 tunnel to provide provisions for future connectivity for the tunnels to be constructed under the Hudson Tunnel Project below West 30th Street and the future Twelfth Avenue shaft within Block 675, Lot 1.

Figure 4-4
Existing Underground Infrastructure



Empire Tunnel (Amtrak)

The Empire Connection provides Amtrak passenger service from Penn Station to Albany and beyond. It was open to Amtrak trains in 1991. The single- track tunnel connects to Penn Station just east of Tenth Avenue and travels westward until turning to the north below the Western Rail Yard (Figure 4-4). This single-cell tunnel is electrified and has a low bench walkway on both sides of the trainway. This tunnel section was constructed by the cut-and-cover method and founded in rock. The tunnel's walls, roof, and invert slab consist of reinforced concrete (Figure 4-5).

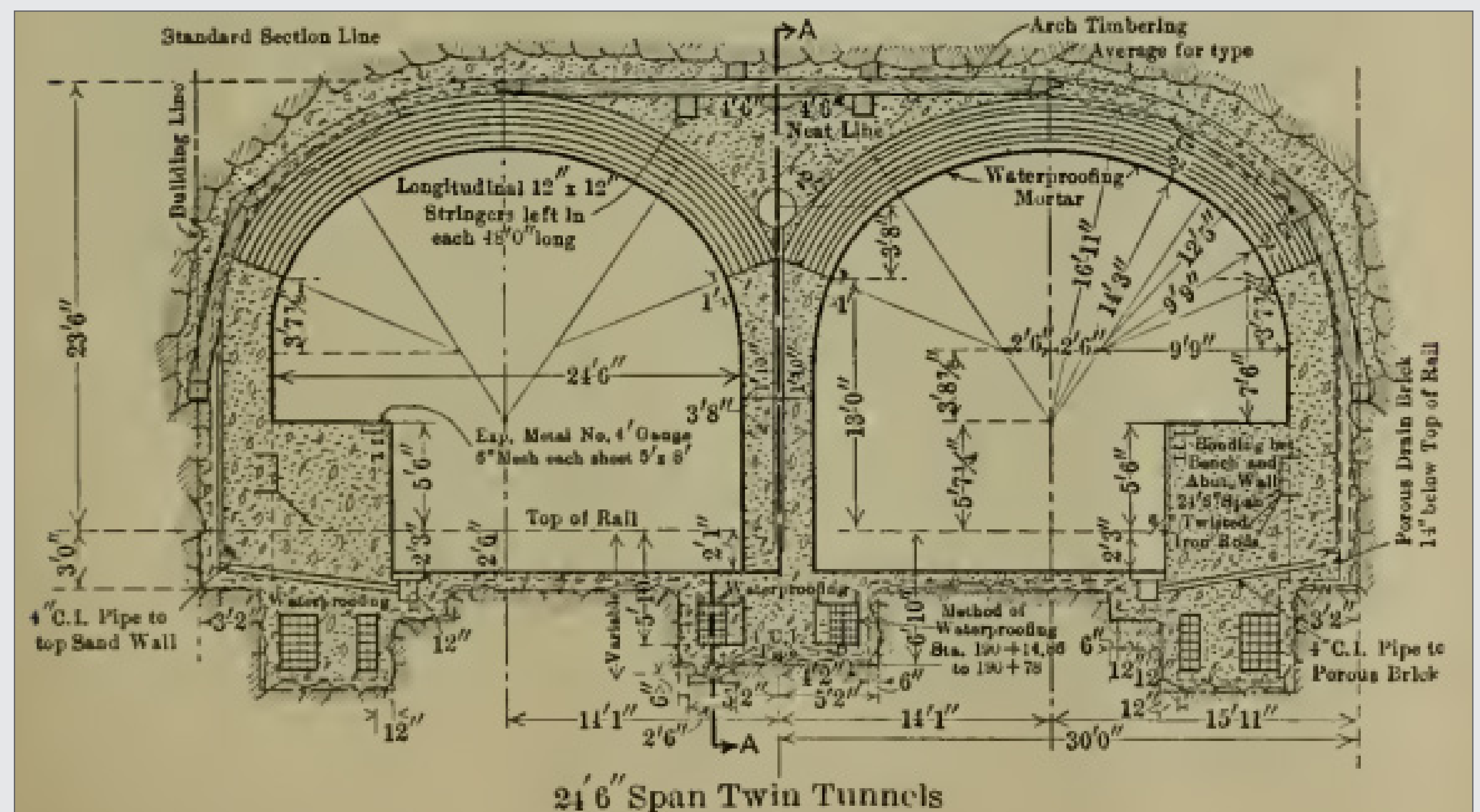
Figure 4-5
Empire Tunnel (Amtrak)

North River Tunnel (Amtrak)

The North River Tunnel was constructed between 1904 and 1908 by the Pennsylvania Railroad to allow its trains to reach New York Penn Station from Weehawken, New Jersey. It opened for service in late 1910. The Manhattan portion of the North River Tunnel commences at former Pier 72 located at Twelfth Avenue and the old West 32nd Street right-of-way (Figure 4-4). It consists of two mined single-track tubes of varying cross-sections under the old right-of-way of West 32nd Street, transitioning to cut-and-cover up to the east side of the Tenth Avenue tunnel portal in Penn Station. Tunneling construction on the land side tunnel was advanced from a temporary construction shaft east of Eleventh Avenue.

The depths of the tunnel from ground surface to tunnel crown vary 20 to 50 feet as the tunnel descends from Penn Station and below the Hudson River. The tunnel east of Eleventh Avenue was excavated by drill-and-blast methods for segments within rock and cut-and-cover methods for mixed-face condition toward Tenth Avenue. The mined tunnel consists of concrete and a brick arch. The cut-and-cover tunnel consists of concrete. The tunnel span for the single tunnel cell varies from 19 feet 6 inches to 24 feet 6 inches and typical tunnel height is around 23 feet 6 inches from top of rail to tunnel crown (Figure 4-6).

Figure 4-6
West 32nd Street Tunnel (North River Tunnel)



No. 7 Line Subway Tunnels (NYCT)

The extension of the existing NYCT No. 7 Line was opened to the public in 2015 and extended the existing No. 7 Line Subway from its previous terminus at Times Square to a new station below Eleventh Avenue and West 34th Street. A set of parallel tail track tunnels were constructed south of the new station and are 21 feet 2 inches in diameter. The tunnels continue south below Eleventh Avenue, were excavated in rock using a tunnel boring machine (TBM) and are lined with a 10 inch precast concrete segmental liner. The crowns of these tunnels are approximately 90 feet below the grade of the LIRR West Side Storage Yard.

Penn Station Utility Tunnels (Amtrak)

A series of below track level tunnels were excavated, constructed, and integrated into the Penn Station system during the original construction of Penn Station (Figure 4-6). The footprint of these tunnels is situated both parallel and perpendicular to the existing platform. They were excavated in rock and consist of reinforced concrete, generally with a rectangular cross section (Figure 4-7). The cross section dimension varies depending on the particular tunnel. They currently provide a below-track passageway for various utilities and other systems with connectivity from the Penn Station Service Building to multiple location within Penn Station.

These tunnels also provide power feeders from the Penn Station Service Building to the Weehawken fan plant (via North River Tunnel) and the First Avenue fan plant (via East River Tunnel). Amtrak's Primary Power Distribution System (PPDS) substation located in the basement of the Service Building supplies 13.2kV power to the Penn Station platform ventilation fans, the chiller plant in the Service Building, the NJ TRANSIT East End Concourse, the Eleventh Avenue Substation, the E-Yard Substation, and the tunnel ventilation facilities in Weehawken, NJ, First Avenue and Long Island City. PPDS is supplied by three 13.2kV Con Edison feeders. A series of parallel duct banks within the below-track utility tunnels run north from the Service Building and subdivide through various tunnels. The 13.2kV feeders to the E-Yard substation (below the Ninth Avenue viaduct and above track level on an elevated platform) and the Ninth Avenue Pump Room are routed through Tunnel B. The feeder to the Ninth Avenue Pump Room (in C-Yard adjacent to West 33rd Street) turns north from Tunnel B into Tunnel No. 5. As shown in Figure 4-8, numerous conduits, cables and pipes (water lines, fire stand pipe steam lines, drain and sewer lines) are installed along the walls and overhead in Tunnel B and Tunnel No. 5 and are particularly crowded in Tunnel No. 5. Recently installed 480V feeders and fiber optic cables are also routed from Moynihan Train Hall to various locations within and below Penn Station.

Figure 4-7
Utility Tunnels (Penn Station)

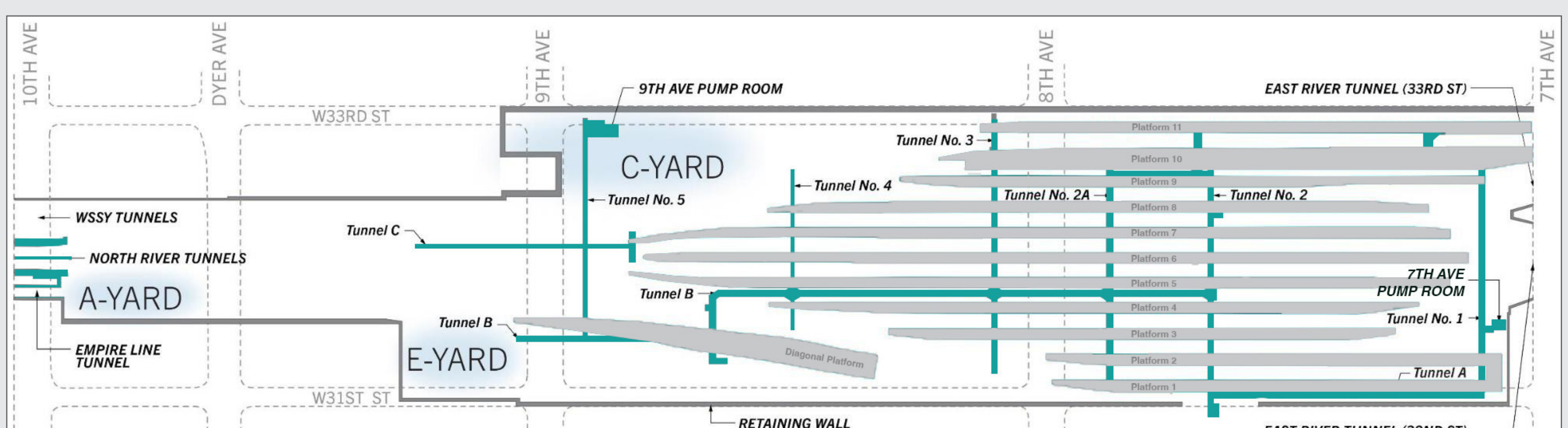
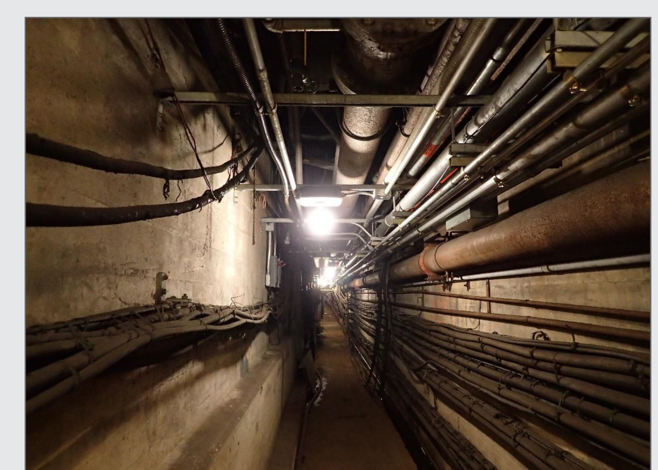


Figure 4-8
Photo of Utility Tunnel No. 5 (Penn Station)



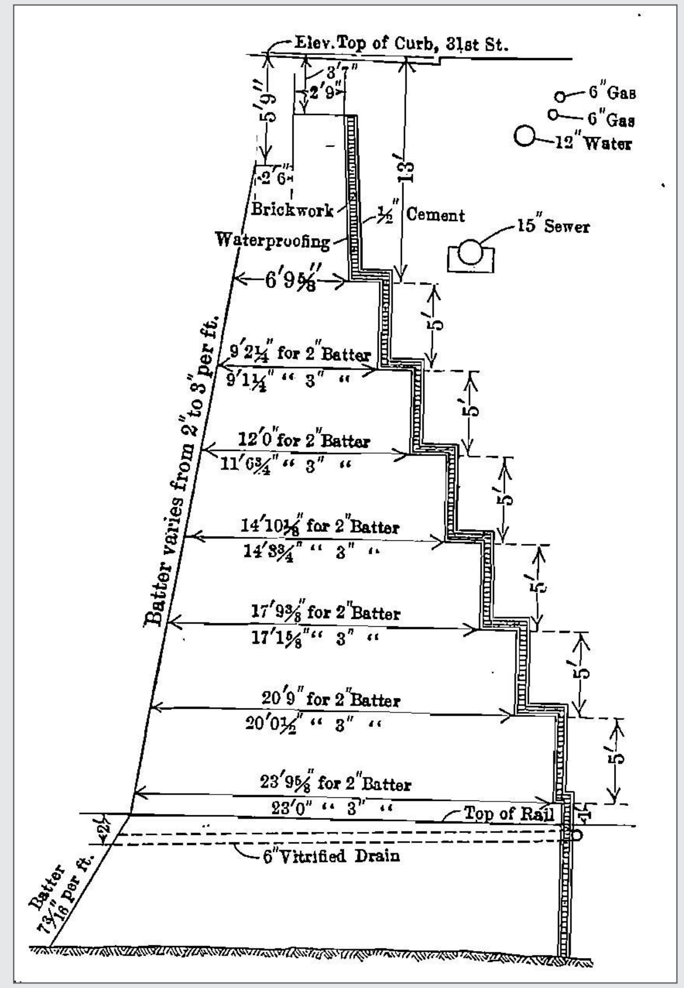
Penn Station West 31st Street Retaining Wall (Amtrak)

An unreinforced concrete retaining wall below West 31st Street serves as the southern limit for Penn Station and Moynihan Train Hall. This wall is located below West 31st Street between Seventh Avenue and Ninth Avenue / E-Yard. This gravity wall is founded on rock and was designed to resist lateral earth and hydrostatic pressures outside of Penn Station. The height of the wall between Ninth and Seventh Avenues varies based on the rock profile but is upward of 50 to 60 feet high in most areas. The gravity wall between Ninth and Seventh Avenues was constructed between 1904 and 1908.

The wall was designed with a stepped back, primarily to allow the waterproofing and brick protection to be held in position more readily. The top step was placed 13 feet below the surface of West 31st Street. Below that point a step was added for each 5 feet of depth to the elevation of the top of rail, or to the foundation of the wall if above that elevation. A 4-inch brick wall was built simultaneously on line with stepped outline at the back of the wall. The brick wall was water-proofed on the side toward the concrete. A 6-inch vitrified pipe drain was laid along the surface of the rock just outside the brick wall. The track face of the wall is battered between 2 to 3 inches per foot. Cross drains were laid from tees in the back drain to the face of the wall at all low points in the rock and at least for every 25 feet of wall length and drain into the train shed. Figure 4-9 shows a cross section of the existing wall.

The gravity wall below West 31st Street supports the southern end of the Moynihan Train Hall train shed level, intermediate levels, NYCT's Eighth Avenue Subway, Penn Station's intermediate levels, and the Penn Station train shed level.

Figure 4-9
Cross Section of Retaining Wall below West 31st Street at Penn Station



Moynihan Train Hall Structure (Moynihan Station Development Corporation)

Located between Eighth and Ninth Avenues, West 31st and West 33rd Streets, Moynihan Train Hall serves as an extension of Penn Station. The train hall is a renovation/expansion of multiple vertical levels built over the train shed. The site includes numerous structures added, and some removed or abandoned, since the original opening of Penn Station in 1910. On the eastern half of the train hall site sits the James A Farley Building, constructed for the U.S. Post Office concurrently with the original yard and opened circa 1914. The western half of the site consists of the Extension to the U.S. Post Office (also known as the U.S. Post Office Annex), constructed in the 1930s. Structural framing, especially the elements within the train yard, consist of steel beams with horizontal and vertical bracing. Concourse girders primarily span north to south with columns located within clear positions between the tracks within the train shed below.

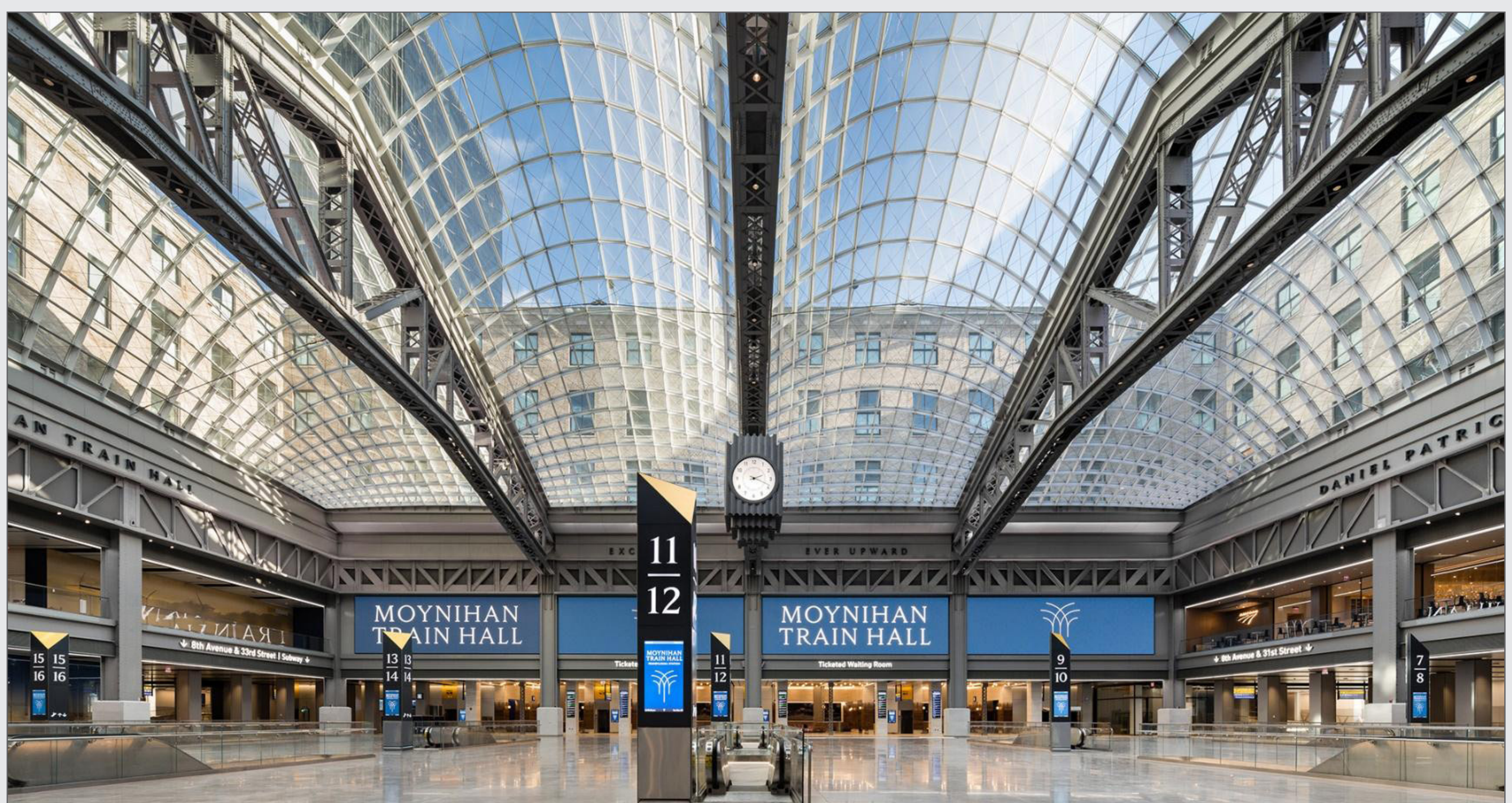
Moynihan Train Hall occupies portions of both buildings. Construction took place in multiple phases, with Phase 1 running from 2012 to 2017 and Phase 2 from 2017 to 2021. Renovations for the train hall involved considerable modifications to the concourse level framing immediately above the train yard. This work included strengthening of existing members, new girders and columns within the train yard, and re-framing of the concourse level floors, in addition to the considerable work visible within the train hall.

The track level below Moynihan Train Hall has seen a similar evolution over time. The original construction included the West 31st and West 33rd Street retaining walls, underground utility/baggage tunnels, platforms, utility structures, and the support frames for the James A Farley Building and West 31st and West 33rd Street viaducts, in addition to the track structure. As part of the Annex construction in the 1930s, steel framing overbuild was added across the yard and new columns were added through the structure.

Of particular importance to the study, an intermediate level was constructed to serve as a traction power switching station along the West 31st Street retaining wall and below the West 31st Street viaduct. The steel structure features girders, which span from the West 31st Street retaining wall to the row of columns supporting the north edge of the West 31st Street viaduct. Minimal vertical clearance exists below the framing structure to track level in this area. Around the time of the Annex construction, the switching station was expanded farther east toward Eighth Avenue and the track alignment leading to Platform 1 and E-Yard below was revised, leading to underpinning of some viaduct columns, widened switching station platforms, and new columns added farther north.

The recent construction for Moynihan Train Hall included the addition of multiple new intermediate-level spaces along the West 31st and West 33rd Street retaining walls. Below West 31st Street includes construction of two new platforms and Fan Rooms 14 and 15/16, which are located immediately west and east of the existing switching station, respectively. These fan rooms were built to house emergency ventilation fans for smoke purge of the platforms in event of an emergency. Fan Room 14 is supported by columns adjacent to the West 31st Street retaining wall and existing viaduct/annex columns to the north. Fan Room 15/16 girders are pocketed into the West 31st Street retaining wall to the south and supported by columns added for the Moynihan Train Hall construction to the north (Figure 4-10 for existing Moynihan Train Hall.)

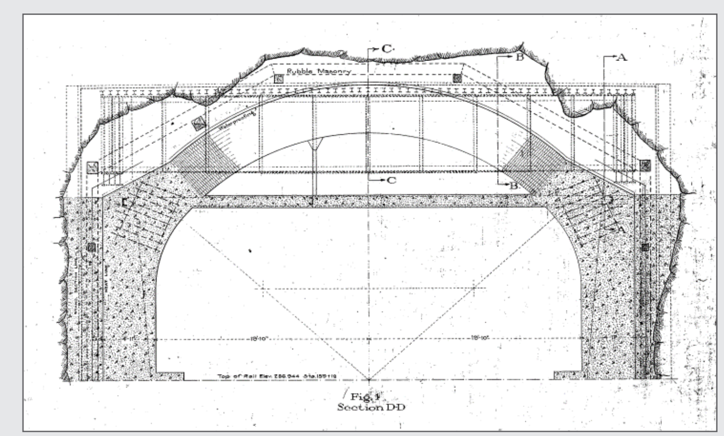
Figure 4-10
Moynihan Train Hall



East River Tunnel (Amtrak)

Between 1904 and 1908, the Pennsylvania Railroad constructed the East River Tunnel, which extends from the eastern end of Penn Station at Seventh Avenue under West 33rd and West 32nd Streets across Manhattan and the East River to Long Island City in Queens (Figure 4-4). The two tunnel "throats" transition multiple tracks from Penn Station into single-track bi-directional tubes (Figure 4-11). These segments of tunnel were constructed by both cut-and-cover and drill-and-blast methods. The tubes were advanced by the drill-and-blast method for full-face rock and the cut-and-cover method for mixed-face condition. The mined segments consist of concrete and a brick arch. The cut-and-cover segments consist of concrete. The typical tunnel span for the mined tunnel section varies from 52 feet to 56 feet and tunnel height is around 35 feet from top of rail to tunnel crown (Figure 4-11).

Figure 4-11
East River Tunnel Cross Section under West 33rd Street



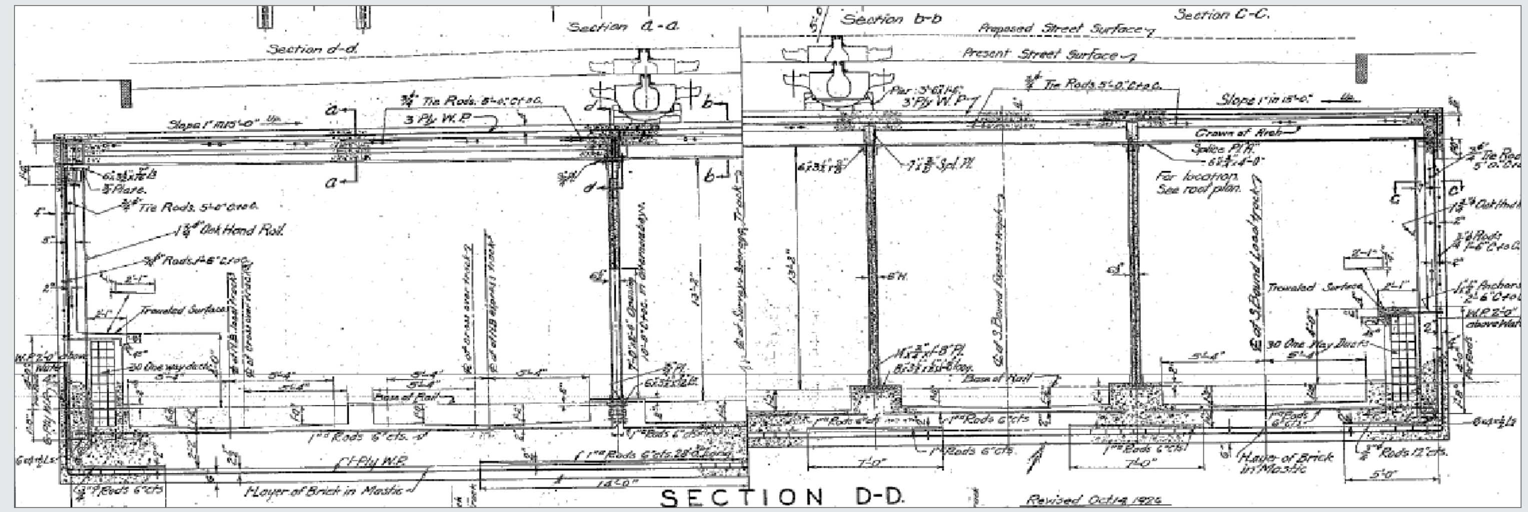
Eighth Avenue Subway Tunnel (NYCT)

This section of the Eighth Avenue IND Subway was constructed in the late 1920s. The stretch of subway, just south of the 34th Street Station, between West 31st Street and West 30th Street accommodates four revenue tracks and an additional center storage track and carries the A, C, and E subway lines. Construction of the subway south of West 31st Street is typical to that of the Seventh Avenue IRT which is described within the following section.

However, unlike the Seventh Avenue IRT, two separate track crossovers are between the northbound and southbound tracks. Construction of this section of subway was by means of the cut-and-cover method and is mostly in rock and subsequently is founded entirely on rock. Concrete footings support structural steel columns and a framed structural steel roof. The exterior walls and roof are encased in concrete. The steel frames are spaced on five-foot centers, typical in most NYCT subway structures built by means of cut-and-cover.

Also atypical to the Seventh Avenue IRT, the subway structure passes over and is supported by the existing Penn Station retaining wall at West 31st Street. The subway structure north of the retaining wall, inside the perimeter of Penn Station, is supported by structural steel framing that distributes the load to columns down to track level. (**Figure 4-12** for cross section of existing IND Subway at Eighth Avenue south of West 31st Street.)

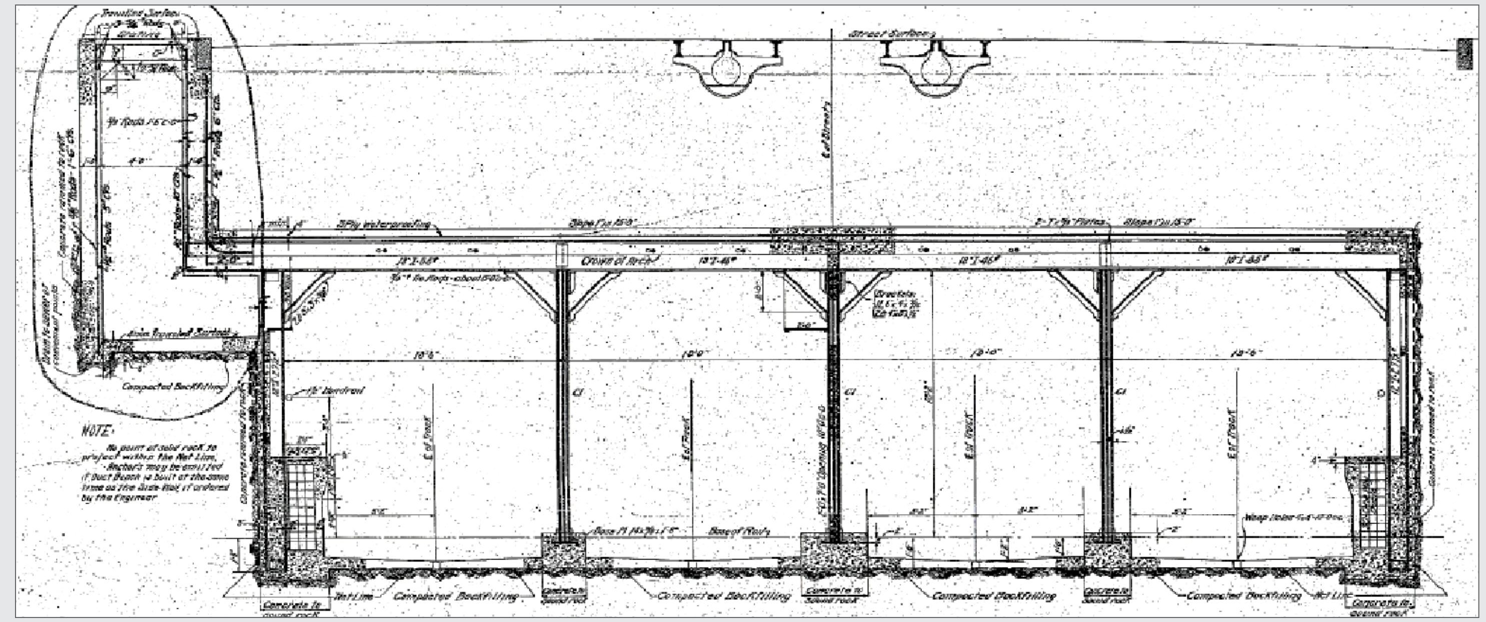
Figure 4-12
Cross Section of Existing Subway at Eighth Avenue



Seventh Avenue Subway Tunnel (NYCT)

This section of the Seventh Avenue IRT Subway was constructed in the late 1910s. The stretch of subway, just south of the 34th Street Station, between West 31st Street and West 30th Street accommodates four single revenue tracks and carries the Nos. 1, 2, and 3 subway lines. Construction of this section of subway was by means of the cut-and-cover method. Based on geotechnical information in the area, rock is above the invert level; as such, the structure itself is mostly in rock and subsequently is founded entirely on rock. Concrete footings support structural steel columns and a framed structural steel roof. The exterior walls and roof are encased in concrete. The steel frames are spaced on five-foot centers, typical in most NYCT subway structures built by means of cut-and-cover. (Figure 4-13 for cross section of existing IRT Subway at Seventh Avenue south of West 31st Street.)

Figure 4-13
Cross Section of Existing Subway at Seventh Avenue



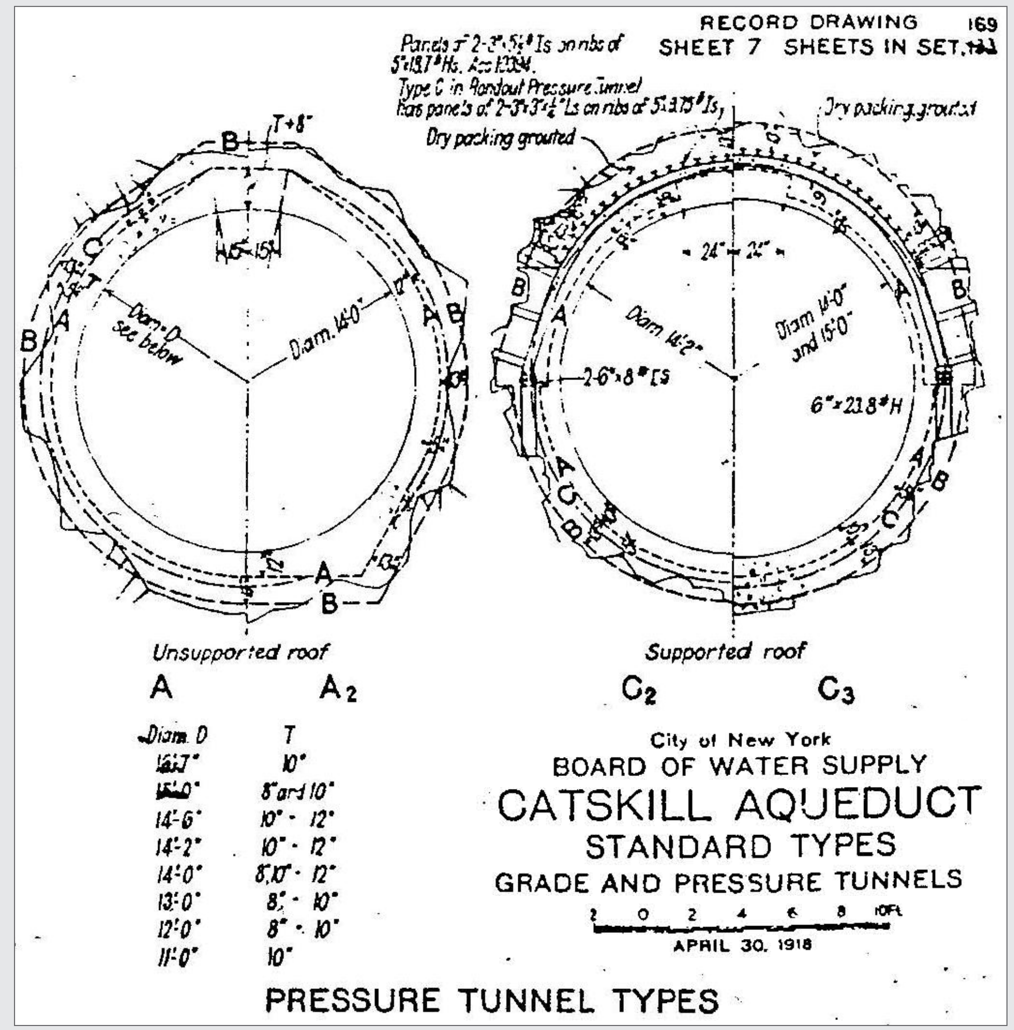
Herald Square Subway Station (NYCT)

The NYCT underground station complex at Herald Square (intersection of West 34th Street with Sixth Avenue and Broadway) provides pedestrian connectivity from street level at multiple entrances to the IND lines below Sixth Avenue (B, D, F, M subway lines) and the BMT lines below Broadway (N, Q, R, W subway lines). A mezzanine level exists below street level. The BMT platform level is below the concourse level and the IND platform level is below the BMT platform level. The station was constructed by means of cut-and-cover but was constructed in multiple vertical phases over its history.

City Water Tunnel No. 1 (NYCDEP)

The City Water Tunnel is below Sixth Avenue as it crosses West 34th Street (**Figure 4-4**). It was constructed in 1913 and is situated at a depth of approximately 200 feet below street level. This tunnel is a critical infrastructure element for New York City's water supply. It supplies water to a major portion of Manhattan, extending from Central Park South all the way to Lower Manhattan. The indication from the construction record drawings is that the section of City Water Tunnel below West 34th Street was excavated to a 17-foot outside diameter without initial support, and the rock mass condition at that location was considered of good quality. The internal diameter is 13 feet, which includes a 2-foot-thick unreinforced concrete lining (**Figure 4-14**).

Figure 4-14
Profiles of pressurized City Water Tunnel No. 1 (1918)



Section 4.2

Track Geometry

Track design alignments for each of the concepts were developed in accordance with the following design guidelines.

New track alignments must tie into the Preliminary Design of the Hudson Tunnel Project alignment at a location no farther west than Twelfth Avenue in Manhattan.

New tracks should conform to the Hudson Tunnel Project Design Criteria. In general, the Hudson Tunnel Project Design Criteria follows Amtrak's Specification 63 - Track Design Specification, with modifications to accommodate the unique spatial and operating environment in New York. These modifications include the following:

- Maximum track gradient of 2.1%, including curve compensation.
- Absolute minimum tangent lengths (straight track) of 65 feet in Penn Station, where approved by the Deputy Chief Engineer Track.
- No curve superelevation (rate of change in elevation between two rails) within Penn Station.
- Vertical curves within Penn Station designed to yard standards where required to fit existing conditions.
- Horizontal clearances within Penn Station to be 7 feet from track centerline plus 1.5 inches per degree of curvature where track is curved.

Station platforms for a 1,020 foot 12-car multiple unit (MU) train or a locomotive plus ten push-pull coaches need to accommodate additional tolerances such that the train engineer is provided adequate length in stopping distance to account for variances in brake system performance or condition of the rail. A typical industry practice is to make the platform 30 feet longer than the longest passenger consist. In addition, a sliding bumper is needed at the terminating end of the track. Typical industry practice is to provide at least 20 feet to provide adequate deceleration distance to dissipate deceleration forces. The platform does not need to extend into the 20-foot bumper zone.

Section 4.3

Geotechnical and Tunneling

An overall characteristic of the various alternatives considered in this report is that most of this new infrastructure is underground construction, all in an urban area. Therefore, underground constructability considerations take a very important role in the evaluation of alternatives. The full breadth of constructability can cover many facets. For brevity and the purposes of this report, constructability considerations are limited to the major factor of general excavation and ground support approaches, and to a lesser extent equipment means/methods, materials, and general work sequencing.

Excavation work would consist of various combinations of open cut (e.g., cut-and-cover) and/or "mining" (e.g., tunneling with TBMs or conventional drill-and-blast methods). In excavation work, the importance of the ground conditions needs to be fully appreciated as it directly impacts constructability factors.

An overview of the topography and ground conditions is presented below. These physical conditions are based on the documents from the Hudson Tunnel Project, the Access to the Region's Core Project (ARC Project), the Hudson Yards Concrete Casing Project, and the No. 7 Line Subway Extension Project where applicable.

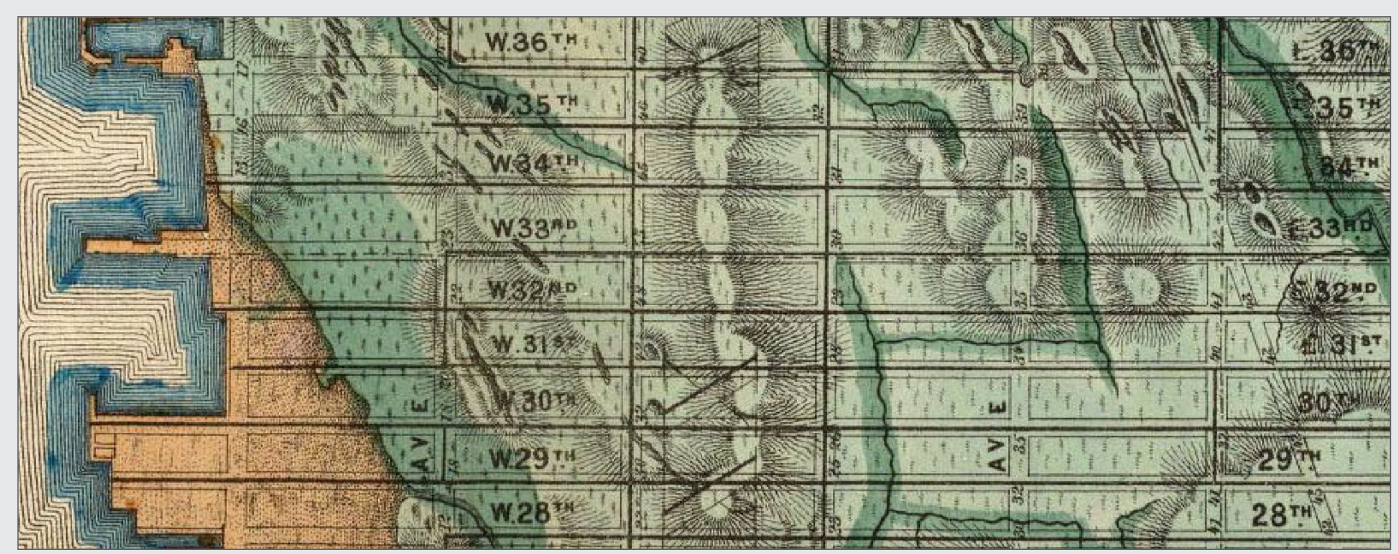
Geology

Topography

Topography is largely controlled by bedrock geology, and Manhattan's elongated ridges trend generally northeast, as does the established street grid. A map of Manhattan's topography and drainage, prepared by Egbert Viele in 1865 before heavy urbanization, shows stream channels trending generally north to south or northwest to southeast in the study area (Figure 4-15). These former stream channels developed along weaknesses in the underlying bedrock and are manifested by depressed bedrock surfaces, as well as by weathered discontinuities in the rock below. Most of these channels, which formerly drained upland areas, were filled during Manhattan's urban development and are no longer reflected in ground surface topography (e.g., rock surface depression on West 34th Street, just east of Eighth Avenue).

Soil overburden conditions predominate at the area around Twelfth Avenue and Hudson Yards; rock conditions are more important proceeding eastward through the remaining study areas. Groundwater conditions are most critical around this area.

Figure 4-15
Topography and Drainage (portion of Viele Map)



Overburden (Soil) Conditions

Thickness of surficial materials along the alignment is generally less than 50 feet, except for areas adjacent to the Hudson River, where the rock surface drops off steeply. Surficial material directly overlying bedrock in Manhattan is primarily dense glacial deposits consisting of a mixture of clay, silt, sand, gravel and boulders. Decomposed rock is also encountered at some locations. The more complex stratigraphy is near the Hudson River shoreline, including the study area, includes made fill and glacial, fluvial, lacustrine and estuarine deposits. Historical records indicate that present-day land areas of Manhattan along the Hudson River extend considerably beyond the original shoreline. Filled for urban development, these areas were former bays or tidal marshes, with organic deposits beneath the fill.

Methane gas from decomposition of localized organic materials in estuarine deposits in the alignment needs to be considered. For example, the ARC contract documents baselined work for the shaft and adjoining tunnels as being "potentially gassy" in accordance with OSHA regulations. The latter impacts construction equipment and construction ventilation.

Bedrock

Bedrock is a deeply eroded assemblage of folded and faulted metamorphic and igneous rocks. The bedrock surface configuration in the area of Penn Station reflects the quality and weaknesses of the underlying rock. Pronounced differential erosion along contacts, faults, and areas underlain by weak or fractured rock produced linear depressions in the bedrock surface (as shown in the Viele maps). Resistant rock areas remain as relative high points on the bedrock surface.

The Hartland Formation and the Manhattan Schist or Walloomsac Formation are the rock formations underlying most of the alignment. They consist of gray interbedded schist, schistose gneiss, and amphibolite, with pegmatite intrusions of various ages. Other rock units include a granite intrusion west of about Eighth Avenue and minor amounts of talc schist, chlorite schist, marble, mylonite, and serpentinite. The latter frequently contains asbestiform minerals that would need special handling and disposal.

The rock structure generally follows the regional northeast structural trend, parallel to the long axis of Manhattan Island. With localized variations, foliation strike is north to northeast, with steep dips to the northwest or southeast in a series of northeast-trending folds.

Groundwater

Groundwater levels have been measured by observation wells/piezometers sealed in overburden and deeper in rock. Typical ground water levels in overburden are 5 feet to 20 feet below the ground surface. Groundwater levels in the rock have a wider range, typically between 5 feet and 65 feet below the ground surface.

West of about Eleventh Avenue, groundwater levels are within 10 feet of the ground surface, regardless of the depth to rock, nearly coinciding with the level of the Hudson River and indicating some tidal fluctuation. Based on groundwater observations presented in the ARC documents, groundwater levels in this area range between elevations 296 feet and 300 feet.

East of about Eleventh Avenue, groundwater levels in both soil and rock wells are within overburden and slightly above the rock surface, with the exception of wells installed in highly fractured rock. Wells sealed in highly fractured rock along West 34th Street had the deepest groundwater levels along the alignment, ranging from 45 to 65 feet below the ground surface and more than 20 feet below the level of the Hudson River. Therefore, it can be assumed that there is no direct hydraulic connection between the rock mass east of Eleventh Avenue and the Hudson River in the vicinity of the alignment.

A weak hydraulic connection between the Hudson River and adjacent rock units and deeper soils is inferred for the portion of the tunnel alignment west of about Eleventh Avenue. This weak hydraulic connection is not sufficient to provide enough recharge to the groundwater system to maintain the initial (i.e., prior to excavation) groundwater levels during and after shaft and tunnel excavations. In this area, groundwater level variation due to tidal and seasonal fluctuations is less than 4 feet.

Groundwater flow in overburden deposits in the vicinity of the Hudson Tunnel Project Twelfth Avenue shaft would be controlled by permeability of soil and degree of weak connectivity with the Hudson River. Groundwater flow at the overburden/bedrock interface would be controlled by the topography of the bedrock surface. The bedrock surface, along with fractures, joints, and weathered zones, would act as conduits transmitting water to topographic lows at the bedrock surface and then into the underlying rock mass.

As a case history example, the completed segments of the Hudson Yards Concrete Casing involved cut-and-cover excavations extending from overburden, well into rock. Pre-excavation grouting was implemented to control groundwater inflows into the excavations in a settlement sensitive area. The grouting program was successful despite some grouting boreholes taking relatively large amounts of grout.

Groundwater flow in the rock mass along the alignment is largely controlled by the network of fracture openings. Zones of high permeability correspond to three different types of rock mass discontinuities:

1. Fault zones,
2. Moderately to steeply dipping mica schist/granite contacts, and
3. Near-horizontal open fractures in massive, competent rock.

Groundwater should be assumed to be brackish west of about Eleventh Avenue, with chloride contents as high as 3% expected. Underground structures would need to address the latter condition with respect to corrosion.

Results of soil-groundwater sampling (ARC Project) along the alignment indicate semi-volatile organic compounds may be encountered in the vicinity. The presence of these types of compounds would require special environmental handling.

Ground Behavior
Soil Below the Groundwater Table
Ground conditions west of Eleventh Avenue consist of soft, compressible, saturated clays and silts overlying dense to very dense glacial deposits, which in turn overlie rock. The exposed rock surface along the alignment is expected to rise from west to east, and localized irregularities in the bedrock surface are anticipated.

Without ground stabilization/treatment measures, soils encountered in this area would be fast raveling, flowing, and squeezing when exposed in excavations. Elsewhere along the alignment where an excavation is below the groundwater table with sands, gravels, cobbles and boulders present, uncontrolled groundwater would flow into the excavation carrying fines, resulting in loosening of the surrounding ground and allowing larger clasts (i.e., cobbles and boulders) to dislodge and slough into the excavation.

Ground Behavior
Soil/Rock Below the Groundwater Table
In the area west of Eleventh Avenue, some excavation would be in the rock with overlying compressible soils (soft clays, silts). Uncontrolled groundwater inflows into the rock section would result in vertical groundwater drainage from the overlying compressible soils. This would result in surface settlement induced by soil consolidation.

The previously mentioned Hudson Yards Concrete Casing tunnels involved cut-and-cover excavations extending from overburden and well into rock. The tunnel between Tenth and Eleventh Avenues was supported in the overburden by secant piles tiebacks into rock, and vertical rock walls below the base of the secant piles. This tunnel segment required 58 verification boring holes with rock in situ permeability testing (e.g., packer permeability), nearly half of which required follow-up rock mass grouting prior to rock excavation. The average amount of grout "take" per hole was considered "Medium" (> 50 gallons <500 gallons), although 6% of the holes had "Heavy" takes (> 1,000 gallons). Grout was Ordinary Portland Cement (water: cement ratios [by weight] 3:1, 2:1 and 1:1) with minor bentonite amounts to control "bleeding." A location was considered a grout candidate when packer testing indicated a permeability greater than the threshold value (2 x 10-4 cm/sec).

Ground Behavior
Rock
Ground behavior during excavation would be dependent on and controlled by discontinuities in the rock mass and the type of excavation methodology and equipment selected by the contractor. A rock mass discontinuity is here defined as a boundary or break in the rock mass, which marks a change in rock properties. Rock mass discontinuities within the study include lithologic contacts, veins, faults, foliation planes, and fractures and joints. These discontinuities have been considered in the rock mass classification presented below. Orientation, alteration, and roughness of these discontinuities would all influence support requirements and ground behavior during excavation.

The general behavior of the rock mass can be described as loosening behavior, which would be dependent on the characteristics and continuity of joints, fractures and foliation within the rock mass and their orientation with respect to the excavation, groundwater presence and the in situ stress field. In general, block and slab formation would occur along joints and/or foliation and would require immediate support to maintain a stable opening.

Loosening behavior is expected to dominate in this project such that potential rock wedge and/or slab loadings would be the primary loads taken by the support systems. Rock fallout and loosening would be a common occurrence if appropriate support, whether temporary or permanent, is not installed in a timely manner. Also, water pressure or water flow along joint surfaces and joint infill material would reduce the stand-up time of blocks in the tunnel face, crown and/or sidewalls and contribute to their movement and fallout.

Rock Mass Quality with Respect to Excavation
Selection of the means, equipment, sequence, and support systems requires consideration of the full range of subsurface conditions expected, contract schedule, and performance criteria and requirements. Typically, a large underground infrastructure would implement some type of a ground classification system. Material reviewed from the ARC documents can be used to present a simplified system to represent the variation in expected conditions. The rock conditions can generally be categorized into three classes — Class I, Class II, and Class III — with Class I being the best condition and Class III being poorer conditions. Table 4-1 presents a simplified system adapted in part from ARC contract documents.

More important is the distribution of these rock classes. The rock classes generally vary along the alignment. Table 4-2 adapted from the ARC documents is an overall approximate summary of the rock class distribution.

Table 4-1

General Rock Classification

Classifications	Distinguishing Rock Mass Characteristics(1)(2)
Class I	▪ Unweathered to slightly weathered ▪ Fracture spacing more than 6 feet ▪ Massive (unjointed) to moderately jointed
Class II	▪ Unweathered to moderately weathered ▪ Fracture spacing 2 to 6 feet ▪ Moderately blocky
Class III	▪ Slightly to highly weathered ▪ Fracture spacing less than 2 feet ▪ Moderately blocky to very blocky and seamy

Table 4-2

Approximate Distribution of Ground Classes

Classifications	Approximate Distribution of Ground Classes
Class I	▪ 40%
Class II	▪ 35%
Class III	▪ 25%

(1) For fractures with minimum persistence of 3 feet.

(2) Terzaghi rock mass description from Rock Tunneling with Steel Supports. 1968. Proctor, R. and T. White.

These general classes are related to rock support demands in terms of support elements requirements (e.g., rock bolt lengths and spacing, shotcrete thickness, etc.). In the following sections, generic support requirements with respect to ground support is presented based on the ARC contract documents that generally cover Classes I through III. The ARC Project is used as a reference to this study since the final design was completed and subjected to numerous rigorous external peer reviews by an international peer review panel.

The tunneling options consist of the following general excavation methodologies:

- TBM (full-face)
- Mined Excavation (drill-and-blast methods and/or partial mechanical excavation)

Ground support is discussed below for each excavation methodology. This is important because in the evaluation of alternatives, standard excavation for mined excavation is not always possible, thereby negating an alternative completely or in some cases implementing a drastic change to a nonstandard ground support system.

Tunnel Boring Machine

Two of the four design concepts discussed later in the report propose utilizing the two Hudson Tunnel Project TBMs to excavate the new running tunnels to the east. While at first glance it appears to be a simple solution to use the Hudson Tunnel Project TBMs, the reality is more complex, particularly with respect to safety aspects during tunnel widening at cavern locations. In addition, the interlocking geometry would need to be studied more thoroughly in future stages of the design.

Ideally the TBMs used to construct the design concepts described in this report would be straightforward hard-rock TBM machines that would utilize temporary ground support systems such as rock bolts, steel straps, etc. This would make it easier and safer to expand the tunnel to a wider interlocking, since the excavated rock surface is always visible and accessible. Additionally, it would be relatively easy to advance the TBM through the area where the diverging tunnels split from the Hudson Tunnel Project alignment.

Temporary rock support for the TBM would be with rock bolts and steel channels depending on ground conditions encountered. Permanent support would be with a cast-in-place concrete liner with waterproofing constructed after TBM excavation completion. A custom-made concrete form shutter would be utilized for forming the fresh concrete as it cures. As an example, reconditioned (used) hard-rock TBM (main-beam type) was utilized for Second Avenue Subway running tunnels.

The grippers react on the rock surface. Figure 4-16 is a photograph looking forward; the left side gripper and bare rock surface have been highlighted. This section would be typical of the best ground conditions; note how smooth and free of defects as the rock surface shows.

Figure 4-16
Second Avenue Subway, TBM Tunnel (Before Placing Permanent Lining)

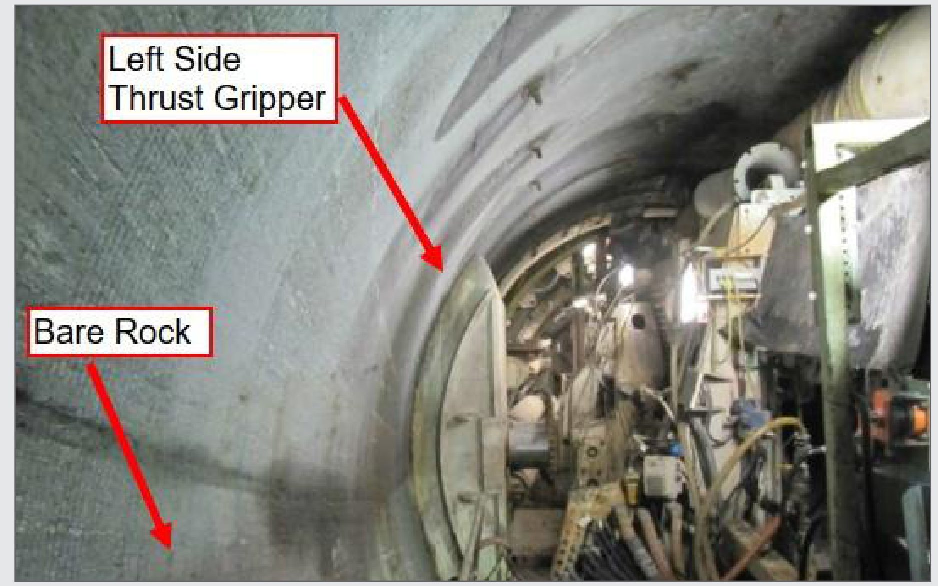


Figure 4-17
Second Avenue Subway, TBM Tunnel with Steel Channels

Figure 4-17 is a photograph of TBM excavation (Second Avenue Subway) through poorer ground whereby steel channels had to be used. The photograph shows the overbreak in the upper left whereby blocking was added to prevent additional rock block fallouts and loosening. It demonstrates how quickly the rock conditions (quality) change along this stretch of the alignment.

The Hudson Tunnel Project TBMs (Hudson River section) will be hybrid pressurized-face TBMs with hard-rock cutting capabilities. It is certainly feasible that such a TBM can excavate the various Manhattan rock formations along proposed tunnel alignments. Despite the need to have pressurized-face capabilities for the very soft weak Hudson River soils, as much as 25% of the Hudson River drive will be in full-face to mixed ground with rock (New Jersey side). Similar type TBMs have already been used locally by the East Side Access Project (Queens segment) and the Siphon Tunnel Project (under New York Harbor, Staten Island to Brooklyn NY). This type of TBM (Figure 4-18) is configured quite differently from that presented in the preceding section. The TBM is enclosed by an external shield that is integrated with the TBM moving forward. Ground support, in the form of precast concrete rings, are installed inside the protection of the shield and extruded as the TBM moves forward.

Thus, the Hudson River TBMs will use precast concrete segments for all ground support regardless of whether in rock or soil. The only means of thrusting the TBM forward is from the leading edge of the last built tunnel lining ring, which is inside the shield (Figure 4-19). A view of a completed precast concrete lined tunnel before finishing works are added is presented in Figure 4-20.

Figure 4-18
Shielded Hybrid Pressurized-Face TBM

Figure 4-19
Thrust Jacks Pushing from Tunnel Lining Ring Inside the TBM Shield

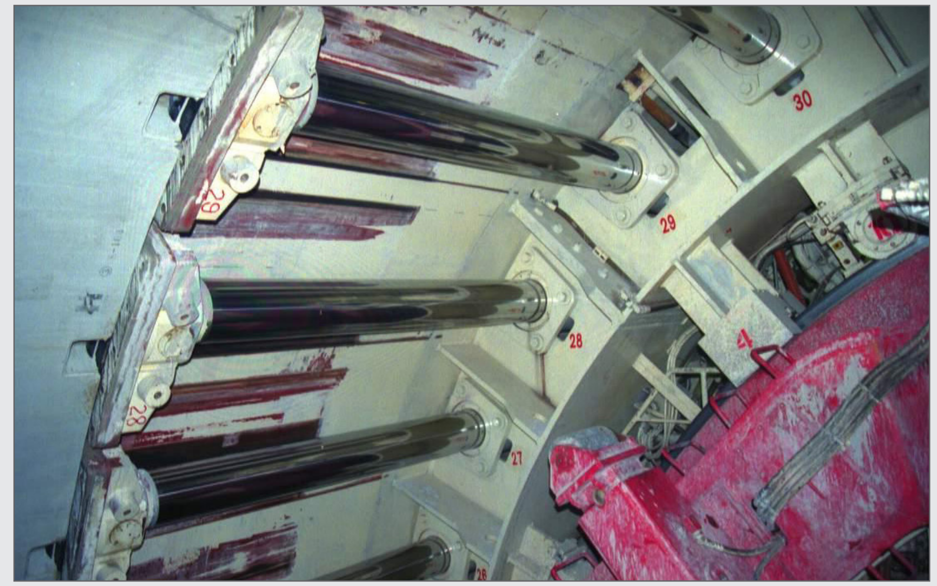


Figure 4-20
Completed Precast Segmental Lining Tunnel (No Finish Works)

Since these TBMs can only use segmental linings, it would require the Manhattan TBM drives to use segments for the entire excavation regardless of the enlarged interlockings required to house the various track alignments within a respective alternative. Also, it would not be possible for one TBM to merge or cross the other with segments in place. Once each TBM completes its drive and is removed, the interlocking widening can commence. The segments would need to be pulled down, which is no easy feat, and there is risk of rock falls (which is a safety issue) since the segments are already providing ground support. This work can be done, but only carefully and would have to proceed westward from the open cut area.

If segments were to be removed, techniques to facilitate segment removal could include not using dowels in the rings and using removable bolts. Also, the amount of reinforcing steel can be substantially reduced. These measures would reduce the amount of effort to carefully remove one ring at a time, expand the opening and subsequently supporting it. The widening would proceed by sequential excavation, an excavation methodology manner described in the next section of the report.

A more sensible TBM alternative would be to use standard main-beam hard-rock machines, although this would be somewhat uneconomical for relatively short drives as found within some of the following design concepts. It should be noted that Hudson Tunnel Project scope includes the Palisades Tunnels that are entirely in hard rock, which is mostly diabase, a high strength rock that is harder than the Manhattan rock formation. If the contractor selects a two-pass lining for the Palisades Tunnels, these machines would be ideal for the Manhattan drives (including having similar tunnel diameters). It is noteworthy when the ARC Project construction commenced, the Palisades Tunnel contractor selected a two-pass lining with a standard hard-rock TBM. The use of refurbished TBMs used on another project is quite common. However, the possibility of used TBMs being available for the Manhattan Tunnels would be quite low. The required Manhattan TBM diameter is not common in the tunneling industry.

Mined Cavern Enlargement and Sequential Excavation

Sequential excavation method (SEM) mining is an approach in which a tunnel is sequentially excavated and supported in a controlled predetermined sequence. The excavation can be carried out with conventional mining methods and equipment, selected according to the ground conditions. This underground excavation method divides the space to be excavated in segments, then mines and supports these segments sequentially, one portion at a time.

SEM mining permits a tunnel of any shape or size to be excavated while TBMs can only excavate a fixed circular diameter. This flexibility makes it useful in areas where ground conditions and obstructions in the ground would not allow for tunneling using a TBM, or where the tunnel shape or size needs to change. Shotcrete (sprayed concrete) and/or rock bolts may be used to temporarily support the tunnel or support the face. Grouting (the injection of a cementing or chemical agent into the soil) may be used to increase the ground's strength and reduce its permeability.

The vast majority of rock excavation in the New York metropolitan region is by drill-and-blast methods. However, there is a recent trend toward using mechanical means such as road headers and hoe rams. For example, all rock excavation in the completed segments of the Hudson Yards Concrete Casing Project was performed with hoe rams. This permitted the contractor more flexibility and eliminated limitations imposed by authorities regarding explosive use. The permanent support installed for this type of tunnel excavation is usually a cast-in-place concrete lining with waterproof membrane placed over any temporary support.

Figure 4-21. illustrates the sequential widening (using SEM methodology) from two prior excavated TBM tunnels into a large cavern, such as needed for a station platform. In this case, the crown area is first excavated by expanding the TBM tunnels by drill-and-blast excavation with support installed. With the crown complete, the cavern is sequentially deepened in segments (see dashed lines). Figure 4-22 is an in-progress photo of TBM widening into a cavern (East Side Access Project, NY).

Ground support for the caverns is anticipated as primarily rock bolts and shotcrete. This ground support is temporary until the permanent lining of cast-in-place (with a waterproof membrane) is constructed once all excavation is completed. The rock bolt lengths, patterns, and shotcrete thickness are dependent upon the overall dimensions of the opening and ground conditions.

Figure 4-23 is an example of rock support as adapted from ARC drawings for a given cavern width.

A roadheader is a piece of excavating equipment consisting of a rotary cutting head mounted on a boom, a loading device usually involving a conveyor, and a crawler traveling on track to move the entire machine forward into the rock face. The excavation is basically a milling process. Roadheaders in tunneling have been used to a limited extent in the New York metropolitan region, primarily because roadheader performance is affected by rock strength and abrasiveness, and the rock characteristics in the area are generally at the upper bound of roadheader practical application (economic). Figure 4-24 is a photograph of a large roadheader.

Figure 4-21
Sequencing of Excavation and Ground Support of TBM Tunnel Widening for Cavern

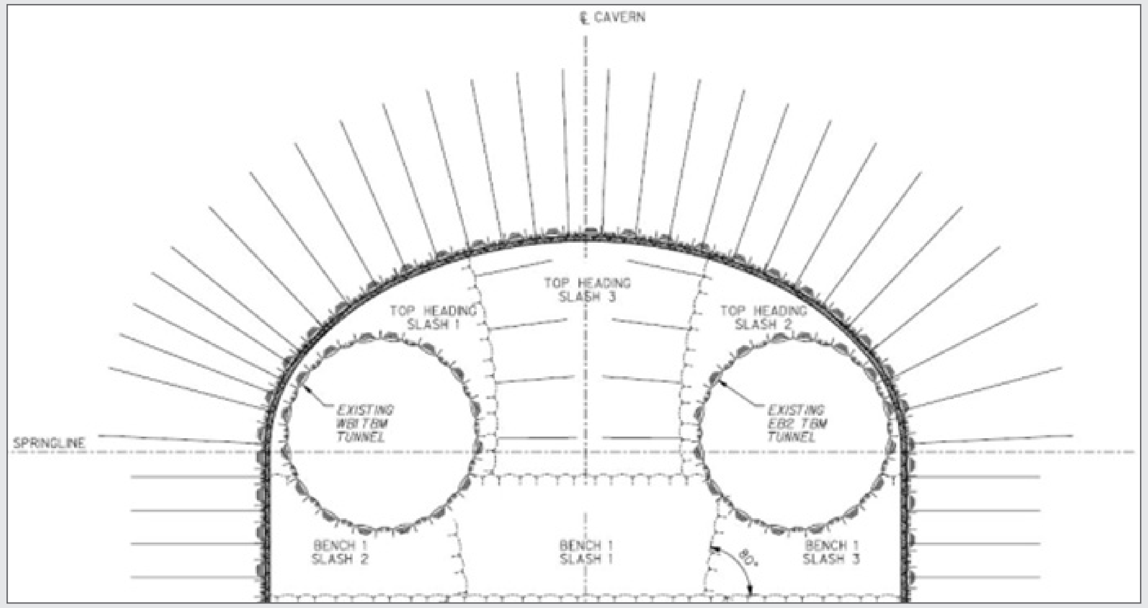


Figure 4-22
TBM Excavation Widening for Cavern Development

Figure 4-23
Example Rock Support (adapted from ARC Contract Documents)

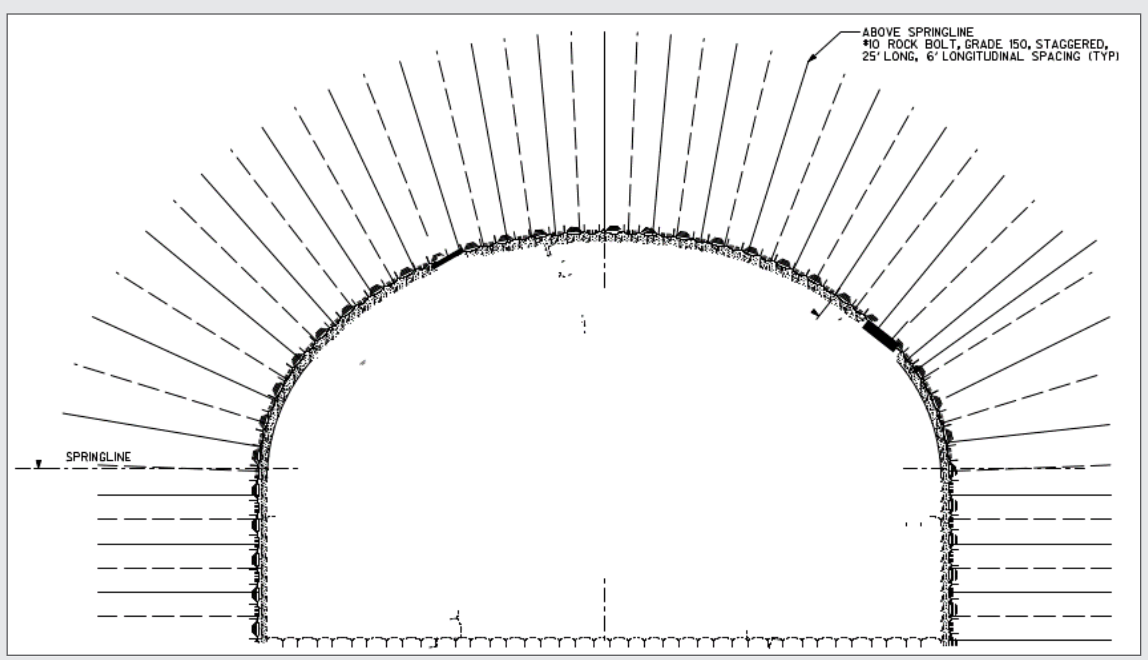


Figure 4-24
Roadheader Excavation Machine

Cut-and-Cover

Cut-and-cover is the oldest method of tunneling. As an example, the early sections of the New York City subways were constructed in this manner.

The basic concept involves a trench excavation, construction of a tunnel box, and then returning the excavation to its original surface state. In urban areas it is a highly disruptive technique, but it is also generally the most economical construction method (Figure 4-25). Where the tunnel alignment is beneath a city street, the construction would cause challenges unique to the environment, such as:

- Congested sites
- Historic areas
- Crisscrossing utility and transit lines
- Special underpinning, structural support, and building protection
- High groundwater levels
- Groundwater contamination
- Maintenance of traffic during construction

However, the disruption could be lessened by using proper staging and providing temporary decking over the trench to temporarily restore traffic, otherwise known as a bottoms-up approach. In some cases, a top-down construction technique is used. The latter, less-common (and more costly) concept involves building the permanent tunnel roof first, and then working below the roof while excavating and constructing the lower sections. It is not a technique used commonly in the New York metropolitan region. Cut-and-cover is a technique usually applied to relatively shallow tunnels and it is not unusual to see it applied to depths of around 60 feet, but rarely does it exceed 100 feet.

Numerous types of excavation support systems, including soldier piles and lagging, temporary slurry walls, soldier piles in tremie concrete systems, jet grout walls, temporary secant pile walls, soil mix walls and element walls have been done in the New York metropolitan region. Many of these techniques were used on the recent Second Avenue Subway, in a highly congested area of Manhattan, with numerous high-rise buildings, extensive utilities, historic and fragile buildings, and heavy traffic, including several bus lines (Figure 4-26 and Figure 4-27).

The Hudson Yards Concrete Casing tunnels were of cut-and-cover with secant piles toed in rock and vertical rock excavation (using tiebacks) below the bottom of the secant piles. Figure 4-28 is a photograph of the latter.

Support of excavation is critical to successfully implementing cut-and-cover construction with minimal impact on surface facilities, structures, and near-surface utilities. Designing such support systems involves the consideration of a variety of factors that could affect its performance and impact the tunnel structure itself. These excavation supports are either temporary or permanent.

Temporary supports do not contribute to the final structure's load bearing support. In general, they consist of soldier piles and lagging, sheet pile walls, secant piles or tangent piles. When supports are permanent, these supporting elements are a part of the final structure and are designed to be left in place after the construction is complete. These include techniques like slurry walls, secant piles or tangent piles.

A recent example of extreme cut-and-cover construction is the Asia transition structure of the Eurasia Tunnel in Istanbul, Turkey, in which the excavation was 550 feet long by 115 feet deep of variable width and all constructed within only tens of feet from the Bosphorus Straits. The work was completed successfully using two stacked rows of a secant pile system and multiple tieback levels (Figure 4-29).

Controlling groundwater is also a significant consideration during cut-and-cover tunnel construction especially within an urban environment. The application of proper techniques would mitigate potential settlement impacts and groundwater drawdown effects on any adjoining structures, facilities and contamination plumes. Options used locally include dewatering by wells or ejectors, watertight excavation systems, permeation grouting, jet grouting and ground freezing.

The East Side Access Project tunnels in the Queens segment, due to the presence of contaminated groundwater plumes, necessitated the use of rigid support of excavation using a combination of slurry walls and jet grouting to limit the groundwater drawdown to less than 2 feet to control contaminant plume migration in Sunnyside Yard.

Figure 4-25
Construction in the Street, Second Avenue Subway Project

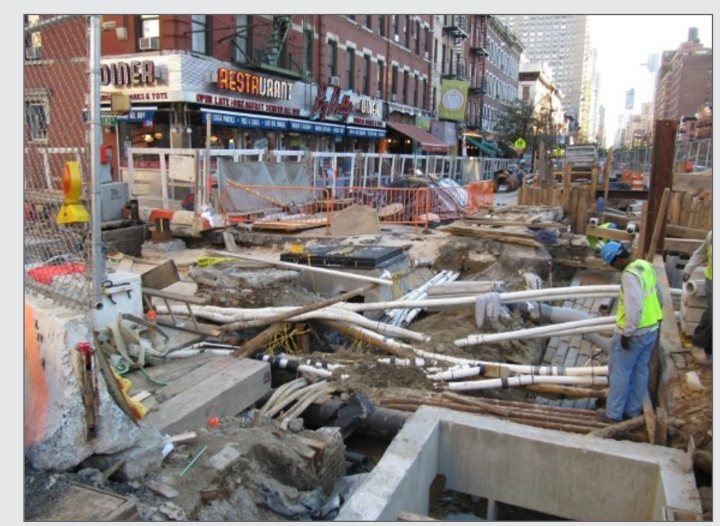
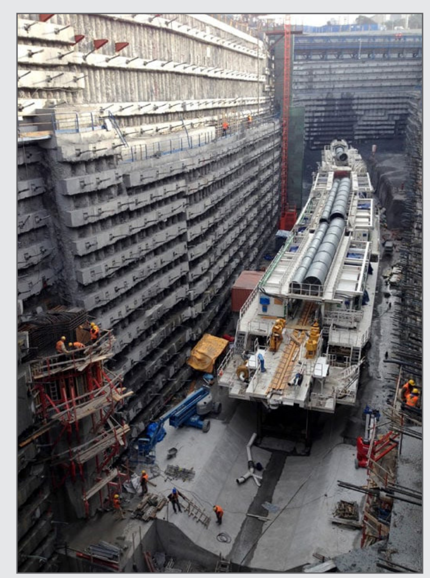


Figure 4-26
Cut-and-Cover Strutted Excavation, Second Avenue Subway Project

Figure 4-27
Slurry Wall Construction Second Avenue Project

Figure 4-28
Hudson Yards Concrete Casing Project

Figure 4-29
Cut-and-Cover Portion of Eurasia Tunnel, Istanbul, Turkey



Section 4.4

Operational Performance

The operational performance of Penn Station is inextricably dependent upon three different components of the railroad system (tunnel, interlocking, and station platform tracks) and the individual capacities of these three components. The lowest capacity among these components is the one that becomes the "constraining" or "governing" capacity, determining the number of trains that can be realistically operated on a consistent and reliable basis during weekday peak period service.

Capacity is a measure of the maximum number of trains that can be operated on a segment of track or through a station or interlocking. It is important to distinguish between the theoretical and practical capacity of railroad system components. Theoretical capacity represents the limit of what the design of the track infrastructure and signaling and train control system can support, assuming that the infrastructure, train operators and train dispatchers are all performing perfectly. In practice, operating conditions always entail some level of variability, and theoretical capacity cannot be sustained over a prolonged period. Therefore, an allowance is made for these variable conditions in the definition of practical capacity, which is what is used as the basis for rail operations and infrastructure planning.

Planned throughput is defined as the volume of trains scheduled on a segment of track or through a station. It is a measure of the extent to which capacity is utilized. Throughput is limited by practical capacity and is often lower than practical capacity, driven by demand for train service or the length, complexity and physical characteristics of the rail network feeding the segment being analyzed.

Tunnel Capacity

This is the total number of trains per hour that can be realistically and reliably operated in the tunnels when viewed in isolation of the capacity of the interlocking complex near the station or the capacity of station platform tracks themselves.

The train length, tunnel's track alignment speeds, the train engineer handling/response times, the underlying signal system (automatic train control or ATC system), the location of ventilation shafts that define the boundaries of the ventilation zones and, finally, the necessary enforcement mechanism that keeps trains apart in compliance with NFPA 130 rules for fire and life safety — all collectively determine the practical capacity of the tunnels.

- The conventional ventilation zone system as currently designed for the Hudson Tunnel Project provides a practical capacity of 24 tph.

Interlocking Capacity

This is the total number of trains per hour that can be realistically and reliably operated through the interlocking complex when viewed in isolation of the capacity of the tunnels or the capacity of station platform tracks themselves.

The train length, interlocking track alignment speeds, the train engineer handling/response times, the underlying signal system (ATC system), the time to reset the routes for conflicting movements and most importantly the number of conflicting movements (determined by whether the interlocking is processing all train movements in and out on the same level or "flat interlocking" vs. at two levels or "grade-separated interlocking") — all collectively determine the practical capacity of the interlocking.

Another important factor affecting interlocking capacity is the design of the interlocking itself. If multiple station tracks are fed by a single lead track versus each track having its own lead, factors such as parallel movement capability and overall interlocking length — many of which are driven by overbuild and constructability considerations — do cause significant variation in attainable capacity.

In the area of the terminal interlocking, where Maximum Authorized Speed (MAS) is often lower than 15 mph, train engineers operate trains at 12 mph to avoid an automatic/penalty braking. This is known as "underspeed" operation and causes the trains to take longer to clear the interlocking.

The route reset time significantly contributes to the interlocking capacity. It is a critical factor in how quickly operating conflicts are resolved and is the elapsed time between the release of an occupied track and establishment of a new route across or to that track. It is both an analytical model variable, as well as a design input. It includes:

- Communication time between dispatcher console and field devices
- Time for wayside/field devices to execute system commands

An extensive field research effort by Amtrak and NJ TRANSIT during multi-day, multiple peak period observations at the dispatching center to calibrate existing NY Penn Station's "A" interlocking determined the route reset time to be 24 seconds.[1]

Based on all the above factors, the practical capacity for various interlocking configurations is shown in **Table 4-3**. These estimates assume a reasonably well-configured interlocking design. For any station concept that involves stub-ended tracks (assessable from only one side of the station), every train that goes in, must come out. Therefore, the practical capacity for the interlocking, in each direction, is half of the total capacity. A bi-level or grade-separated interlocking reduces the number of conflicting train movements in the interlocking (i.e., inbound movements that block the railroad for outbound movements, or vice versa), which results in higher practical capacity. Similarly, a station configured for through-running also reduces and potentially eliminates the need for conflicting train movements, so this configuration also provides higher practical capacity. The table also presents the maximum peak hour utilization that is assumed at Penn Station for the various alternative configurations of platform groups and interlockings that were considered in this analysis.

Existing Penn Station doesn't fit neatly into these configuration categories. The station operates in a hybrid mode with both turnback and through-running operations. 'A' Interlocking on the west side of the station feeds both stub-ended and through-running tracks. Its practical capacity, therefore, falls in-between the stub-ended and through-running capacities. It serves 24 tph in the peak direction of travel, which is considered the limit of the practical capacity of the existing flat interlocking.

1 It should be noted that about 5 seconds of this time is comprised of FRA-mandated loss of shunt time (which cannot be lower due to regulatory constraints). The overall route reset time would be longer if Penn Station were to use Amtrak-standard electric-powered switches. Amtrak makes a special exception for air-powered switches at Penn Station, a critical engineering design exception that enables 24-second route reset time, to maximize throughput.

Table 4-3

Interlocking Practical Capacity for 2-Track Rail Line Feeding Station with Multiple Platforms

Station Configuration	Interlocking Configuration	Practical Capacity 2 Directions	Practical Capacity Per Direction	Maximum Utilization Per Direction at Penn Station
Stub-ended	Flat (single level)	40 tph	20 tph	20 tph
Stub-ended	Bi-level	60 tph	30 tph	24 tph
Through-running	Flat (single level)	60 tph	30 tph	24 tph* 28 tph**

* Based on trains operating through the existing North River Tunnel and East River Tunnel and existing Penn Station interlockings.
** Based on trains operating through the new Hudson River Tunnel and East River Tunnel and purpose-built new interlockings.

Station Platform Track Capacity

This is the total number of trains per hour that can be realistically and reliably accommodated at the station platform tracks when viewed in isolation of the capacity of the tunnels or the capacity of interlocking.

The number of platform tracks, the split of "train turns," the station dwell time for each train turn, the clearing or "platform refresh" time between the successive trains on the same platform track as well as the variation in train equipment — all collectively determine the practical capacity of the platform tracks.

"Train turns" refers to the type of arriving train and its turn-back departing train. These could be revenue trains (those carrying passengers) and non-revenue trains (those carrying crew only). These directly affect the station dwell times because of the various activities performed (while the train is berthed on a platform track), and they enable recovery of lateness of the late arriving train so that it departs on time. Recovery time is of high importance for achieving the doubling of trans-Hudson rail capacity at the station, since the lines and trains proposed to be served by it will be traveling considerably long distances, with multiple station stops along the way. The dwell times below are the dwell standards for trains turning in the station agreed upon by the Partners.

- Revenue train (arriving) to Revenue train (departing): 22 minutes scheduled minimum
- Revenue train (arriving) to Non-revenue train (departing): 15 minutes scheduled minimum
- Non-revenue train (arriving) to Revenue train (departing): 15 minutes scheduled minimum

Split in "train turns" refers to the ratio of trains that are revenue to revenue versus those that are revenue to non-revenue (AM peak) or non-revenue to revenue (PM peak).[2] This split is 1/3 versus 2/3 during what is known as "peak of the peak," whereas the splits vary during "shoulders of the peak." Outside of the peak period, the revenue/non-revenue split of train turns entirely vanishes; that is, every inbound revenue train turns to an outbound revenue train during the off-peak period.

- Out of every three revenue trains arriving inbound at Penn Station in the AM "peak of the peak," only one turns to an outbound revenue train, whereas the remaining two turn to outbound non-revenue trains.
- Out of every three revenue trains departing outbound from Penn Station in PM "peak of the peak," only one turns from an inbound revenue train, whereas the remaining two turn from inbound non-revenue trains.

Platform clearing or refresh time refers to the time between a train departing a platform track and the time of the next arriving train on the same platform track. Prior planning analyses have often assumed this time as 4 minutes when the departing train and the next arriving train are in opposing directions.

Recent detailed rail operations simulations conducted collectively by WSP, Amtrak and NJ TRANSIT revealed that because of longer train lengths (up to 12 cars), a higher route reset time (discussed before as 24 seconds) and "underspeed" (12 mph operating speed in 15 mph MAS section) operation by train engineers requires a platform clearing time of 5 minutes minimum to maintain reliable and realistic operations for longer peak periods, twice a day, every weekday.

Finally, the type of rolling stock and the differences between them lead to equipment manipulations that determine train slots and, ultimately, station platform capacity. Electric rolling stock (from lines or portions/zones of lines that are electrified) can only be sent back to lines or portions/zones of lines that are electrified. The dual-powered rolling stock (from lines or portions/zones of lines that are non-electrified) can be sent to any line or zone whether electrified or not; however, doing so causes an imbalance of equipment between electric vs. dual-powered rolling stock. Unless the entirety of NJ TRANSIT and MTA MNR Port Jervis Line are fully electrified, a strict adherence must be followed for electric-to-electric and dual powered-to-dual powered equipment for electrified and non-electrified lines, respectively. This is a critical factor in creating realistic, operable equipment manipulations. This factor affects how and when an inbound train can be appropriately turned for an outbound train — at a slot that could be supported by that line (whether electric or diesel) or the zone of that line, often leading to asymmetric and further longer dwells at New York Penn Station.

Based on all the above factors, at the station platform tracks (in isolation) where all trains are turning back (i.e., changing direction), the practical capacity varies based on the total number of available tracks and the required number of tracks:[3]

- 8 platform tracks can accommodate up to 21 tph
- 9 platform tracks can accommodate up to 24 tph
- 10 platform tracks can accommodate up to 27 tph
- 11 platform tracks can accommodate up to 29 tph
- 12 platform tracks can accommodate up to 32 tph

These practical capacity volumes were used to establish the required number of tracks for both alternatives.

The capacity of a stub-ended platform track configuration, with all trains turning back, will be constrained by both the number of platform tracks and the interlocking configuration. Providing nine stub-end platform tracks, for example, would enable full utilization of a bi-level interlocking, accommodating 48 tph (24 tph in each direction). With fewer platform tracks, the interlocking would not be fully utilized to its practical capacity. Providing more than nine platform tracks would not increase throughput above 48 tph, since the interlocking capacity would govern.

Station platform capacity and the required number of tracks for through-running operations (Alternative 2) is described in **Appendix B**.

2 The AM peak Is defined as 6AM-10AM, with "peak of the peak" from 7AM-9AM. The PM peak Is defined as 4PM-8PM, with "peak of the peak" from 5PM-7PM.

3 Practical capacity in trains per hour was calculated by dividing the two-hour peak capacity by two and rounding down to the nearest whole number.

Section 4.5

Emergency Ventilation Systems

Fire-Life Safety

While the focus of this feasibility report is on expanding the capacity of the station, several of the alternatives analyzed require additional tunnels in order to maximize the station capacity. These new tunnel structures must of course have proper fire-life safety measures. This section only reviews the highlights on compliance for tunnel ventilation, focusing instead on aspects impacting the station design.

Tunnel Ventilation

The tunnel ventilation system would address various tunnel operating conditions. Under normal operating conditions, when trains are moving freely throughout the tunnels, the system should be able to remove train-generated heat during the warmer months by using the airflows developed by the piston effect of moving trains to exchange tunnel air with outside air. Under congested (or perturbed) operations, when trains are stopped or moving slowly for extended periods, the system should preclude tunnel temperatures from reaching levels above the design operating temperatures of the onboard equipment. Under fire emergency conditions, when a train is stopped and experiencing a fire, the system should be able to control the movement of hot gases and smoke to maintain visibility and keep emergency routes smoke-free to facilitate safe evacuation of passengers and fire-fighting operations (Figure 4-30).

The emergency ventilation system would comply with the latest edition of National Fire Protection Association (NFPA) 130, Standard for Fixed Guideway Transit and Passenger Rail Systems, and Amtrak Engineering Practice EP4006, Overbuild of Amtrak Right-of-way Design Policy.

The tunnel ventilation system would be connected to Amtrak's existing SCADA system and incorporated into the Emergency Action Plans. The SCADA system would be upgraded (key operational control personnel will be trained) to accommodate all the new system associated with the tunnel ventilation system.

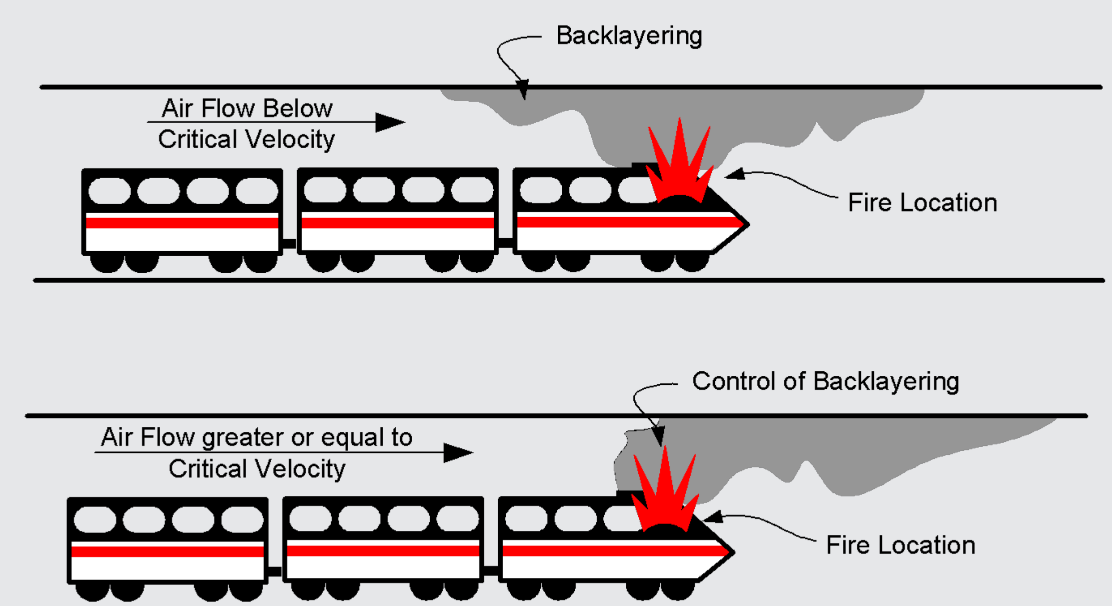
Egress / Access

For tunnels, emergency exits to the surface, including fire resistive enclosed stairways and passages, must be provided every 2,500 feet and must be separate from ventilation shafts (but can be adjacent). An exit provides a means for people to leave the tunnel environment and reach the surface. According to NFPA 130, in lieu of exits every 2,500 feet, cross passages would be provided, spaced no farther than 800 feet apart. A cross passage provides a means for people to move from one tunnel to another. Means of egress and exits from the tunnel would serve as emergency access routes.

Egress from the train is via side doors to tunnel walkway. Mobility impaired occupants would be assisted in detraining by train staff.

For stations, NFPA 130 requires sufficient egress capacity to evacuate the platform occupant load from a station platform in 4 minutes or less and that the station shall be designed to permit evacuation from the most remote point on the platform to a point of safety in 6 minutes or less. The points of safety for Penn Station will comply with NFPA 130 Section 3.3.42: "An enclosed exit that leads to a public way or safe location outside the structure, an at-grade point beyond any enclosing structure, or other area that affords adequate protection for evacuating passengers." The following locations would comply with NFPA 130: 1) the enclosed exit at the platform end that leads to a public way outside the station; 2) an at-grade point beyond any enclosing entrance; and 3) the station concourse protected by an emergency ventilation system designed in accordance with NFPA 130 and approved by the Authority Having Jurisdiction (AHJ). The regulation stipulates that travel distance on a platform to means of egress (escalator, stair or pedestrian ramp) be no greater than 325 feet.

Figure 4-30
Smoke Control Criteria



Hudson River Tunnel Emergency Ventilation System

To meet the emergency ventilation requirements in the Hudson Tunnel Project tunnels, the 30% design includes three tunnel fan plants and a tunnel duct extraction system. The Hudson River Tunnel section includes fan plants on both shores of the Hudson: one in Hoboken, New Jersey, and the other east of Twelfth Avenue in Manhattan. The third fan plant would be located in Manhattan at the portal of the tunnel where it connects to A-Yard at Tenth Avenue. The Hoboken and the Twelfth Avenue fan plants would connect to the running tunnels and duct systems through a series of shafts and dampers. The A-Yard fan plant would connect to the tunnels only. **Table 4-4** lists the fan capacities. **Figure 4-31** presents a schematic of the tunnel ventilation system and ventilation zones. Each tunnel fan plant would effectively operate with three pairs of vertically mounted axial-flow fans and a standby fan, except for the A-Yard fan plant, which would only operate with six horizontally mounted reversible axial-flow fans due to vertical limitations. Each pair has been developed to connect to the tunnels through independent shafts. One pair would serve the tunnel duct system that runs throughout the tunnels. This pair would also include an extra standby fan. These fans are single-direction fans that only would operate in exhaust during a fire/smoke emergency. The remaining two pairs of fans would connect to the running tunnels through a series of dampers. These fans would be reversible and would be able to supply air to or exhaust air from the tunnels at the base of the fan plants. Each fan would have an isolation damper and sound attenuators located at both sides of the fan. The two independent shafts serving the running tunnels would have bypass capability in the fan plant to allow the exchange of tunnel air with outside air without fan operation. A cross section of the tunnel showing the ventilation duct is presented in **Figure 4-32**.

It should be noted that the Hoboken and Twelfth Avenue fan plants would each have a third fan to serve the tunnel duct system associated with the longer Palisades and Hudson River tunnels. However, the system is being designed so that no more than two of these three fans operate (in parallel) at the same time with the third fan acting as a standby in case one fan is out of service according to Amtrak EP4006.

Table 4-4

Hudson River Tunnel Fan Plant Capacity

Fan Plants	Fan Type	No. of Fans	Each Fan Airflow (cfm)
Hoboken	Trainway	4	150,000
	Tunnel Duct	3	150,000
Twelfth Avenue	Trainway	4	150,000
	Tunnel Duct	3	150,000
A-Yard	Trainway	6	100,000

Figure 4-31
Hudson Tunnel Project Ventilation System

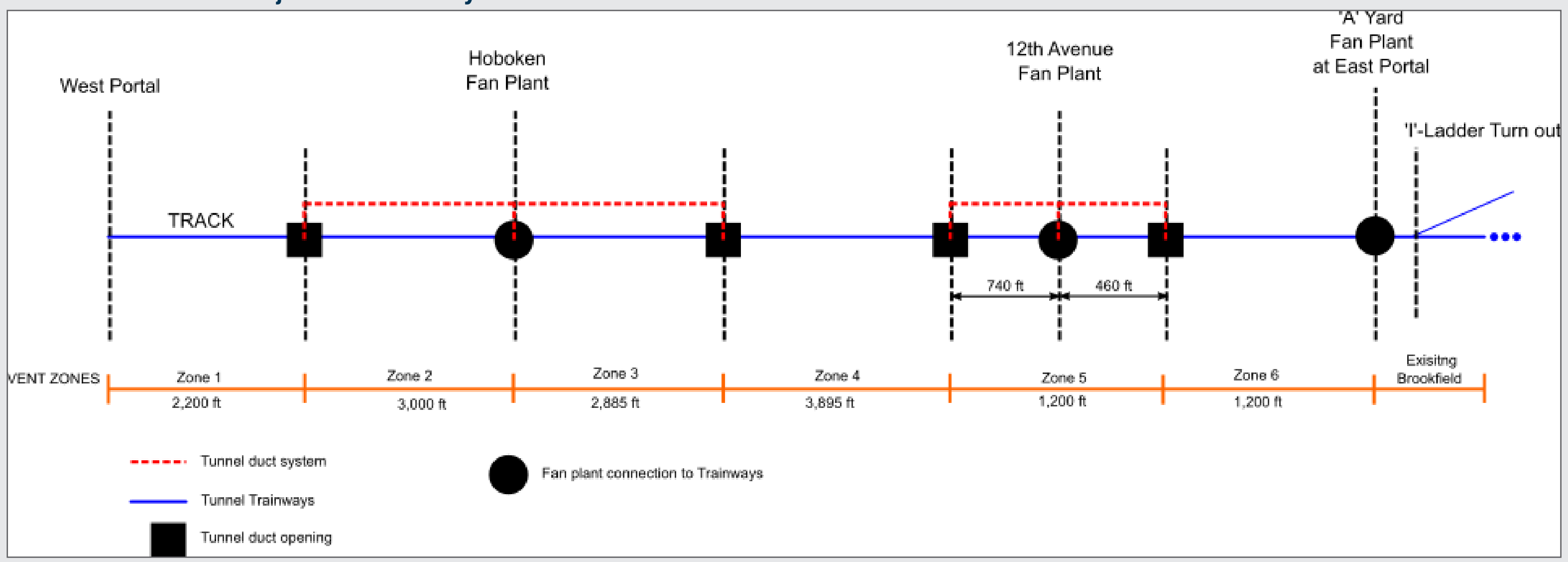
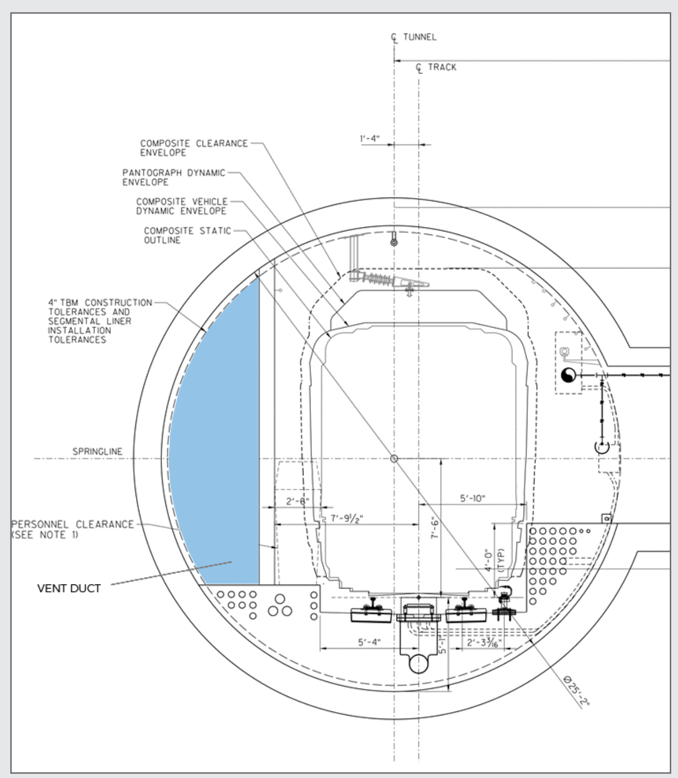


Figure 4-32
Typical Tunnel Cross Section Showing Ventilation Duct



Existing Emergency Ventilation Systems for Penn Station, Moynihan Train Hall, and Brookfield Overbuild

Penn Station Emergency Ventilation System

The existing Penn Station platform-level ventilation system includes 11 variable speed fans (within seven different fan rooms throughout the station and with an overall capacity close to 3,000,000 cubic feet per minute [cfm]), dampers, variable frequency drives, and a control system. Each fan room has direct connections from platform areas to street gratings or vent shafts surrounding Madison Square Garden and Two Penn Plaza.

The platform fan capacities range from 72,000 cfm to 330,000 cfm. Each fan can be operated in supply or exhaust. The variable frequency drive allows the fans to be run at lower speeds for platform cooling and ventilation during non-emergency scenarios. Fans are controlled by the SCADA control system with pre-programmed emergency ventilation modes (initiated by Amtrak's operational control center personnel that address fire emergency scenarios and ventilation platform and track needs) that only address fire emergency scenarios on the platform. The fans are powered with dual power feeders, but they are not connected to any diesel generators.

The make-up air for the platform ventilation system comes from station entrances and platforms. Outside air is drawn to the platform area through the open station entrances, stairs, and escalators that connect the platforms to the concourses. The platform ventilation system was designed to meet NFPA 130 requirements with the current station configuration.

Moynihan Train Hall Emergency Ventilation Station
The Moynihan Train Hall emergency ventilation system serves the platforms and tracks immediately west of the existing Penn Station, underneath the James A. Farley Building. Moynihan Train Hall has an emergency ventilation system that consists of six fan plants and eight bi-directional emergency ventilation fans, associated dampers, variable frequency drives, and sound attenuators. The total capacity of the emergency ventilation system is approximately 1,500,000 cfm.

The emergency ventilation system was designed to meet NFPA 130 criteria for fires occurring on the platform level or on trains. The emergency ventilation system takes into account the existing Penn Station emergency ventilation system and acts in concert with the existing Penn Station ventilation system to meet NFPA 130 criteria at the existing Penn Station platforms and tracks. The platform fan capacities range from 125,000 cfm to 250,000 cfm.

The design of the ventilation system followed an engineering analysis permitted by NFPA 130. A computational fluid dynamics model was developed to simulate the station configuration and the interaction of the ventilation system with the design fire. The results of the simulations were used to optimally size the emergency ventilation fans and to develop optimal operating modes for fires on the platform or track level of Moynihan Train Hall.

Brookfield Overbuild Emergency Ventilation System
The Brookfield Overbuild is a commercial development over the train yard tracks west of Moynihan Train Hall and east of Dyer Avenue (between Tenth and Ninth Avenues). The emergency ventilation system serves the tracks immediately west of Moynihan Train Hall, underneath the Brookfield Overbuild. The emergency ventilation system consists of eight fan plants and eight bi-directional emergency ventilation fans, associated dampers, variable frequency drives, and sound attenuators. The total capacity of the emergency ventilation system is approximately 280,000 cfm. The lower ventilation system capacity compared to Moynihan Train Hall and existing Penn Station is due to the higher ceiling height and ducted ventilation system. The higher ceiling height acts as a large smoke reservoir, which allows smoke to accumulate in the ceiling region and the ventilation duct network is able to extract the smoke more efficiently.

The emergency ventilation system was designed to meet NFPA 130 criteria for train fires underneath the Brookfield Overbuild. An engineering approach consisting of computational fluid dynamics modeling was used to determine the optimal ventilation fan capacity and configuration to meet NFPA 130 criteria. The platform fan capacities are 35,000 cfm.

Facilities and Traction Power

Con Edison Power
Any alternative will require a tunnel emergency ventilation system, each consisting of two to four new fan plants. The fan plants will work together in various pre-determined push-pull ventilation modes as a single coordinated system. Therefore, the tunnel ventilation power must be available for all the distributed fan plants as a single system.

Large power demand can only be supplied by high tension/medium voltage (MV) services by Con Edison, or low voltage (LV), made available by Con Edison originating from a utility "spot network." The typical tunnel ventilation fans also require the power supply be strong enough to tolerate quick reversing and fast startups of fans per NFPA-130, which usually require upsizing/strengthening the supply source. Within Manhattan areas Con Edison uses standalone distribution power grid systems that are known as 13.2kV "networks." A high tension service substation has to follow detailed Con Edison and code compliance requirements and specifications including the required step-down transformers to supply the fan plant.

Subject to space availability and feasibility, Con Edison spot networks are preferred to a customer's similar parallel type 13.2kV/480V substations if power is to be only used locally. A spot network is of higher reliability, requires less maintenance than a 13.2kV/480V substation counterpart, and can supply several separate 480V services and can include a second backup service as source. A disadvantage is that a spot network location must be close to the fan plant and above the flood plain per Con Edison requirements.

Given the large transit and commercial development projects in the area, including the Penn Station Capacity Expansion Project, Con Edison is expected to further expand and strengthen the 13.2kV network systems. However, adding electric power feeders, spot networks and other grid plant through already congested areas will require careful long and short-term planning. The single "high reliability service" and, alternately, the service with an additional separate service are feasible emergency ventilation power source options per NFPA 130 and have already been used in other New York tunnel and rail yard projects, including East Side Access, Second Avenue Subway Phase 1 and 2, and Vanderbilt/Atlantic Yards. Based on the proposed fan plant locations, each fan plant would require a local Con Edison 13.2kV/480V spot network with minimum two 480V services (the second as a 100% backup) instead of a large local generator.

Backup Power

Due to the expected large fan plant loads and transient motor start requirements, a fan plant back-up generator set would need to be large and oversized to account for additional transient start capabilities. Unless the generators are interconnected at 13.2kV, the generator power can only be used to back-up the local fan plant. Since an emergency generator is able to supply loads within approximately 10 seconds, consistently meeting this requirement becomes more challenging above a certain size.

On-site fuel storage is required for a back-up generator used for emergency purposes, which means diesel fuel storage is required at the fan plant site. The sizable diesel generator fuel tank and fuel piping would also represent additional unwarranted fire hazards to be further mitigated to satisfy the local more stringent regulations.

Generators require auxiliary equipment and controls such as fuel pump and piping systems, back-up charger and battery systems, louvers, installed and protected in accordance with code and local requirements and regulations. A diesel generator for fan plant back-up power is a challenging option due to the required very large generator size impacting real-estate, emission control, stored fuel, maintenance/repairs/life span and other technical challenges for the required generator size. Due to the complexity and required large size of a diesel generator fully backing up a fan plant, this option may not be more reliable than a utility service back-up or require less real-estate than the separate electric service or high reliability options.

Traction Power

For any alternative where there is no direct train connectivity to existing Penn Station and a new separate station expansion is proposed, traction power will need to come from another source. There are two possible options for traction power, either feed from an Amtrak source or feed from a utility and then convert to Amtrak's standard power needs. Both options should remain open at this stage of feasibility. At least one new traction power substation will be required for the station expansion. The station will need to convert high voltage from Con Edison to 12kV, 25Hz. This will require Con Edison to provide the required infrastructure and circuitry to feed the frequency converting traction power substation. The 25Hz power would need to be generated for the station, by implementing either static converters or motor-generators to convert 60Hz to 25Hz. Additionally, the station would transform the power from the high voltage feed to a usable 12kV traction power appropriate for the trains.

If space constraints preclude a frequency converting traction power substation, it is still possible to bring power through the new tunnels from either an existing source, such as Sub 42 (North Bergen, NJ), or a new traction power substation constructed west of the Hudson River.

5 Alternatives Considered

In this chapter, we assess all the alternatives and design concepts. Each section begins with an overall description of the alternative, followed by in-depth analysis of each design concept. At the end of each design concept, an overall assessment is provided. **Chapter 6 — Summary** provides a complete summary of all the assessments.

5.1

Alternative 1
Under Penn Station

Design Concept 1:

Underpinning — Single Level

Design Concept 2:

Mined — Single Level

Alternative 1 was developed to examine the feasibility of an alternative that confines all underground station infrastructure within the existing footprint of Penn Station. The alternative consists of new tracks and platforms in a station expansion provided in a new lower level beneath existing Penn Station. The main benefits of this alternative are superior connectivity to the existing Penn Station and no need for additional real estate acquisition.

Keeping all underground station infrastructure within the existing footprint of the existing station is a defining feature of this alternative. Pedestrian connectivity to Penn Station (including ADA accessibility), emergency exiting, new concourse space, and BOH space for mechanical and electrical equipment would all need to be accommodated either in the new station infrastructure, and/or within existing Penn Station for this alternative to be considered feasible.

Two design concepts were evaluated for this alternative, both with ten new station platform tracks on a single horizontal level below the existing track and platform level within the existing footprint of the station. The difference between these two design concepts (Underpinning - Single Level and Mined — Single Level) is the method of constructing new station expansion infrastructure below the existing station footprint. The Underpinning — Single Level design concept would require underpinning over 1,000 existing columns between Eighth and Seventh Avenues, which is not technically feasible. The Mined — Single Level design concept is vertically separated from the existing station and would not require any underpinning.

The underground station infrastructure for both design concepts falls entirely within the existing station footprint, although additional parcels beyond the station footprint are also required to provide construction access. The Mined – Single Level design concept requires more additional parcels as compared to the Underpinning — Single Level design concept, as the mined concept requires pedestrian connectivity and fire life safety connections between the existing station and the station expansion. New tunnel ventilation facilities would be required at this location, requiring even more permanent parcel acquisition beyond the footprint of the existing Penn Station to support fire life safety requirements.

Ultimately, the Mined — Single Level design concept was determined to be infeasible, because it did not meet the minimum operational requirements. The feasibility of a bi-level mined design concept was investigated in order to provide the required operational performance of the new station track configuration. However, in establishing the alignment profile for the bi-level mined alignment, the western limit of the new

5.1.1

Alternative 1
Under Penn Station

Design Concept 1: **Underpinning — Single-Level**

Key Take-Aways

1. 10 new station tracks at same elevation added below existing Penn Station tracks connecting to Hudson Tunnel Project design via new tunnels, with no direct train connectivity to existing Penn Station.
2. Requires complex tunneling below Penn Station and major structural underpinning of existing columns, introducing complex staged construction within active railroad operations.
3. Pedestrian movement from new station up through existing Penn Station track level would require major reconstruction of existing platforms with existing tracks permanently removed, which is considered not reasonable.
4. Selected lower level platform tracks potentially could be extended to a future new tunnel across Manhattan and East River. Therefore, compatible with future vision for through-running regional metro.
5. Fails engineering and operational feasibility assessment. Therefore, **design concept does not advance further.**

station platforms begins east of Seventh Avenue, and the eastern limit is east of Broadway, an entire city block east of Penn Station, well beyond the existing station footprint. The cavern excavations would also come within a few feet of City Water Tunnel No. 1, a distance which could potentially compromise this infrastructure, and is therefore unacceptable. For these reasons, the bi-level mined design concept was deemed infeasible and was not evaluated further.

Alternative 1 does not pass the technical feasibility review and therefore is not considered further.

5.1.1.1

Design Concept Summary

Alternative 1, Design Concept 1 would add ten platform tracks on a single level located directly under the existing station footprint, bounded roughly by West 31st Street, West 33rd Street, Ninth Avenue and Seventh Avenue. The depth of the new platforms is approximately 75 feet below the existing Penn Station platforms. This concept is predicated on direct tunnel and rail connectivity to the Hudson River Tunnel infrastructure by means of a proposed bellmouth enlargement at Twelfth Avenue and West 30th Street and within the WRY. The bellmouth is a proposed structure that would create space for additional railroad tracks to connect with the two tracks currently planned for the Hudson Tunnel Project. The running single-track tunnels bifurcate from the bellmouth and extend eastward through cavern enlargements housing a rail interlocking below Penn Station and continue east as the tracks diverge into the platform tracks below the footprint of Penn Station, directly below the existing platform tracks (Figure 5-1).

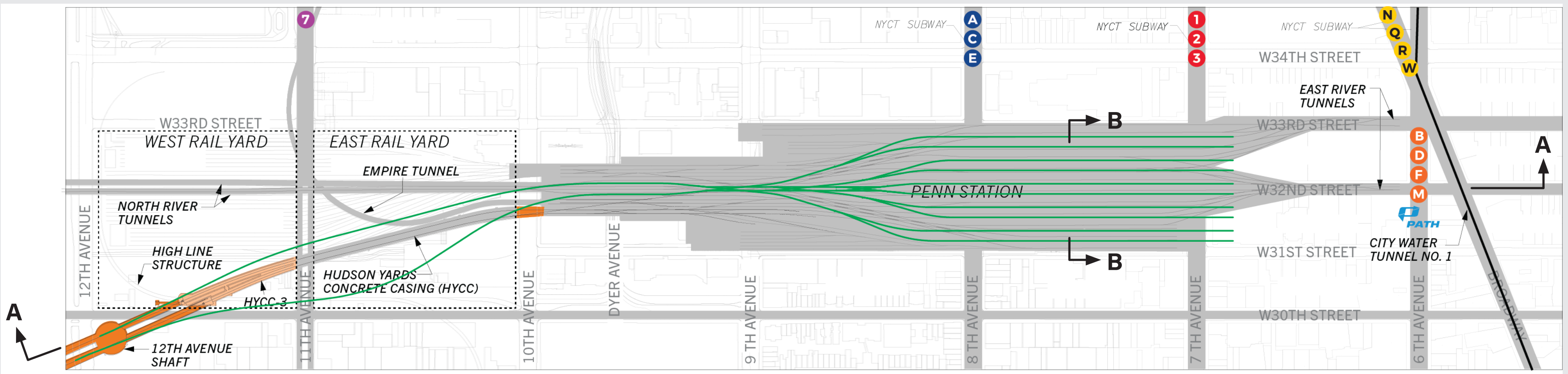
This concept would require underpinning of the existing columns of Penn Station from Eighth Avenue to Seventh Avenue, including the underpinning of the affected Eighth Avenue subway columns within Penn Station between West 33rd and West 31st Streets.

This new concourse would only be accessible via the existing station footprint and would not add any new street level access. To access the new concourse, multiple tracks from the existing station would need to be removed to provide space for vertical circulation serving the concourse below. The track and platform removal would force a larger operational change, as the likely location for these cores would be within the space of Tracks 7 through 16 (which are some of the most frequently used in operations). As both tracks are "through" tracks, all operators would lose flexibility, which reduces the value of the additional new lower tracks. Lastly, these elements would require additional space on the lower level within Penn Station and could present circulation conflicts. Passengers would most likely wait closer to the new cores, if they don't have advance knowledge that their train would depart from the deepest level increasing local area congestion on the upper concourse level.

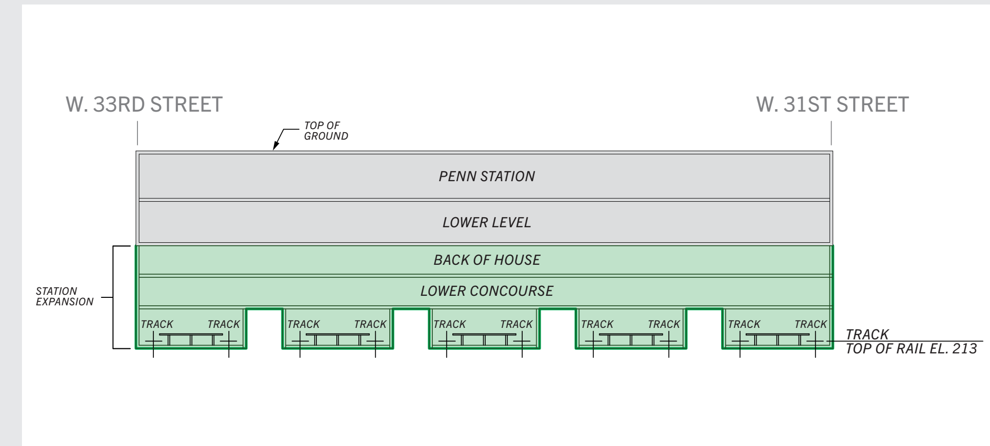
All engineering drawings related to this concept are provided within Appendix A.1. This design concept does not pass the engineering feasibility assessment due to high complexity and the inability to stay within the existing footprint. In addition, it does not meet the operational performance requirements for this project. It is not recommended to carry this concept forward for further analysis.

Figure 5-1

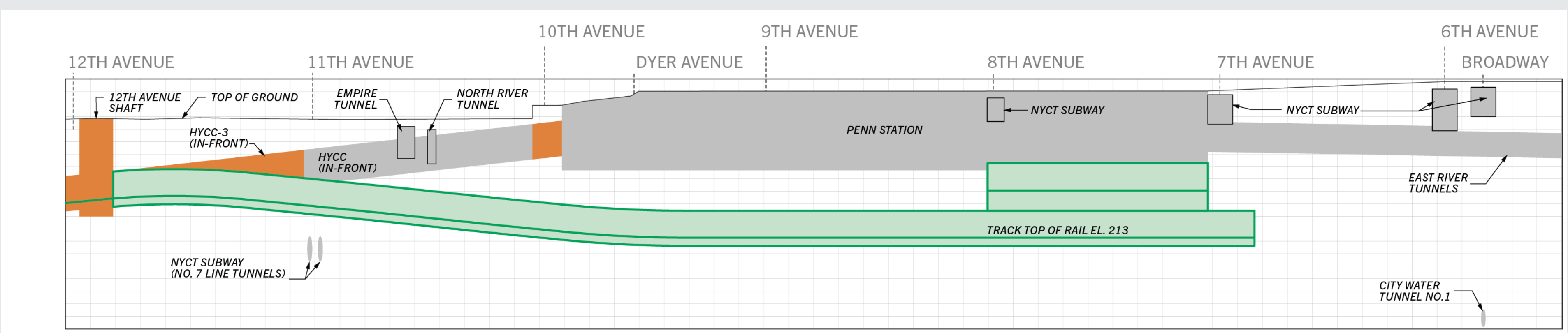
Alternative 1, Design Concept 1: Plan, Profile, and Cross Section



Design Concept Plan



Cross Section B-B



Profile Section A-A

5.1.1.2
Engineering Feasibility

Track Geometry

See Figure 5-2.

General
This design concept would provide ten platform tracks, with five center platforms in a single level, located below the existing platform tracks. This platform complex would be reached by two lead tracks that diverge from the Hudson River Tunnel via a bellmouth structure at Twelfth Avenue. Around Tenth Avenue, the two new lead tracks converge under the Hudson River Tunnel alignment and branch out via a symmetrical interlocking into the platform tracks.

Horizontal Alignment
This concept diverges from the bellmouth via No. 20 turnouts. The westbound lead track runs roughly parallel to the Hudson River Tunnel alignment below Hudson Yards.

The eastbound lead track roughly follows the West 30th Street alignment eastward for 500 feet, where a sweeping reverse curve brings it parallel to the westbound alignment. Both alignments enter the Penn Station footprint at Tenth Avenue, roughly in line with the existing North River Tunnels. The westbound lead has superelevated, spiraled curves supporting 45 mph operations for 2,200 feet between Twelfth Avenue and an interlocking just west of Ninth Avenue, at which point the speed drops to 15 mph for the 2,300 feet to the east end of the platforms. The eastbound lead supports 45 mph from Twelfth Avenue to the beginning of the reverse curve, which restricts speeds to 30 mph for the ensuing 1,500 feet to the interlocking just west of Ninth Avenue, 15 mph for 2,300 feet to the east end of the platforms.

This alternative has minor alignment deviations such as non-compliant tangent lengths, non-spiraled curves in the 15 mph zone and insufficient distances between turnouts, which would need to be approved by Amtrak.

Other than the No. 20 turnouts at the bellmouth, all special trackwork consists of No. 10 double crossovers, standard turnouts and double slip switches. Due to a lack of available track length to fit in the interlocking at Ninth Avenue, the track configuration depicted contains overlapping slip switches and double crossovers, a maintenance challenge that should be avoided if possible. If this concept advances further, this interlocking requires further study.

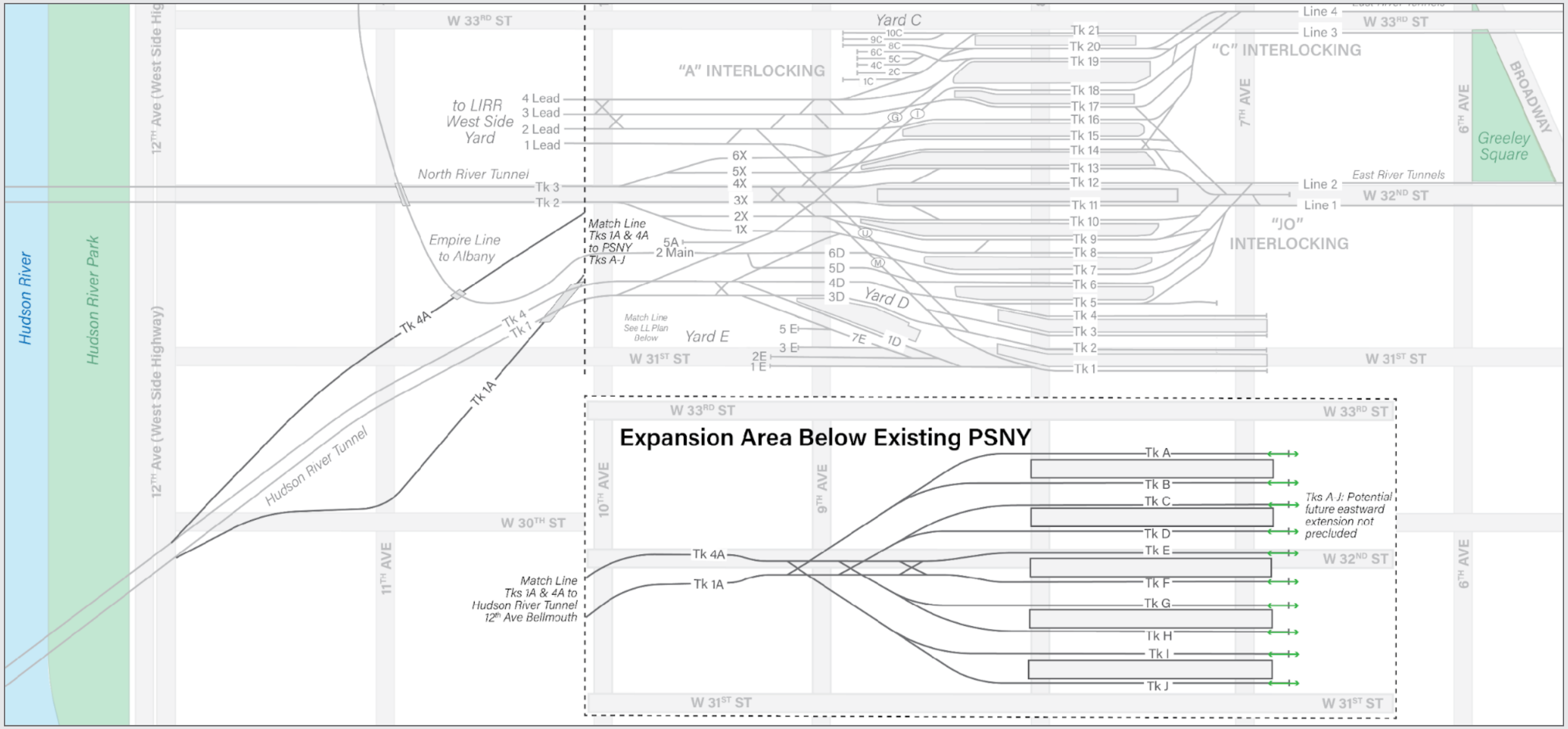
Vertical Alignment
The vertical alignment of Track T3 has excessive grades east of Eleventh Avenue, where grades at the project maximum of 2.1% are coincident with horizontal curves, driving the grade up to nearly 2.3% with curve compensation. As with other concepts, the compensated grade through the diverging No. 20 turnouts at Twelfth Avenue is 2.11%. Vertical curve lengths are appropriate for the design speeds despite minor deviation from Spec 63 main line standards for rate of change. No horizontal clearance deviations have been identified.

Station Platforms
This concept provides for five center platforms, each 30 feet wide and 1,050 feet long to allow a tolerance for stopping distance. The concept provides adequate tangent length west of the platforms such that the platforms would not need to be tapered for carbody end excess and center excess. The top of rail elevation for the station tracks is approximately El. 213.

In summary, the track geometry is considered acceptable, though if this concept were to advance, each deviation would need to be studied in greater detail.

Figure 5-2

Track Schematic



Constructability

See **Figure 5-3**, which references each of the following areas.

Bellmouth — General ①
For this study, the bellmouth is defined as a proposed structure that will create space for additional railroad tracks to connect with the two tracks currently planned for the Hudson Tunnel Project. The bellmouth would be located between Twelfth Avenue and Eleventh Avenue, with the exact location and geometry varying between proposed options. The current Hudson Tunnel Project design includes two parallel mined tunnels constructed by SEM between the Twelfth Avenue shaft and the HYCC-3 cut- and-cover tunnel north of West 30th Street, within the WRY. Any alignment alternative that requires direct connectivity to the Hudson Tunnel Project at this location would require an engineering solution to mitigate the impact of the bellmouth on planned Hudson Tunnel Project elements. The planned mined tunnel design below West 30th Street would need to be eliminated, and a large cut-and-cover excavation from the Twelfth Avenue shaft encapsulating new tunnel connections at West 30th Street and within the WRY would need to be redesigned.

Alternative 1, Design Concept 1 would require significant redesign of the Hudson Tunnel Project — Manhattan Tunnel infrastructure (currently in an active procurement[4]) and HYCC-3 (currently in construction). The FTA signed a Full Funding Grant Agreement with the Gateway Development Corporation on July 8, 2024, which commits the final piece of funding for the Hudson Tunnel Project and enables construction to begin. See **Figure 5-4**.

4 The Manhattan tunnels and shafts "core and shell" scope of work is included within the Manhattan Tunnels Contract P1B, which has a notice to proceed for construction anticipated in Q4 2024, with a Draft Request for Proposals released to the contracting community in Q1 2024. The tunnel final liner and support of excavation of the shafts have been designed to 100% level. The "fit out" of these tunnels and shafts is included within a subsequent Contract (P2), which is currently being advanced by the engineer of record. The 60% design was completed in Q1 2024 and is currently progressing towards 90% design. This design is based on the established geometry of the previous Contract P1B tunnel and shaft elements.

West of Twelfth Avenue Shaft ①
The alignment requires widening the Hudson River Tunnel SEM tunnels west of the Twelfth Avenue Shaft, below Twelfth Avenue. The proposed mined tunnel enlargement linearly increases to incorporate the proposed turnouts. For the Hudson Tunnel Project, parallel SEM tunnels would be mined between the Twelfth Avenue Shaft and temporary shafts, below Twelfth Avenue. Ground treatment in the form of ground freezing would be required to pre-treat the poor ground prior to any tunneling. The affected NYCDEP interceptor sewer piles (see **Section 4.1**) below Twelfth Avenue would be underpinned from within the SEM tunnel and structurally integrated with the initial tunnel liner consisting of curved structural steel members. The proposed widening of SEM tunnels at the interface with the interceptor sewer below Twelfth Avenue increases the risk of impacting existing infrastructure (**Figure 5-5**).

As documented within NYCDEP's performance criteria, "the top of the support frame/ring to the bottom of the existing interceptor sewer to be at least 6 feet." Currently, the vertical separation dimension is approximately 12 feet. Widening the cross section of the SEM tunnels by approximately 50% to incorporate the track alignment will drive the elevation of the tunnel crown higher and closer to the underside of the interceptor sewer, potentially within the 6-foot limit provided by NYCDEP. In addition, adequate space around the perimeter of the tunnel is required to horizontally drill and install ground freezing pipes, such that a frozen zone can form with sufficient clearance from the existing sewer. SEM tunneling and underpinning of the Twelfth Avenue interceptor sewer has an inherent risk associated with this type of construction. Increasing the size of the tunnels and the complexity of the ground treatment and underpinning works from within the tunnels introduces significant additional risk.

Twelfth Avenue Shaft ①
The Twelfth Avenue Shaft geometry and adjacent fan plant shaft including all internal elements such as structural framing, emergency egress, flood gates, and all applicable systems including electrical and ventilation equipment configurations would need to be redesigned to accommodate the addition of two tracks. The alignment would require significant redesign and changes to the shaft. Clearances required for the two additional tracks would interfere with the shaft perimeter and column configuration that support the various below ground levels and future overbuild. It is proposed to increase the diameter of the shaft below Twelfth Avenue and West 30th Street.

Setting out flood gates on or around a turnout would be challenging, as no moving parts are allowed at the flood wall location. It is unclear at this level of study if the moving parts of a turnout would be located at the floodwall location; the track and structural design would need to be reviewed in a subsequent design phase, if this alternative is advanced, to further evaluate concept feasibility.

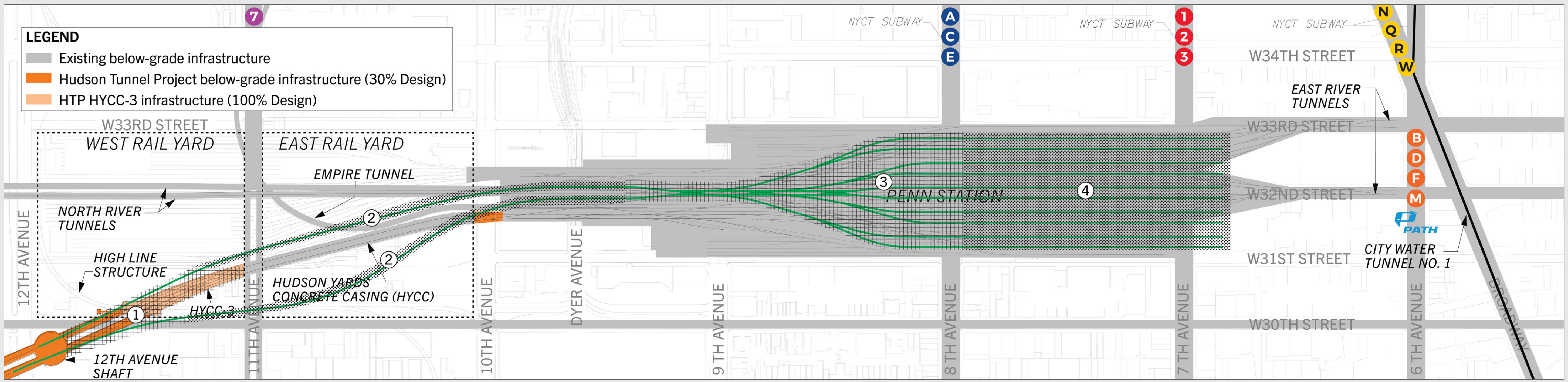
The current circular shaft support of excavation design was engineered to act as a compression ring element with local tunnel/fan plant penetrations with minimum use of internal bracing. With the addition of the cut-and-cover tunnels to the east, and larger penetrations, future redesign needs to consider internal bracing both within the shaft and within the cut-and-cover tunnel as tiebacks are not an option. Depending on the span between support of excavation walls, intermediate king piles may be required.

Bellmouth — West 30th Street and NYCDEP Combined Sewer ①
An active combined sewer/storm drainage is located under West 30th Street, for which the foundations are unknown but are expected to be timber piles. Ground conditions are very poor as this is a reclaimed area whereby a river marsh land has been filled. Below fill levels, ground conditions consist of soft clays and silts over variable rock depths.

To construct a cut-and-cover tunnel within and across the limits of West 30th Street, the combined sewer box would need to be diverted during the duration of construction

Figure 5-3

Constructability Map: Alternative 1 (Under Penn Station): Design Concept 1: Underpinning - Single Level



1 **Bellmouth**

2 **TBM Tunnels**

3 **Mined Tunnels**

4 **Underpinning and Excavation Under Penn Station**

utilizing steel pipes or flumes and supported either by adjacent pre-installed slurry wall panels (where applicable) or new pile frames constructed below the diverted footprint with the tunnel excavation. Large diversion manholes would be required at each end of the steel pipes/ flumes with connection to the existing sewer. The piles supporting the temporary steel pipes/flumes will present a geometric challenge during cut-and-cover excavation as strut supports will be required diagonally between slurry walls at an obtuse configuration to the piles at multiple vertical levels, adjacent to Block 675, Lot 1. Multiple struts at obtuse angles will add more constraints to construction operations by reducing the length of unobstructed bays available for crane moves in and out of the excavation.

East of the Lot 1 limits within West 30th Street a high-rise building (Block 675, Lot 39) has recently been constructed such that a temporary sewer relocation option is not feasible as it would be geometrically constrained between the existing sewer and the high-rise building. It is proposed to support this section of sewer in place either by installing closely space steel "needle" beams below the sewer and making a structural connection to the adjacent slurry wall panels on either side of the street, or by supporting the needle beams by hangers supported by a structural street decking system above (Figures 5-6 and 5-7). Both of these sewer options present concerns, as the logistics of installing and rotating steel needle beams between the slurry walls, under the sewer, and between the existing sewer piles is challenging and requires additional study to prove feasible.

A more efficient, and potentially a more feasible approach along West 30th Street, is to install a temporary and robust pumping system over the duration of the tunnel excavation and construction such that the stretch of sewer that is within the proposed limits of cut-and-cover construction could be demolished to facilitate a less challenging relocation or support in place, as discussed above. The pumps could be submersible, and temporary pipes could be potentially buried under the northern sidewalk. If burying these large pipes is not geometrically feasible within the sidewalk, taking into account the other existing below grade utilities at these locations, considerations could be made to support the pipes above ground level. The sump pump and the pump room to house the pump controls would be near Eleventh Avenue and would most

Figure 5-4

Bellmouth Geometry

NOTE: The track alignment shown is generic for illustrative purposes and does not reflect a specific design concept discussed in this report.

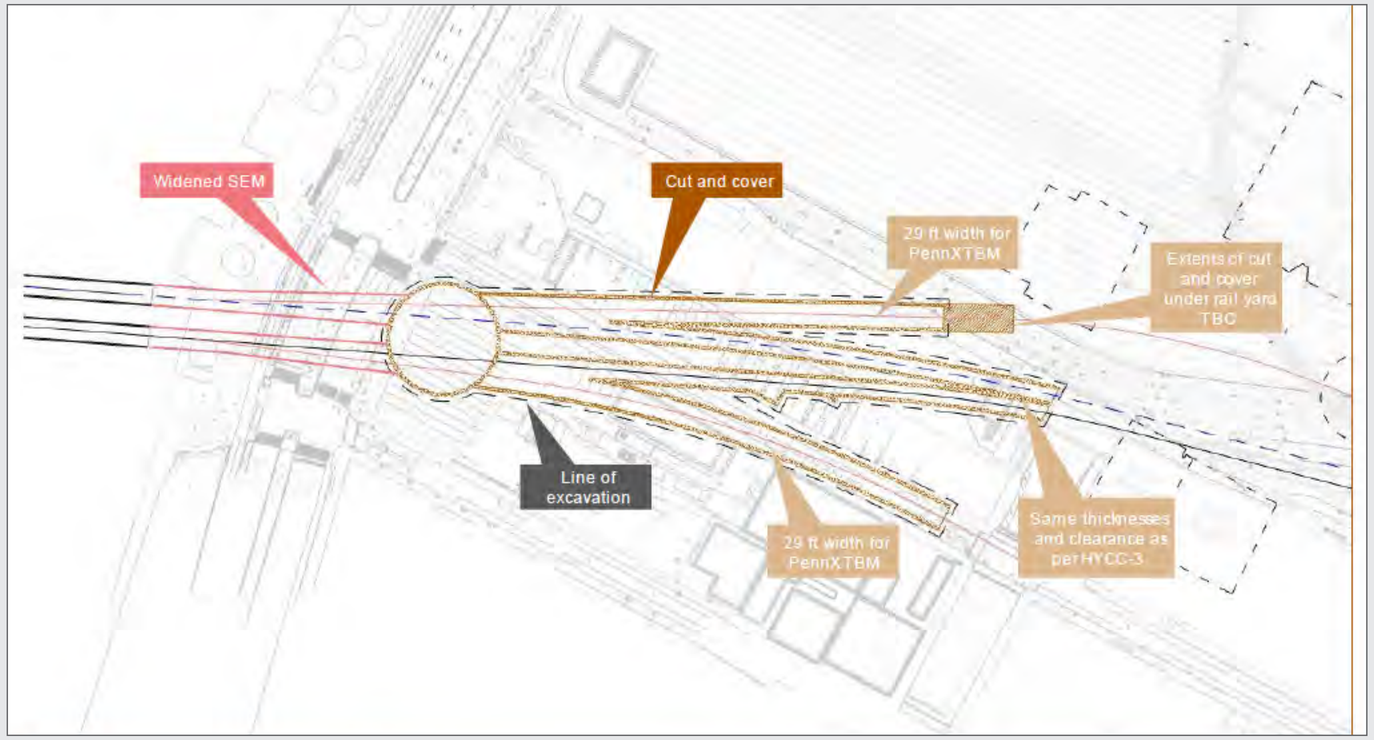
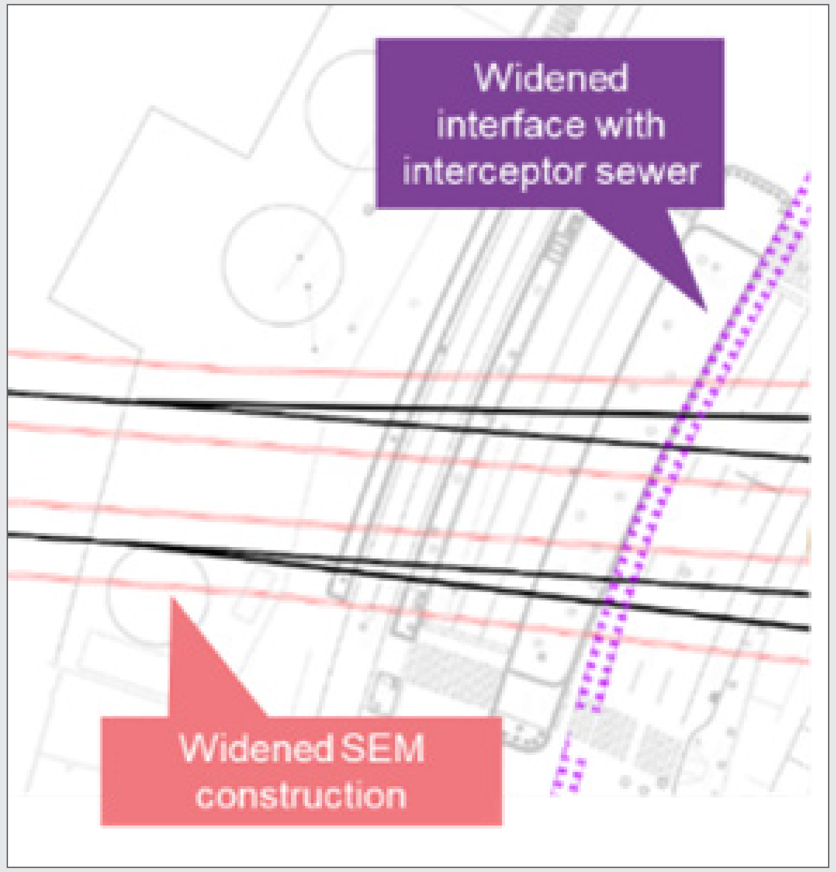


Figure 5-5

Interface with Twelfth Avenue Interceptor Sewer



likely require a standby generator. Additional studies would be required to size all of these temporary systems, assess if there is adequate adjacent real estate north of West 30th Street to house all of these temporary structures while also providing adequate access for MTA and LIRR maintenance and fueling from West 30th Street. NYCDEP's Shaft 26B servicing City Water Tunnel No. 3 is located just west of Tenth Avenue and north of West 30th Street and the High Line. Any new tunnel alignment that is within a 200-foot radius of this shaft would need to be coordinated with NYCDEP in a subsequent phase of design, if this concept is advanced. However, the construction of the shaft is fairly recent, and it is likely that any tunnel alignment proposed will not be considered a feasibility concern as long as the shaft is not immediately adjacent.

The Track T3 tunnel crosses West 30th Street diagonally and is directed north of West 30th interfering with the existing High Line which would require underpinning multiple structural bents of the High Line piers east of the HYCC-3/High Line interface, where the launch of a TBM would occur (Figure 5-8). Underpinning of the High Line requires a better understanding of the geometry between the sewer and the cut-and-cover tunnel. Additional analysis and staged approach for underpinning the High Line is required in a subsequent phase of design, if this concept is advanced. Further coordination is required with NYCDEP and NYC Department of Parks & Recreation for sewer impact and High Line underpinning, respectively, to obtain proof of concept approval.

Bellmouth - WRY ①

Enlargement of the HYCC-3 tunnel within the WRY requires additional underpinning of the High Line foundations which consist of grouped timber piles below a concrete pile cap. Inter-spatial zones between tracks that do not serve a purpose for overall tunnel fit-out would be available for new temporary pile supports (Figure 5-9). Once the tunnel walls are constructed, the permanent load would be transferred to the tunnel roof. However, a staged approach compliant with HYCC-3 design criteria must be adopted and the tunnel structures must be completely waterproofed with the added challenge of requiring temporary "block outs" within the tunnel roof such that the temporary underpinning columns could be removed, and permanent columns installed supported by the tunnel roof.

Figure 5-6

Needle Beam Support Under Sewer

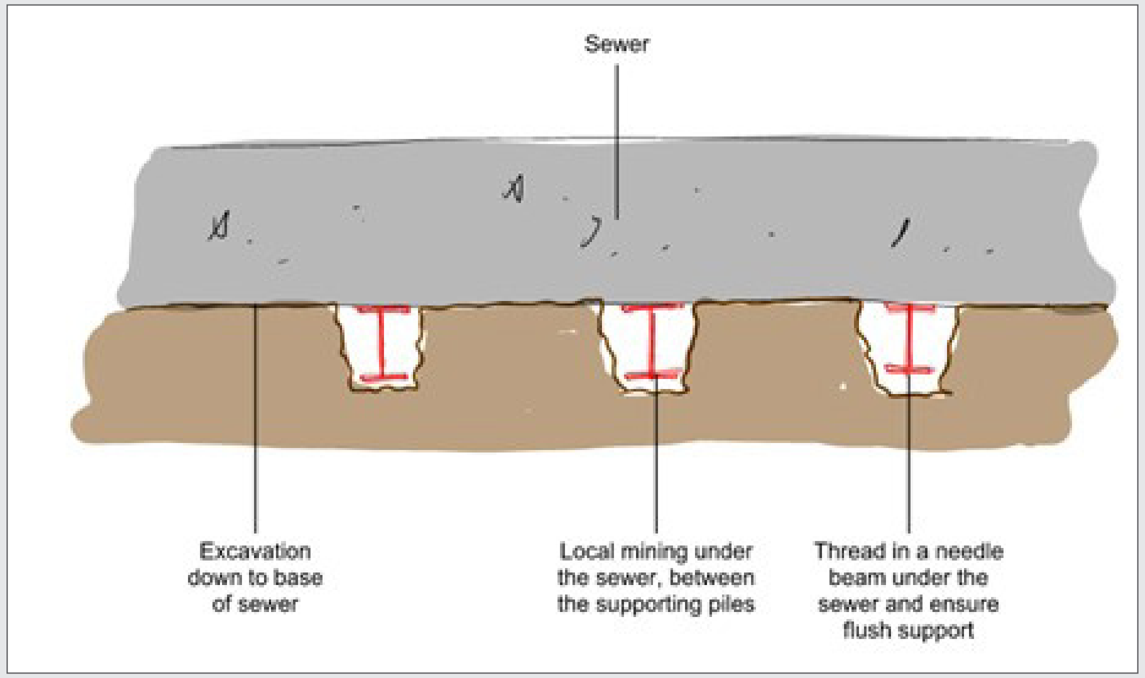
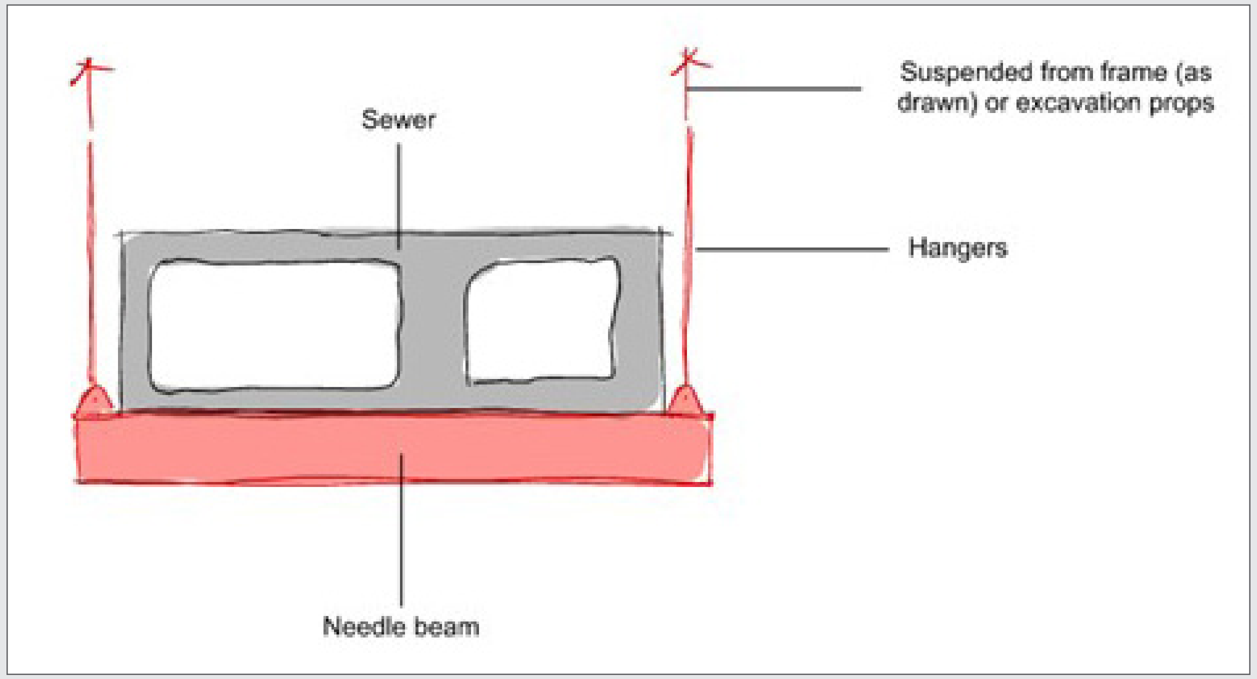


Figure 5-7

Hanger Support of Sewer



North of the High Line, the same overbuild criteria and structural support principles for the currently designed HYCC-3 tunnel would apply. The HYCC-3 design prescribes specific design criteria for limiting vertical and lateral loads above, adjacent to and below the tunnel box. Enlargement of the HYCC-3 tunnels would further reduce the footprint available for placement of the overbuild deep foundations and would alter and potentially limit Related Companies' overbuild design flexibility, especially as it relates to the design and location of a lateral force-resisting system which will require significant space outside and adjacent to the HYCC-3 tunnel footprint. Future coordination and approval of redesign by Related Companies, who own the air rights on the WRY, is critical to advance proof of concept.

TBM Tunnels ②

Termination of TBM drives would terminate around Eighth Avenue, short of the western limits of the station platforms, and short of the underpinning construction limits. As stated previously, TBMs would be removed in pieces or backed-up and/or partially abandoned in-place depending on the specific TBM configuration. An alternative to launching the TBMs from the east is not feasible for this concept as there is no temporary shaft available to launch them within the overall footprint of Penn Station.

Mined Tunnels ③

Mined cavern enlargements are required from between Dyer Avenue/Ninth Avenue and east to Eighth Avenue, short of the western platform limits of the new station tracks to facilitate various interlockings and track turnouts. Between Dyer Avenue and Ninth Avenue, there are no building columns to underpin because this is the segment within the train shed below Brookfield's over-track platform (see Figure 5-10). The tunnel and track profile of these required enlargements are dictated on the required vertical separation of cavern crown, to the active train shed immediately above. Therefore, the crown of the tunnel was determined based on the rock pillar and temporary support required due to the rock quality of this area and to not jeopardize the existing train shed and associated infrastructure. Once the crown of the interlocking cavern is established, the elevation of the adjacent approach caverns to the platform limits is similar, which then establishes the top of rail for the station platforms tracks below Penn Station within the tunnel cross section.

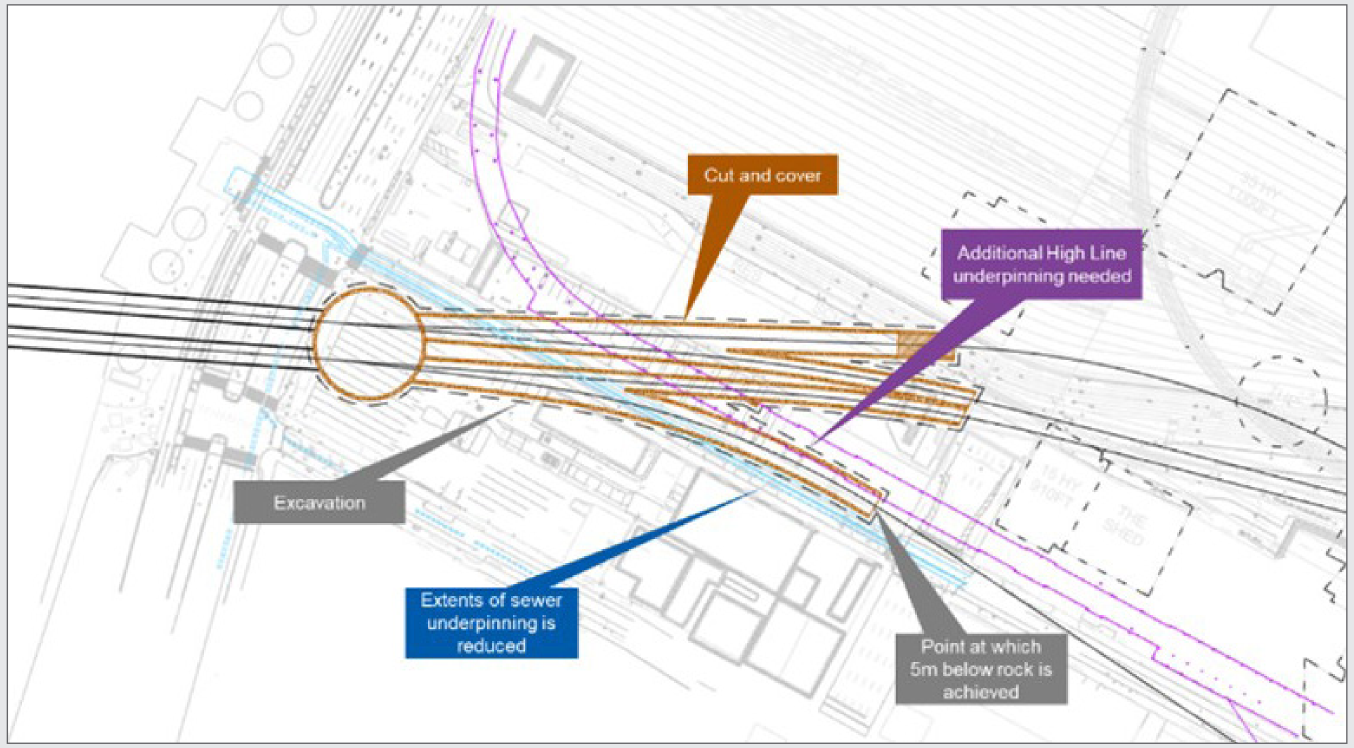
Underpinning and Excavation Under Penn Station ④

As the top of rail elevation for the station platform tracks was established as discussed above, the vertical zone within the new platform limits to the existing platforms above would be excavated via open cut within rock, while staging the underpinning of existing Penn Station infrastructure that falls within or adjacent to the excavation footprint. All affected existing below-track utilities would need to be relocated accordingly. To perform this type of excavation, track-level access within Penn Station is required as low headroom drill rigs would auger a series of mini piles, adjacent to each of the foundations requiring underpinning and permanent removal. The final tip elevation of the mini piles would terminate below the future track level below as not to impose any permanent load to the structure housing them. In this scheme, a needle beam is connected to a set of mini piles by means of a pile cap (see Figure 5-11). The load of the column is transferred to the pile cap and adjoining mini piles by means of a jacking operation, permanently.

Figure 5-8

Cut-and-Cover Extent

The track alignment shown is generic for illustrative purposes and does not reflect a specific design concept discussed in this report.



Rock excavation and supply of all construction materials for the new station platform level would require access via a temporary shaft adjacent to Penn Station (i.e., outside the Penn Station footprint, which would require real estate acquisition to perform demolition of existing structures to excavate the temporary access shaft) or utilizing the adjacent caverns and running tunnels previously mined to an access point either at the Twelfth Avenue shaft or via the proposed fan plant location shaft site with means of a lateral connecting tunnel. Without a temporary access shaft adjacent to Penn Station to support these major operations, the construction schedule would be severely affected, as the only access point would be through a series of underground tunnels blocks away from construction. Construction would also be very arduous and unsafe. Excavation using a bottom-up approach in rock would be ongoing at the same time underpinning from above is being installed, as would construction of the multiple vertical structural floors by new columns and beams while bracing the mini piles and transferring the load back to newly constructed columns (see Figure 5-12). This approach would also have major operational implications to Penn Station. Conversely, the more traditional approach for this type of construction would be a top-down approach, working from existing track level, excavating rock, and installing structure all from within and through Penn Station. All incoming and outgoing materials would need to be accessed through Penn Station and out to street level where a dedicated construction access site would be needed to facilitate the operation with street access for all construction vehicles. Similar to the bottom-up approach, this is also not considered reasonable.

> **In summary, underpinning the more than 1,000 columns and other below existing track-level structures (e.g., utility tunnels) unique within Penn station, even considering the various construction stages that would be required to continue operations during construction, is not considered feasible.**

Figure 5-9

High Line Underpinning Concept

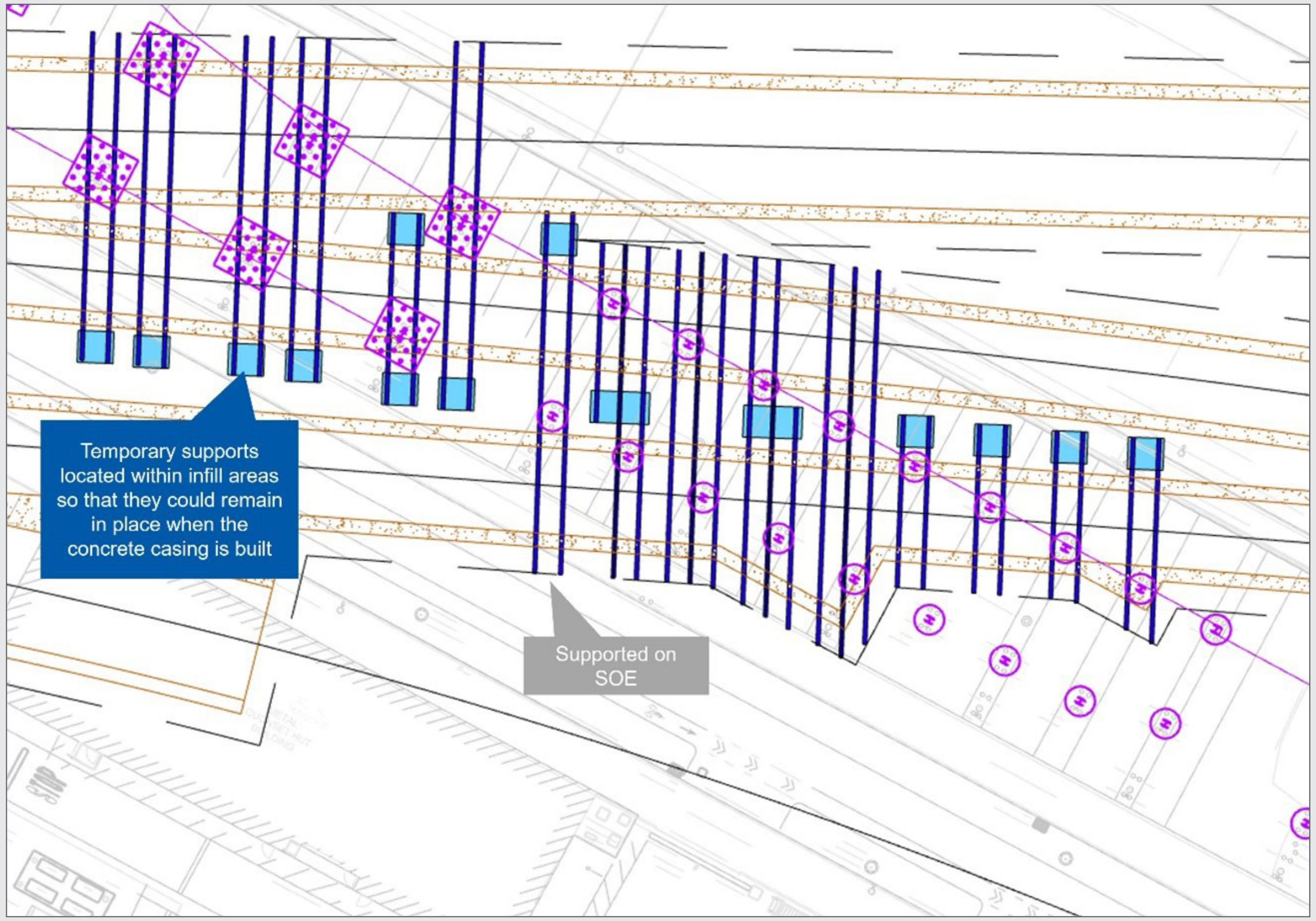


Figure 5-10

Tunnel Profile

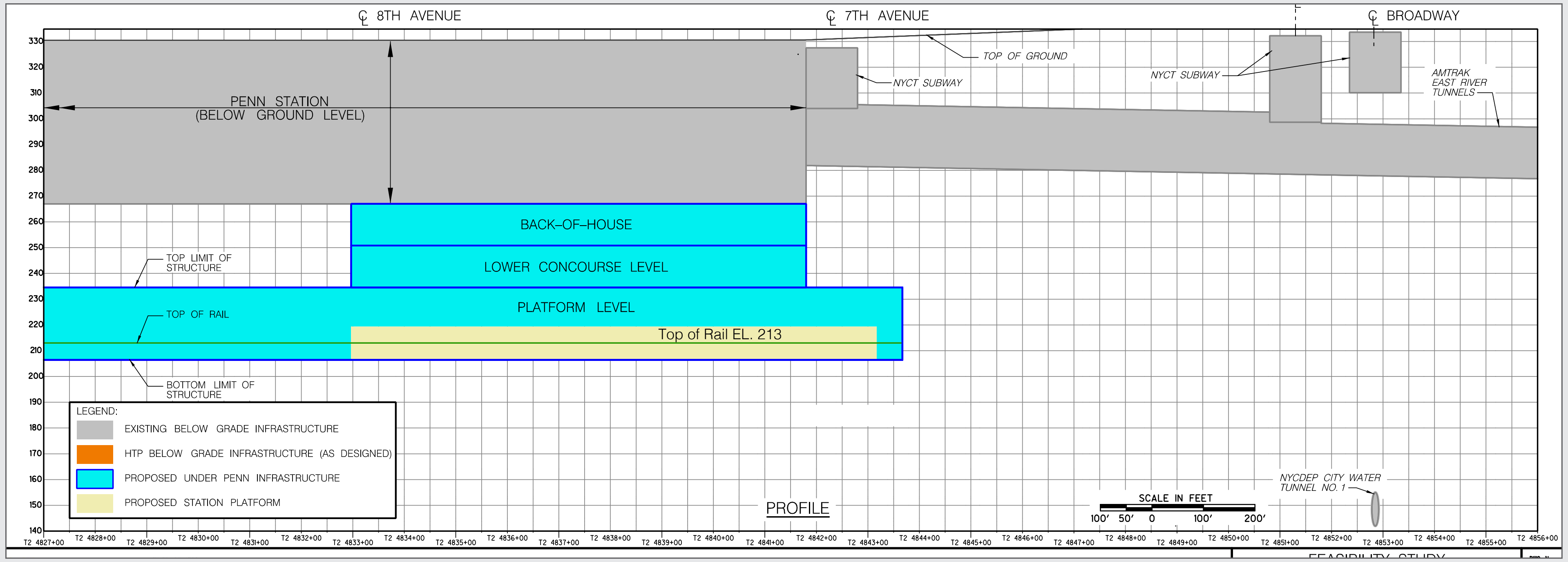


Figure 5-11

Underpinning of Existing Structure

1. Decommission existing adjacent tracks, create construction zone
2. Remove and relocate below track utilities, drainage, etc.
3. Drill and install mini piles with low headroom equipment
4. Install minipile footing
5. Install collar to existing columns, transfer load from existing to new minipile system by jacking
6. Excavate rock around minipiles down to final elevation, bracing minipile system from top down
7. Install permanent footings and columns
8. Install permanent beams at existing track level and new lower levels (serves as additional bracing)
9. Transfer load from minipiles to permanent columns by jacking
10. Remove temporary underpinning system (minipiles, footings, collars, etc.)
11. Construct new trackwork, track systems, drainage, catenary, platforms, etc.
12. Recommission existing adjacent tracks, remove local construction zone
13. Repeat steps 1-12 at adjacent location

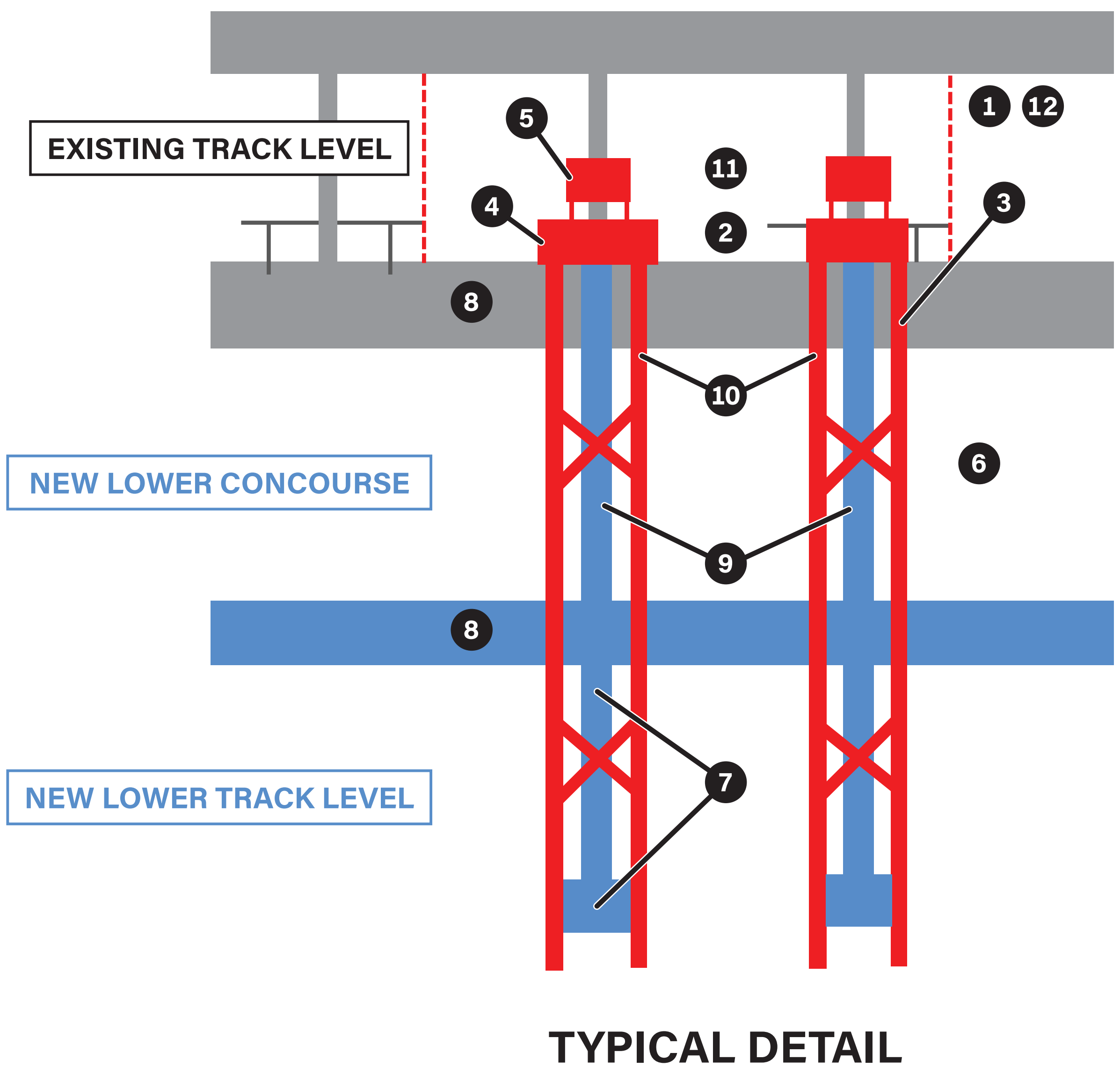
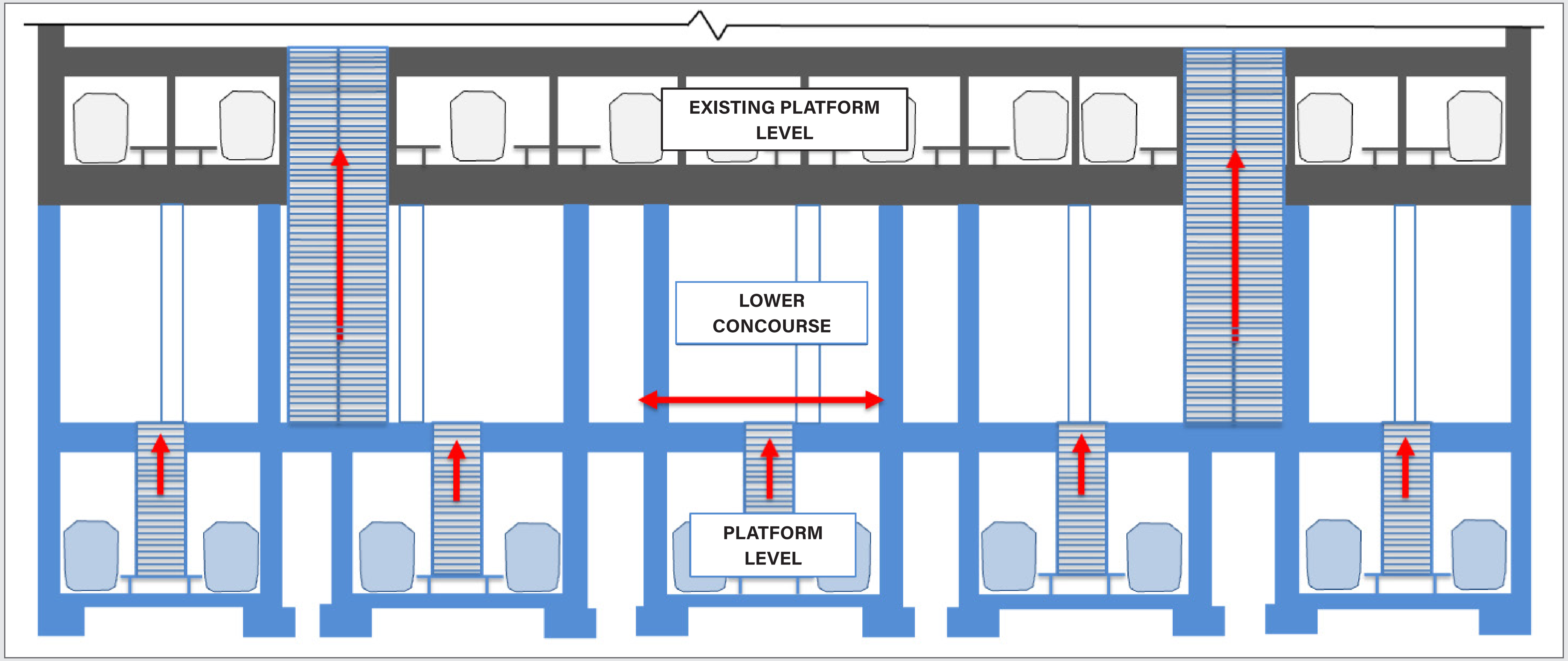


Figure 5-12

Partial Cross Section of Existing Penn Station with Station Expansion Below

Note: Figure is for illustrative purposes only to demonstrate how egress from the expanded station below impacts the existing tracks above.



Fire-Life Safety

The fire-life safety feasibility review for this concept includes the following three regions:

- Connection to Hudson Tunnel Project Twelfth Avenue fan plant and bellmouth
- Tunnels between Twelfth Avenue fan plant and station expansion
- Station expansion

Connection to Twelfth Avenue Fan Plant and Bellmouth
The proposed tunnel alignment would tie into the Hudson Tunnel Project alignment as discussed under the bellmouth section above. The Twelfth Avenue fan plant has been designed specifically for the Hudson Tunnel Project without any consideration to any future trainway connections. Connecting the fan plant to the proposed tunnels would significantly impact the ability to meet the critical velocity and impact fire-life safety in the event of a train evacuation. This expanded track network at the bellmouth would require ventilation analysis and would require significant redesign of the fan plant to accommodate the additional trainways. The tunnel systems located within the high bench and those supported on the tunnel's wall would need to be redesigned to accommodate a bifurcation configuration at the bellmouth.

The ventilation ducts adjacent to the trainway would need to be maintained without significant impacts to the fan plant performance. Additional ventilation ducts would be required above or adjacent to each additional track for a train fire in the bellmouth and individual tunnel sections. The duct size could be on the order of 100 square feet per track based on project experience. The feasibility of ventilation ductwork and damper locations needs to be addressed. Additional studies are required to substantiate the ventilation concepts and spatial requirements.

The bellmouth region has four diverging tracks. One train per vent zone is required in the bellmouth region, and it may significantly affect the train throughput. If the Authority Having Jurisdiction approves more than one train in the bellmouth, mitigation fire-life safety measures must be determined to mitigate the impacts of an incident train on potential non-incident trains.

Tunnels between Twelfth Avenue Fan Plant and Station Expansion
The proposed concept would include a ventilation design for the tunnels meeting the requirements of NFPA 130. Locating feasible fan plants would be a challenge in the densely populated area between Twelfth Avenue and the proposed new station expansion. A fan plant and emergency exits are required east of Tenth Avenue, and west of the station expansion to meet NFPA 130 ventilation criteria, one train per vent zone and emergency exit spacing requirement of 2,500 feet. A maximum of three vent zones can be allowed between two fan plants with a ventilation duct within the tunnel and without dampers in the tunnel. Building cross passages at 800 feet spacing between two running tunnels is not feasible due to the physical constraints of the existing infrastructure within Hudson Yards. However, additional property acquisition would be required outside of the current footprint of Penn Station and would require tunnels below Penn Station from the proposed tunnel alignment to the fan plant to provide both emergency exiting, tunnel ventilation, and space for other utilities.

The dimensions of the fan plant and subsequent real estate would need to be determined based on the equipment required for the fans, silencers, dampers, ductwork, and the ancillary equipment (e.g., electrical/traction power switching stations, emergency generator and fuel tank rooms, starters, egress stairwells, motor control center, sump and fire pumps, communication related panels, signal rooms, and other equipment). The fan plant would primarily be designed for providing ventilation to the trainways as well as emergency egress, power, drainage, fire-life safety systems and communications.

Diverging tracks west of the proposed station expansion may significantly affect throughput when keeping with the criteria of one train per vent zone. Ventilation ducts would be required above the tracks for a train fire within the zone between the running tunnels and station expansion. For enlarged caverns, the duct size could be on the order of 200 to 300 square feet (i.e., approximately 100 square feet per track) based on project experience. The feasibility of ventilation ductwork would need to be addressed and studied further. Additional studies are required to substantiate the ventilation concepts and spatial requirements.

Station Expansion
The emergency ventilation system would be designed to be integrated with Amtrak's operational control center SCADA system and meet NFPA 130 criteria for fires occurring on the new platform level or on the train consists. At least one fan plant is required near each end of the proposed station within the station footprint. The emergency ventilation system would need to serve the station platforms and tracks. For Design Concept 1, over-platform ductwork would be required. Based on previous project experience, a new emergency ventilation system would consist of four to eight emergency ventilation fans, associated dampers, variable frequency drives, and sound attenuators. For Design Option 1, the total capacity of a new emergency ventilation system for the new platforms, and lower concourse should be determined by computational fluid dynamics analysis. The new back-of-house level above the new lower concourse and platform level would have adequate space to house the fan plant; however, connectivity outside the existing Penn Station footprint for air intake and exhaust is required to be considered feasible.

In summary, fire-life safety is not considered feasible without additional permanent real estate acquisitions.

5.1.1.3
Operational Performance

The operational performance of the Under Penn Station Alternative is based on the earlier described practical capacities, as described in **Section 4.4**.

For this concept, the individual practical capacity of each of the infrastructure elements is as follows:

- Tunnel Capacity: 24 tph
- Interlocking Capacity: 20 tph (due to the interlocking being flat/single-level)
- Station Platform Track Capacity: 27 tph (due to ten available tracks)

Therefore, the governing capacity of the overall new tunnels in conjunction with station expansion is 20 tph, the constraining number of the above three. This is what this design concept could support for a reliable and realistic operations for longer peak periods, twice a day, every weekday. Therefore, the practical capacity does not meet the required 24 tph criteria and is not considered operationally acceptable.

In addition, this alternative also requires the removal of tracks within existing Penn Station in order to make vertical circulation possible between the station expansion and the main concourse. While a detailed design for the number of tracks that would have to be eliminated is not available at this time, analysis showed that for each track removed from existing Penn Station, the throughput capacity of the existing station would be reduced by between three and four tph per track. Therefore, the overall net increase in total station capacity would be substantially lower with this design concept, after taking into account the loss of tracks (and commensurate reduction in trains per hour) from the existing station. Assuming the removal of two tracks — which would result in 6 fewer trains per hour — the net gain would be 14 tph.

Operational Routing Flexibility
This design concept has no possibility for the station expansion tracks to be connected to the existing North River Tunnel. This severely limits how the station expansion is utilized in the event of the outages of the new tunnels in cases of routine maintenance of tracks (ballast, ties, rails), rail systems (catenary, signaling, communications) and other tunnel systems.

5.1.1.4
Compatibility with Future Vision for Cross-Regional Rail

The vision for future rail service articulated by the FRA in NEC FUTURE and reflected in the railroads' long-range service objectives calls for the introduction of regional metro services along the Northeast Corridor, including the New York metropolitan region. It would link selected branch lines and local services on both sides of the region, generally within 30 miles of Manhattan. The regional metro trunk line would operate through-running, headway-based service on dedicated tracks through a portion of New York Penn Station and beneath the Hudson and East rivers. Intercity trains and longer-distance suburban trains would continue to operate on a traditional timetable basis using parallel tunnels and the remainder of the platform tracks at Penn Station.

This design concept does not deliver the service vision in full, but it does not preclude future implementation of the full vision for integrated cross-regional service. Specifically, it allows for the potential future extension of selected lower level tracks to the east. Regional metro could be operated through the new Hudson River Tunnel, the lower level of the expanded Penn Station, and this future eastward tunnel — providing the separate, dedicated, trunk line route that characterizes regional metro. Suburban and intercity trains would be able to utilize the existing portions of Penn Station, although the existing station would have reduced capacity to serve these trains if removal of existing platform tracks is required.

This concept therefore passes the future rail vision compatibility test.

5.1.1.5
Overall Assessment

Table 5-1 summarizes this concept's performance for each of the Step 1 screening criteria.

This concept does not pass the engineering feasibility assessment due to high complexity. In addition, it does not meet the operational performance requirements for this project. It is not recommended to carry this concept forward for further analysis.

Table 5-1
Step 1 Performance Results
Alternative 1 (Under Penn Station),
Design Concept 1: Underpinning — Single-Level

Step 1 (Pass / Fail)

Track Geometry	Constructability	Fire-Life Safety	Operational Performance	Future Regional Rail
Pass	Fail	Fail	Fail	Pass

5.1.2
Alternative 1 (Under Penn Station)

Design Concept 2: Mined Tunnels — Single-Level

The assessment of this concept was based on a review of prior work.

Key Take-Aways

1. 10 new station tracks at same elevation added below existing Penn Station tracks connecting to Hudson Tunnel Project via new tunnels, with no direct train connectivity to existing Penn Station.
2. Requires complex tunneling below Penn Station.
3. Station infrastructure for pedestrian connectivity between existing station and expansion cannot be contained within the existing station footprint.
4. Selected lower level platform tracks potentially could be extended to a future new tunnel across Manhattan and East River. Therefore, compatible with future vision for through-running regional metro.
5. Fails engineering and operational feasibility assessment. Therefore, **design concept does not advance further.**

5.1.2.1
Design Concept Summary

Like Alternative 1, Design Concept 1: Underpinning — Single Level, this concept adds ten additional tracks under the existing Penn Station; however, this concept creates these tracks via mined tunnels. Unlike the Underpinning Concept, this concept provides vertical separation to the underside of Penn Station and no direct connectivity up into Penn Station's station tracks. Therefore, this concept does not require the underpinning of any existing structures within Penn Station. The depth of the new platforms is approximately 75 feet below the existing Penn Station platforms. This concept is also predicated on direct tunnel and rail connectivity to the Hudson River Tunnel infrastructure by means of the proposed bellmouth enlargement at Twelfth Avenue and West 30th Street and within the WRY. The running single-track tunnels bifurcate from the bellmouth and extend eastward through cavern enlargements housing a rail interlocking below Penn Station and continue east as the tracks diverge into the platform tracks below the footprint of Penn Station (**Figure 5-13**).

This concept is also based on the important distinction of the Under Penn Station Alternative that all underground station infrastructure and pedestrian connectivity would be located within the existing footprint of Penn Station. However, as there is no direct connectivity immediately up and into Penn Station in this concept, the new concourse space cannot be contained within the existing station footprint.

All engineering drawings related to this concept are provided within **Appendix A.2**. This design concept does not pass the engineering feasibility assessment due to high complexity and the inability to stay within the existing footprint. In addition, it does not meet the operational performance requirements for this project. It is not recommended to carry this concept forward for further analysis.

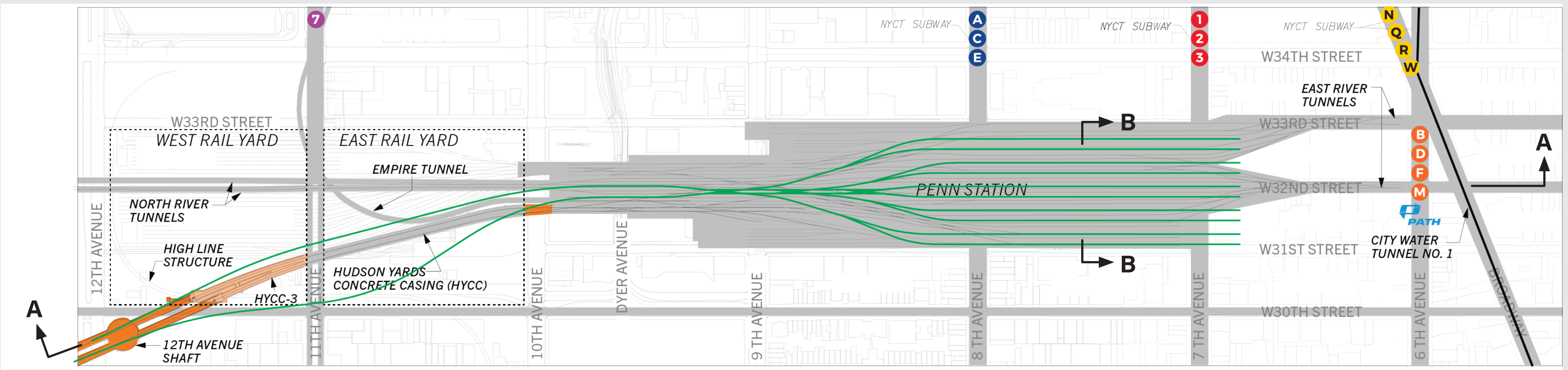
5.1.2.2
Engineering Feasibility

Track Geometry

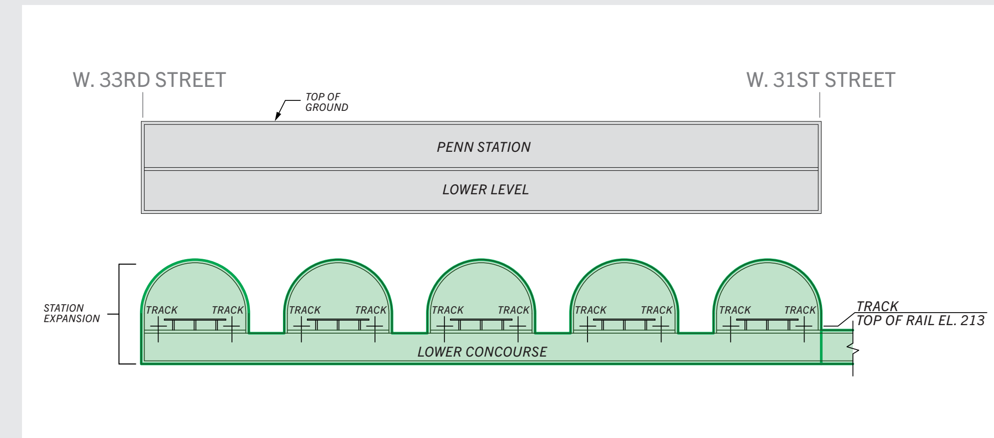
See **Figure 5-14**. The track geometry for this concept is identical to that discussed within the Underpinning — Single-Track Concept above.

Figure 5-13

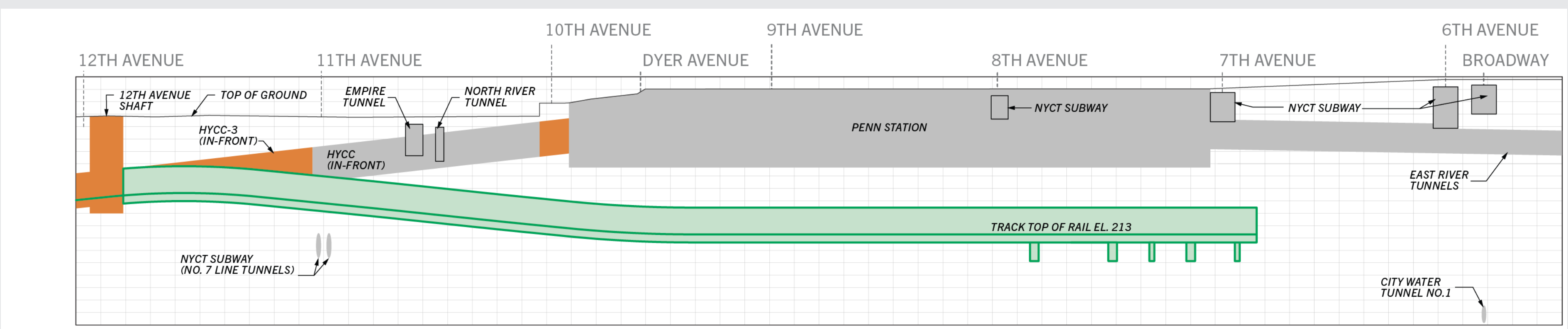
Alternative 1, Design Concept 2: Plan, Profile, and Cross Section



Design Concept Plan



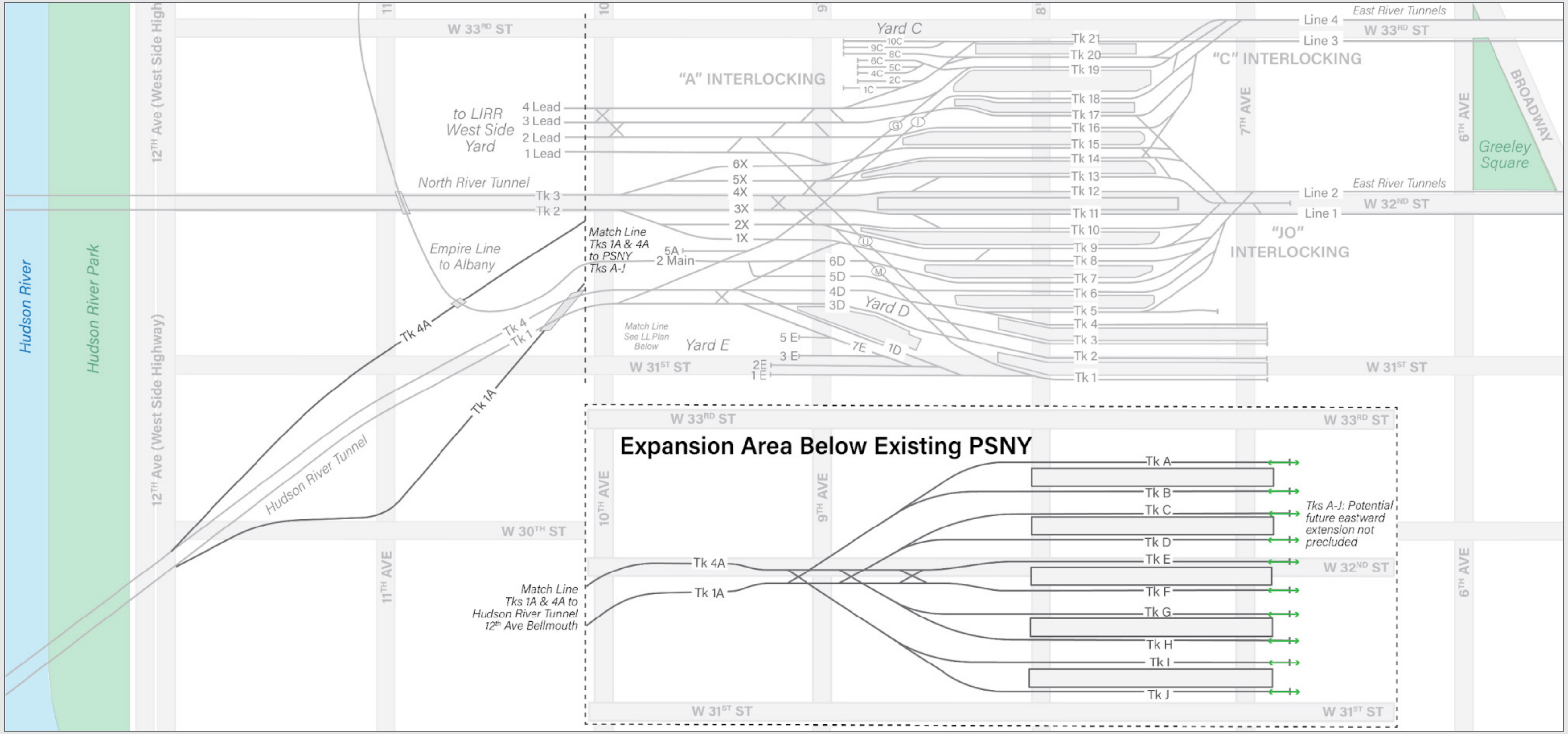
Cross Section B-B



Profile Section A-A

Figure 5-14

Track Schematic



Constructability

See Figure 5-15 which references each of the following areas.

Bellmouth ①
Track geometry and subsequent bellmouth arrangement are identical to that discussed with the Underpinning — Single-Level Concept above.

TBM Tunnels ②
The use of TBMs for this concept is generally common to the discussion provided in Section 4.3. The difference between the Underpinning - Single-Level Concept and this concept is the termination of TBM drives would extend farther to the eastern limit of the station platforms.

Mined Tunnels ③
The use of mined tunnels (cavern enlargements after TBM drives provide initial rock excavation) for this concept is generally common to the discussion provided in Section 4.3. The difference between the Underpinning — Single-Level Concept and this concept is mined cavern enlargements would be required to extend farther to the eastern limit of the station platforms.

As the track geometry is identical to the Underpinning — Single-Level Concept, a series of five parallel mined caverns housing the station platform tracks would consist of two tracks with a center platform, resulting in ten platform tracks total (see Figure 5-16).

As discussed above, additional smaller sized passenger tunnels would need to be excavated below and perpendicular to the series of mined station caverns within the new platform limits such that pedestrians could exit the platforms and travel down from the platforms, over to a location not located under the Penn Station footprint, and up many vertical levels to make connectivity to the extended Penn Station concourse levels and street level.

In summary, constructability of the mined tunnels and enlarged caverns is considered feasible; however, additional real estate outside the footprint of Penn Station would be required to support these operations. This concept therefore fails the constructability criterion, because it is not possible to confine all construction impacts within the existing station footprint.

Fire-Life Safety

The fire-life safety feasibility review for this concept includes the following three regions:

- Connection to Hudson Tunnel Project Twelfth Avenue fan plant and bellmouth
- Tunnels between Twelfth Avenue fan plant and station expansion
- Station expansion

Connection to Twelfth Avenue Fan Plant and Bellmouth
The proposed concept is identical to the Underpinning Concept discussed above.

Tunnels between Twelfth Avenue Fan Plant and Station Expansion
The proposed concept is identical to the Underpinning Concept discussed above.

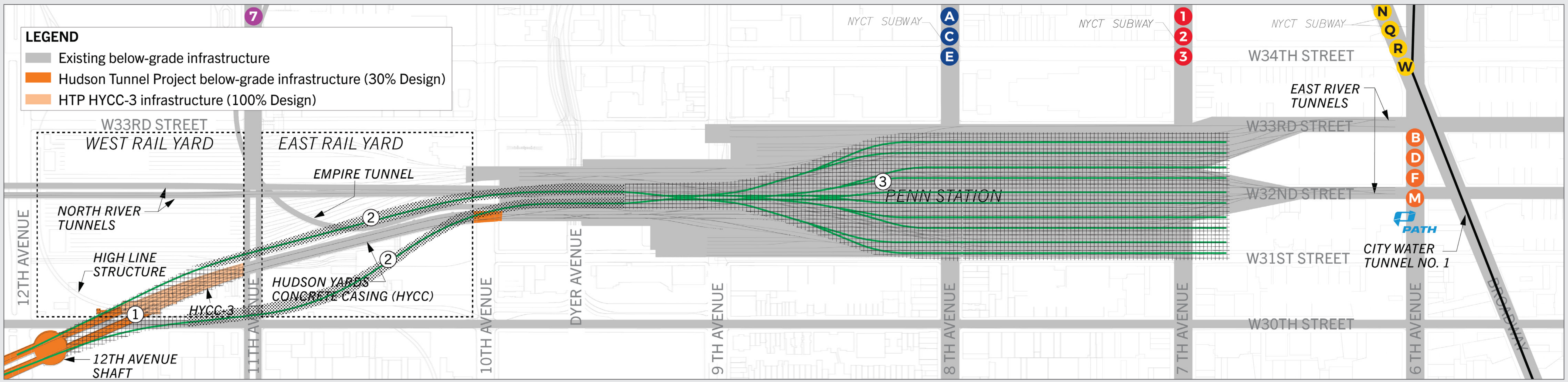
Station Expansion
The emergency ventilation system would be designed to be integrated with Amtrak's operational control center SCADA system and meet NFPA 130 criteria for fires occurring on the new platform level or on the train consists. At least one fan plant is required near each end of the proposed station within the station footprint. The emergency ventilation system would need to serve the station platforms and tracks. For Design Concept 2, additional property acquisition would be required outside of the current footprint of Penn Station and would require tunnels below Penn Station from the proposed tunnel alignment to the fan plant to provide both emergency exiting, tunnel ventilation, and space for other utilities. This would occur near the west end of the station expansion, and near the east end of the station expansion.

In Design Concept 2, the new station configuration would tie into existing Moynihan and Penn Station by means of extended concourses above track level including multiple exits directly to the street. Egress provisions are required from the new lower-level tracks to a new concourse level (outside the existing footprint of Penn Station) and up to street level. Comprehensive NFPA 130 egress analysis including the surrounding existing stations would need to be performed.

In summary, without the ability to locate fan plants outside the Penn Station footprint, and as numerous additional real estate acquisitions would be required, this concept is considered not feasible.

Figure 5-15

Constructability Map: Alternative 1 (Under Penn Station): Design Concept 2: Mined - Single Level



① **Bellmouth**

② **TBM Tunnels**

③ **Mined Tunnels**

5.1.2.3

Operational Performance

As the track geometry for this concept is identical to that discussed above for the Underpinning — Single-Level design concept, so is the operational performance.

- Tunnel Capacity: 24 tph
- Interlocking Capacity: 20 tph (due to the interlocking being flat/single-level)
- Station Platform Track Capacity: 27 tph (due to ten available tracks)

The governing capacity of the overall new tunnels in conjunction with station expansion is 20 tph, the constraining number of the above three. Therefore, the practical capacity does not meet the required 24 tph criteria and is not considered operationally acceptable.

5.1.2.4

Compatibility with Future Vision for Cross-Regional Rail

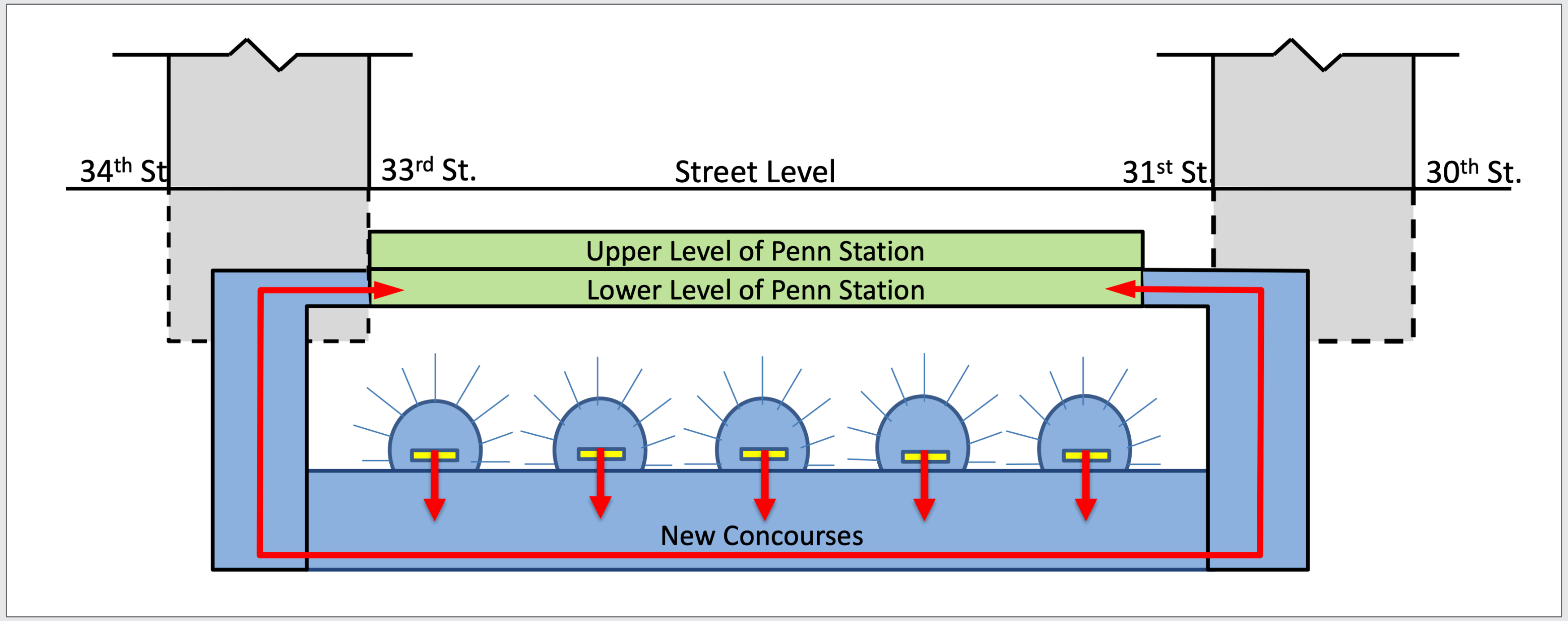
The vision for future rail service articulated by the FRA in NEC FUTURE and reflected in the railroads' long-range service objectives calls for the introduction of headway-based regional metro service and the continued operation of timetable-based intercity and suburban rail services along the Northeast Corridor, including the New York metropolitan region.

This design concept does not preclude the potential future extension of selected lower level tracks to the east. Regional metro could be operated through the new Hudson River Tunnel, the lower level of the expanded Penn Station, and this future eastward tunnel — providing the separate, dedicated, trunk line route that characterizes regional metro. Suburban and intercity trains would be able to utilize the existing portions of Penn Station, although the existing station would have reduced capacity to serve these trains if removal of existing platform tracks is required.

This concept therefore passes the future rail vision compatibility test.

Figure 5-16

Cross Section of Existing Penn Station with Station Expansion Below



5.1.2.5
Overall Assessment

Table 5-2 summarizes this concept's performance for each of the Step 1 screening criteria.

This concept does not pass the engineering feasibility assessment due to the inability to contain all underground station infrastructure within the existing footprint. In addition, it does not meet the operational performance requirements for this project. It is not recommended to carry this concept forward for further analysis.

Table 5-2
Step 1 Performance Results
Alternative 1 (Under Penn Station),
Design Concept 2: Mined Tunnels– Single-Level Concept

Step 1 (Pass / Fail)

Track Geometry	Constructability	Fire-Life Safety	Operational Performance	Future Regional Rail
Pass	Fail	Fail	Fail	Pass

Design Concept 1:
Full Reconstruction — Side-by-Side Operations

Design Concept 2:
Limited Track and Platform Reconfiguration

5.2

Alternative 2 **Through-Running**

Alternative 2 examines the feasibility of converting the existing station to all through-running, as a way to double Penn Station's trans-Hudson rail capacity enough to accommodate the planned growth in train traffic, and support cross-regional rail service as discussed in Chapter 2, without physically expanding the station. Informed by international experience and leveraging the specific characteristics of the station and approach infrastructure, it would replace the current commuter rail network with a combination of six through-running regional metro lines configured to accommodate higher-frequency service and longer-haul commuter service in the remainder of the regional rail network.

Amtrak's NEC service would operate as it does now, with all trains running through the station in revenue-to-revenue service during peak periods. Amtrak's other long-distance and international service would terminate at Penn Station during non-peak hours before moving through the station to storage and maintenance in Sunnyside Yard (drop-and-go operation). Most suburban commuter trains from areas not served by the regional metro would run through Penn Station in drop-and-go operation, terminating in a yard to await the next peak period or turning back at turnback stations in New Jersey and Queens.

This concept deviates from international experience and best practices as described in Chapter 2 by not purpose-building separate tracks and platforms for the higher-frequency regional metro service at the major hub train station. This results in some compromises for both the regional metro service and the remaining suburban and intercity services at the station.

All trains would continue to operate through the low-speed and severely space-constrained existing approach interlockings on both sides of the station — 'A' Interlocking on the west side and 'C' and 'JO' Interlockings on the east side. This will slow down the regional metro train movements, reduce train movement flexibility and capacity for other train services, and increase the potential for delays or incidents in one part of the station to affect operations in other parts.

Dedicating a portion of the existing station to regional metro would reduce the number of tracks and platforms available for more traditional suburban and intercity train operations, reducing flexibility for train dispatchers and station operators to accommodate train delays, train servicing and repair needs, train crew support, cycling or positioning train equipment, and other functions that typically occur at major stations and are most efficient at a centralized location.

Despite the lack of precedent for this concept, our analysis nonetheless seeks to determine whether there is an operational regime in which the existing Penn Station train shed can: (1) separate services with different operating characteristics; (2) provide the required capacity in the station; (3) provide sufficient capacity in the approach interlockings; (4) deliver bi-directional service to the full rail network during peak periods; and (5) be constructed and implemented with a manageable degree of physical and service disruption.

Two design concepts for reconfiguring the tracks and platforms at Penn Station were developed:

- Design Concept 1 — Full Reconstruction with Side-by-Side Operations
- Design Concept 2 — Limited Track and Platform Reconfiguration

These design concepts represent two different approaches to balancing operational capacity and constructability. Design Concept 1 maximizes throughput capacity and operational flexibility at Penn Station itself, based on complete reconstruction of the entire track and platform level of the station, at the cost of constructability. Design Concept 2 tests the potential for a relatively limited investment at Penn Station to deliver increased station capacity with relatively limited construction impacts, at the cost of providing less operational capacity.

Both concepts depend upon extensive capital investment beyond Penn Station itself to enable interoperable service through Penn Station and on the regional rail network. This includes providing storage yard capacity and stations for turning back suburban trains — both in northern New Jersey and in either western Queens or the Bronx.

Ultimately, neither of the Alternative 2 design concepts was found to be feasible. There is no feasible way to reconstruct the track and platform level of Penn Station and its supporting infrastructure to accommodate all-through-running train service that meets the operational performance needs of the station and rail network both during and after construction.

The full reconstruction to provide enough tracks and wide platforms (Design Concept 1) comes close to meeting the operational performance requirements, but has a fatal flaw with regard to delivering reverse-peak direction service. Constructing and implementing it would require extensive structural work and cause massive and unacceptable structural and service disruptions to the station, adjacent structures, and the wider rail network. The limited track and platform reconfiguration plan (Design Concept 2), which poses lesser constructability challenges, cannot provide the required operational capacity. These two scenarios bound the range of options for reconfiguring the station. There is no design concept in between these two boundary conditions that can meet the five criteria articulated earlier in this report. With fatal flaws in both design concepts, Alternative 2 is deemed not technically feasible and is not recommended for further consideration.

5.2.1

Alternative 2 **Through-Running**

Design Concept 1: **Full Reconstruction — Side-by-Side Operations**

Key Takeaways

1. Maximizes number of station tracks served by wide platforms within existing station footprint (17 total).
2. Cannot meet the operational requirement to increase service to 48 tph in each direction and still maintain reverse-peak-direction service on suburban routes.
3. Requires massive structural work to remove, modify or replace over 1,000 structural columns within the station envelope.
4. Structural system needed to re-support four major existing overbuild structures would not meet reasonable engineering standards for a well-designed transportation terminal.
5. Capital project within Penn Station is **not constructable** with a reasonable level of disruption to station operations.
6. Fails constructability and operational feasibility assessment. Therefore, **design concept does not advance further.**

5.2.1.1

Design Concept Summary

Alternative 2, Design Concept 1 assumes that the existing footprint of Penn Station between West 31st and West 33rd Streets is a clean slate, and that the locations of through-running tracks and wide platforms can be optimized within the existing railroad footprint. The objective of this concept is to fit as many tracks as possible within the station footprint and to maximize the station's capacity for through-running train operations (both revenue-to-revenue and drop-and-go).

All platforms in the reconstructed station would be at least 30 feet wide to facilitate passenger circulation and allow boarding passengers to descend to platform level in advance of the start of the boarding process, which allows platform dwell times to be shortened. The station tracks would connect to the existing and planned tunnels on both sides of Penn Station. All tracks would be aligned to connect directly to both a Hudson River tunnel and an East River tunnel. The concept shown in Figure 5-17 provides a total of 17 platform tracks, which meets the minimum requirement for station capacity for the mix of regional metro, suburban, and intercity train services described in Chapter 2, enabling the tunnels feeding Penn Station to operate at their maximum practical capacity of 24 tph per track during peak periods.

Trains from New Jersey would operate through Penn Station and continue onward beneath the East River to Queens. Likewise, trains from Long Island and from the New Haven Line and the East Bronx would run through Penn Station and continue onward beneath the Hudson River to northern New Jersey. Because this concept would require all trains from New Jersey and Queens to run through Penn Station, investment would be needed to accommodate regional metro and suburban trains beyond the limits of the existing station. Far-side turnback stations and associated storage yards would be required in northern New Jersey for LIRR and Metro-North New Haven Line trains operating from the east, and in western Queens or the southeast Bronx for NJ TRANSIT trains. The new or expanded yard east of the East River would supplement NJ TRANSIT's storage and maintenance capabilities at Sunnyside Yard. The northern New Jersey yard would need to replace the capacity and functionality of the existing LIRR West Side Yard and provide additional midday storage capacity. The configuration of rail service through Penn Station when converted to 100% through-running, with far-side yards and turnback stations, is illustrated in Figure 5-18. More specific details on train operations are provided in Section 5.2.1.3 (Operational Performance).

Figure 5-17

Penn Station Illustrative Track and Platform Configuration — Design Concept 1 — Full Reconstruction — Side-by-Side Operations

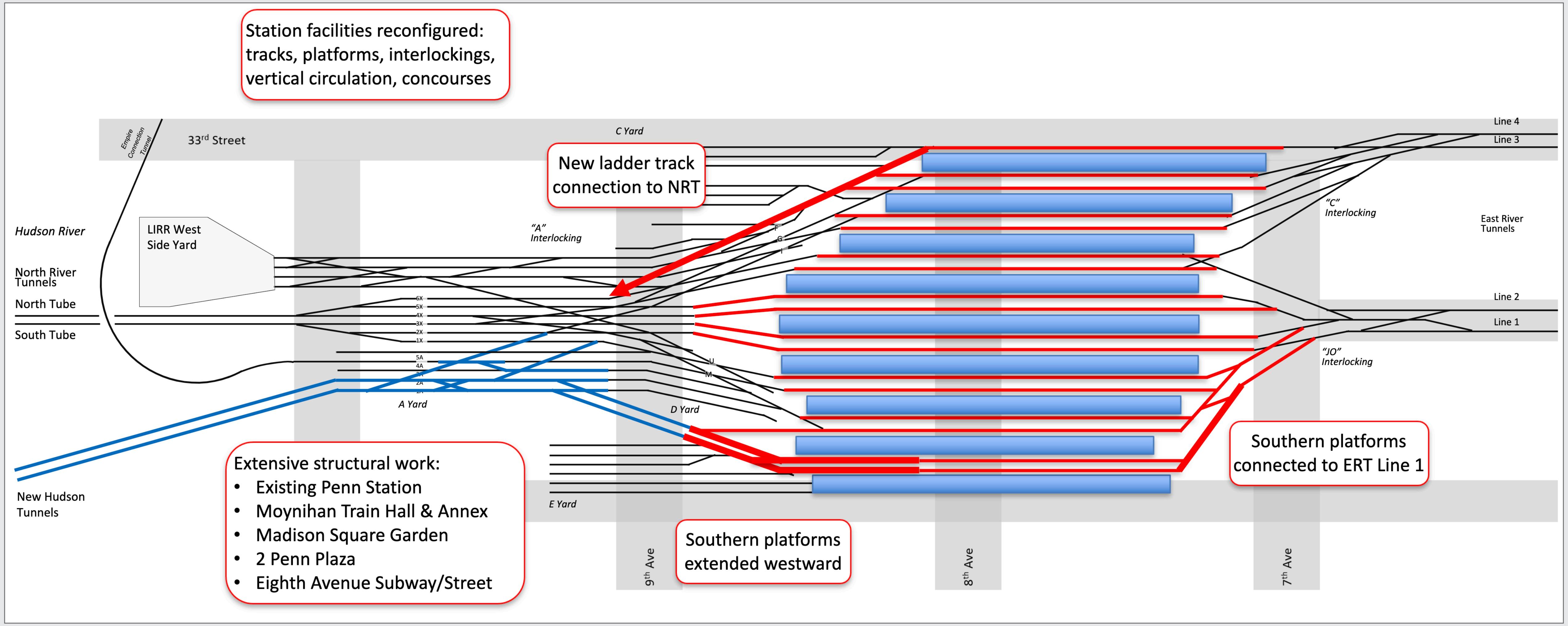
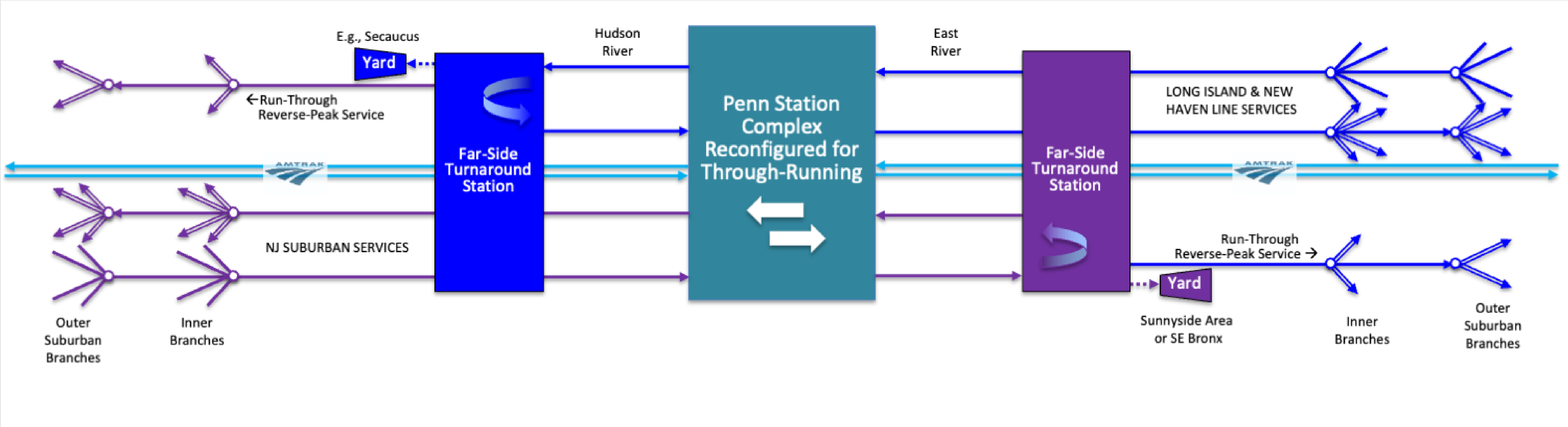


Figure 5-18

Peak Service Patterns Upon Completion of Penn Station Through-Running and Far-Side Yard Facilities



5.2.1.2
Service Concept

Alternative 2, Design Concept 1 would allow for through-running regional metro service at Penn Station as described in Chapter 2, with six regional metro lines. This service would be headway-based and have dedicated platform tracks at Penn Station. It would fully utilize two tracks in tunnel under the Hudson River and two tracks in tunnel under the East River. Track connections in New Jersey and Queens would enable these regional metro trains to utilize the local tracks on the Northeast Corridor and LIRR Main Line, as well as connect to the Hell Gate Line and several inner branch lines in New Jersey and on Long Island.

Additional suburban rail service would be provided to and from the portions of the regional rail network beyond the limits of regional metro service. This suburban service also would be through-running at Penn Station, operating to and from turnback stations and storage yards on the far side of the Penn Station complex from their point of origin. Suburban trains would operate from Long Island and the New Haven Line to a turnback point in northern New Jersey, and trains from New Jersey would operate to a turnback point in western Queens or the southeast Bronx.

Amtrak Acela and Northeast Regional service would operate at half-hourly intervals during peak periods. Amtrak is expected to continue its current practice of having high-speed Acela trains pass or "overtake" the Northeast Regional trains at Penn Station. Typically, the regional train arrives at Penn Station first, followed by the Acela train. After discharging and boarding passengers (some of whom receive assistance from "red cap" porters with their luggage), changing crews, and servicing the food and beverage car, the Acela train departs first, followed by the regional train. The Acela trains have scheduled dwell times of 15 minutes and the regional trains being overtaken can have dwell times of 30 minutes. With wide platforms in the future station, these dwell times potentially could be reduced to 8 minutes for Acela and 15 to 18 minutes for Northeast Regional trains, but these trains still would consume considerable track capacity within the station.

These overtakes can be accomplished more efficiently at the station than elsewhere on the railroad, where commuter trains generally consume the capacity available on the local tracks and Amtrak trains generally are confined to the express tracks on portions of the NEC with four main tracks. Planned future Amtrak service includes semi-hourly Acela express service and semi-hourly Northeast Regional (or equivalent) service, so these overtakes are assumed to continue to occur at Penn Station twice each hour during peak periods in both directions of travel — simultaneously occupying four station tracks.

Amtrak will operate other trains through Penn Station in addition to Acela and Northeast Regional service. Keystone Corridor trains serve the corridor between Philadelphia and Harrisburg, PA. Amtrak Empire Corridor trains serve the Hudson Valley, Albany, and western New York State. Additional Amtrak trains operate to North Carolina, western Pennsylvania, and Vermont. Long-distance trains are expected to continue to operate at approximately existing levels, with overnight service to Florida, New Orleans, and Chicago, and daytime service to Toronto and Montreal. Generally, these trains would be scheduled outside of the weekday peak periods, although late-arriving trains occasionally need to be accommodated during the peak.

The Amtrak Empire Corridor trains enter the western side of Penn Station from a separate single-track tunnel along the far west side of Manhattan and over the Spuyten Duyvil bridge to the Bronx. In the future, suburban trains on the Metro-North Hudson Line may also use the Empire Connection track to reach Penn Station. These Empire Corridor or Hudson Line trains could operate through Penn Station to Queens via the East River Tunnel, but in so doing they would reduce the capacity available for through-running trains from New Jersey. The alternative approach, assumed in this analysis, is for these Empire/Hudson Line trains to use Penn Station as a terminal, turning back at the Penn Station platforms.

The Amtrak and suburban services are assumed to use the Penn Station tracks and tunnel tracks not used by regional metro service. These trains may use specific platforms or groups of platforms at Penn Station, but they will operate in mixed traffic in the tunnels and on the main line tracks feeding the Penn Station complex.

Multiple options were considered for allocating trains to tunnels and station tracks, by type of service and direction of travel. The most efficient allocation would retain the existing directionality of train movements through the existing and planned new tunnels on either side of Penn Station. This results in the operation of two distinct track and platform zones within Penn Station, referred to as side-by-side operations, with the northerly platform tracks serving the existing Hudson River Tunnel and East River Tunnel Lines 3 and 4, and the southerly platform tracks serving the new Hudson River Tunnel and East River Tunnel Lines 1 and 2. Each zone would serve both westbound and eastbound traffic.

Proposed track usage within the Penn Station complex would be as follows:

North Side System

- Westbound through-running service from East River Tunnel Line 4 (beneath East 33rd Street) through the two or three northernmost Penn Station tracks to North River Tunnel north tube
- Eastbound through-running service from North River Tunnel south tube through north-of-center Penn Station tracks to East River Tunnel Line 3 (beneath East 33rd Street)

Empire Service

- Three tracks reserved for Empire/Hudson Line service (assumed to be turnback service)[5]

South Side System

- Westbound through-running service from East River Tunnel Line 2 (beneath East 32nd Street) through south-of-center Penn Station tracks to the new Hudson River Tunnel north tube
- Eastbound through-running service from the new Hudson River Tunnel south tube through the two southernmost Penn Station tracks to East River Tunnel Line 1 (beneath East 32nd Street)

This design concept is evaluated in depth in the following sections.

5 Turning Empire trains at the station would preserve balanced service that maximizes the throughput in the four Hudson River Tunnel tubes and four East River Tunnel tubes. Running Empire trains through Penn Station to Sunnyside Yard in Queens would shorten platform dwell times and increase the station's throughput capacity, but these trains would occupy East River Tunnel slots that then would not be available for trains operating to or from New Jersey.

5.2.1.3
Operational Performance

The configuration that would theoretically provide the greatest operational flexibility and least friction for Alternative 2, Design Concept 1 would be "right-hand running," with the seven northerly tracks in the station used by westbound through-running trains, the seven southerly tracks in the station used by eastbound through-running trains, and the three tracks in the middle of the station reserved for Empire/Hudson Line service. The ReThinkNYC proposal for Penn Station through-running assumes right-hand running. If the railroad and station were being designed from scratch, this would be a logical way to organize operations.

However, the existing track layout between Newark, NJ and Woodside, Queens is designed specifically for the existing operational regime, which does not support right-hand-running. The right-hand-running concept could work at Penn Station and could work in New Jersey with the construction of new track connections, but it has a fatal flaw at Harold Interlocking, a four-level junction in Queens that is the busiest and most complex railroad junction in the U.S., depicted in cross-section in **Figure 5-19**. Harold is highly customized to match the zonal operation of Penn Station, as described in **Section 2.2** and illustrated in **Figure 2-2**. In this configuration, the two center East River Tunnel tracks, Lines 2 and 3, cross before entering Harold. There is no location within the Harold Interlocking complex, or between Harold Interlocking and the East River, where East River Tunnel Lines 2 and 3 could be "swapped" or where new tracks could be built to restore the right-hand running directionality of traffic through Harold. Configuring Harold for right-hand running is not technically feasible without losing a significant share of its train capacity (estimated at 25% to 50%) for a period of years during construction.

Side-by-side operations would avoid this fatal flaw. The direction of flow to and from Penn Station with side-by-side operations would match the existing directional configuration at Harold Interlocking, meaning that the interlocking would not need to be reconstructed to accommodate a change in the direction of flow. Therefore, the side-by-side operating regime has been adopted for Alternative 2, Design Concept 1.

Within the framework of side-by-side operations at Penn Station, there are two potential ways of operating regional metro service and suburban/intercity service. In both operational concepts, regional metro trains would occupy a dedicated pair of tunnel tracks on both sides of Penn Station (one tunnel track in each direction of travel). Suburban trains and Amtrak intercity trains would share the other pair of tunnel tracks. **Figures 5-20** and **5-21** depict the following two operational concepts:

- Operational Concept 1A — Regional Metro Service on North Side/All Other Services on South Side
- Operational Concept 1B — Regional Metro Service Outside/All Other Services in the Middle

Concept 1A would assign regional metro service to the northern four platform tracks, with suburban and intercity services utilizing the middle and southern portions of the station, similar to the arrangement described below for Alternative 2, Design Concept 2. Concept 1B would assign regional metro or local suburban train services to the tracks on the northern and southern edges of the station and concentrate Amtrak and suburban service in the middle of the station, which is better served by the station facilities at the Moynihan Train Hall. Both of these operational concepts are illustrative, and neither of them has been developed to the level of detailed operations planning or subjected to computer simulation. Each option has advantages and disadvantages:

Operational Concept 1A: Regional Metro Service on North Side/All Other Services on South Side

Advantages

- Regional metro trains in both directions would be accessed from the same area of the station (the north side concourses currently used by LIRR passengers), with convenient access to and from the subways.
- Ample platform track capacity for regional metro (three tracks in each direction).

Disadvantages

- Relatively fewer platform tracks available for suburban and intercity services, resulting in shorter average dwell times for these services and an increased potential for train departure delays.
- Empire Line platforms centered on Moynihan Train Hall — not the highest and best use of the Moynihan Train Hall access facilities.
- Potential operational conflict in Queens between eastbound regional metro trains heading from East River Tunnel Line 3 to the LIRR Main Line local track while eastbound suburban trains are heading from East River Tunnel Line 1 to the LIRR Main Line express track.
- Requires changes to track connections in New Jersey to align the express and local tracks properly.[6]

6 The capital improvements that are part of the Gateway Program will align the express tracks on the NEC with the two existing North River Tunnel tubes, while the local tracks will be extended from Newark through Secaucus and connect into the new Hudson River Tunnel. Design Concept 1A reverses this track usage — routing the regional metro "local" trains to the existing North River Tunnel and the suburban and intercity "express" trains to the new Hudson River Tunnel. Different track connections would be required in the Secaucus and Kearny area to sort the trains properly.

Figure 5-19
Harold Interlocking: Six-Levels of Transportation Infrastructure

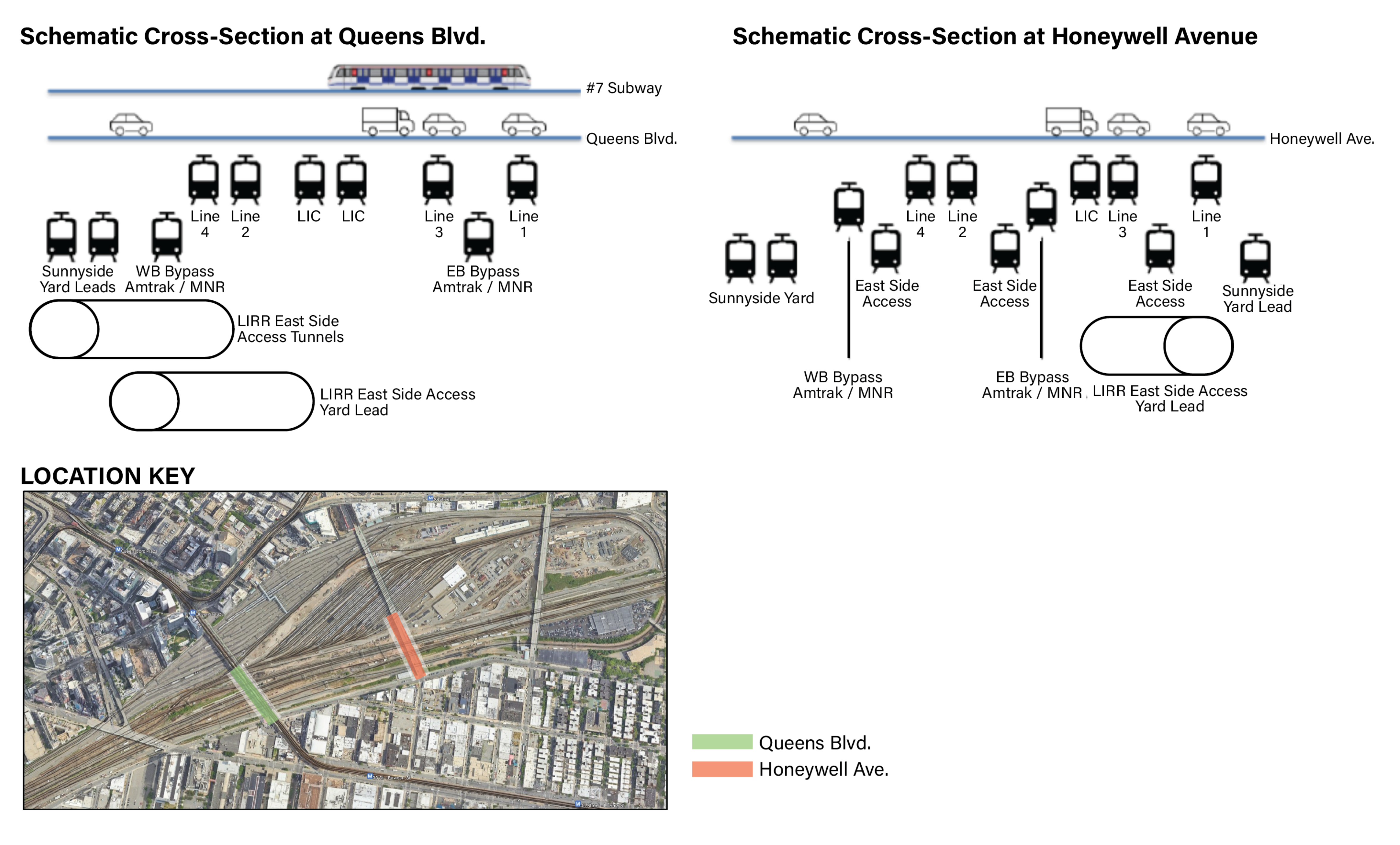


Figure 5-20

Illustrative Track Usage Concept 1A
Side-by-Side Operations — Regional Metro Service on North Side / All Other Services on South Side

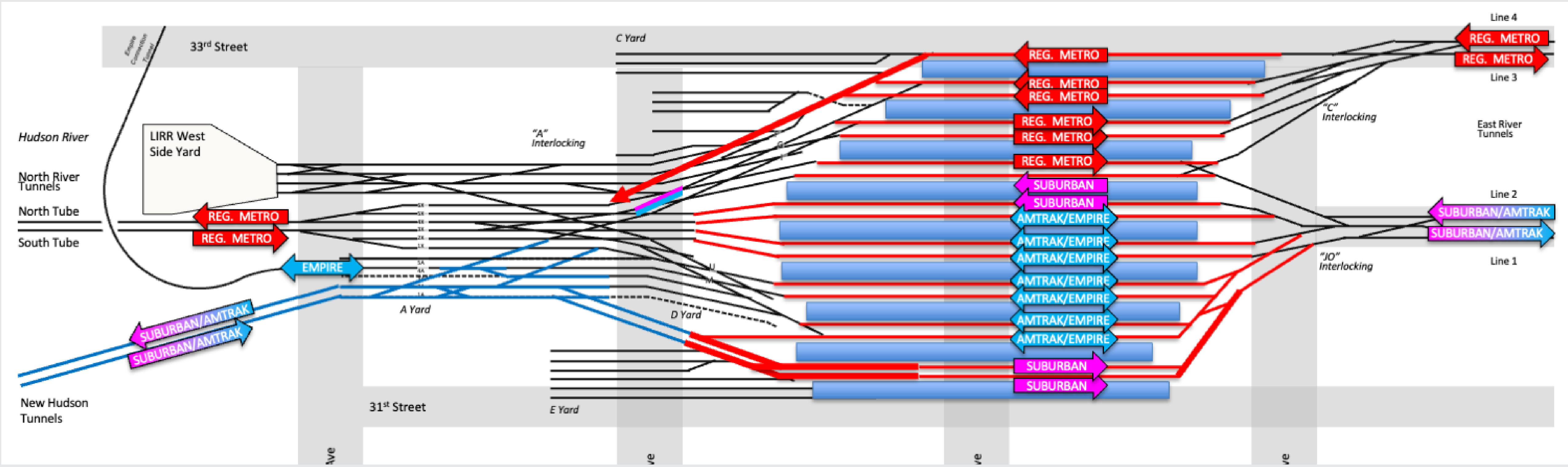
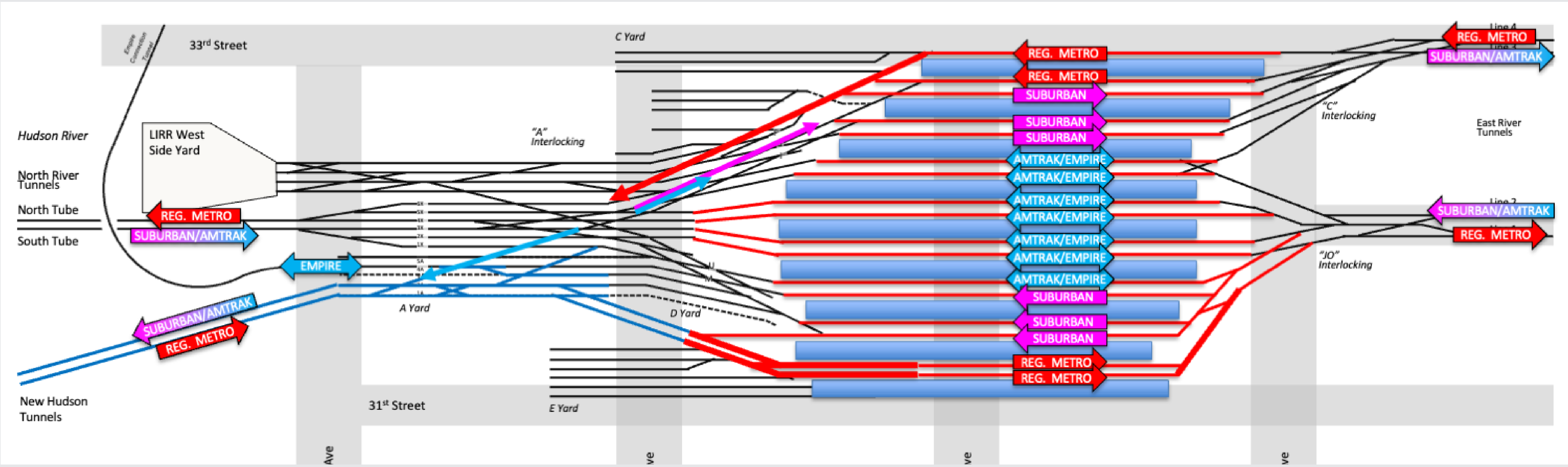


Figure 5-21

Illustrative Track Usage Concept 1B
Side-by-Side Operations — Regional Metro Service on the Outside / All Other Services in the Middle



Operational Concept 1B: Regional Metro Service on the Outside/All Other Services in the Middle

Advantages

- Amtrak through trains and Empire trains concentrated in middle of station — offers more flexibility in assigning trains to tracks.
- Intuitive grouping of suburban services — trains to Long Island, the Bronx, and New Haven Line destinations on north side of station; trains to New Jersey destinations on south side of station.
- Avoids the operational conflict in Queens between eastbound regional metro and suburban trains headed toward Long Island that would be present in Operational Concept 1A.

Disadvantages

- Wayfinding would be a challenge for regional metro passengers — with westbound trains on the extreme north side of the station and eastbound trains on the extreme south side of the station.
- This concept also requires changes to the track connections in New Jersey, slightly different from those required in Operational Concept 1A.

Neither operational concept is perfect, but both are potentially feasible for delivering regional metro service. For purposes of this analysis, the second option was considered to be more reasonable since it avoids potential train movement conflicts in Queens. It also right-sizes the station for regional metro service (two platform tracks in each direction dedicated to regional metro service), allowing the other 13 station tracks to be shared among Amtrak NEC service, New Jersey and Long Island suburban service, and Empire/Hudson Line service. The increased platform capacity for Amtrak and suburban services would improve the reliability of these services, better accommodate late trains, including long-distance trains, and provide train dispatchers greater flexibility in assigning trains to platform tracks within the station. Operational Concept 1B was used as the basis for concept assessment.

This concept would be able to deliver throughput of 48 tph in each direction through the station, matching the capacity of the four Hudson and East River Tunnel tracks, but, as described in a subsequent section, does so by sacrificing existing levels of reverse peak suburban service. The northern zone and southern zone of the station would each deliver 24 tph per direction. In the operational concept that maximizes the flexible use of station platform tracks for all types of train service (Concept 1B), the zones of the station would operate as follows:

Northern Zone:

- Westbound regional metro service at 24 tph would use the northernmost two tracks — serving 12 tph per track, with dwell times in the range of two to three minutes, consistent with transit-style service.
- Eastbound suburban trains would operate at an estimated 16 to 18 tph using two or three station tracks — serving 6 to 8 tph per track, with dwell times in the range of 5 to 8 minutes, consistent with through-running service at wide platforms.
- Eastbound Amtrak through trains would use two or three tracks — which would support:
  - Acela-Northeast Regional overtakes simultaneously occupying two tracks twice per hour.
  - Additional Amtrak service operating either in-between the half-hourly Acela-Northeast Regional trains or utilizing a third track, with dwell times estimated at 8 minutes.

Center of the Station:

- Empire Line Connection: 4 to 5 tph in each direction (either 2 tph Empire + 2 tph Hudson Line or 3 tph Empire) — assumed to turn back on three platform tracks, to preserve balanced flow through the Hudson and East River tunnels.

Southern Zone:

- Westbound Amtrak through trains would use two or three tracks — which would support:
  - Acela-Northeast Regional overtakes simultaneously occupying two tracks twice per hour.
  - Additional Amtrak service operating either in-between the half-hourly Acela-Northeast Regional trains or utilizing a third track, with dwell times estimated at 8 minutes.
  - Westbound suburban trains would operate at an estimated 16 to 18 tph using two or three station tracks — serving 6 to 8 tph each, with dwell times in the range of 5 to 8 minutes.
  - Eastbound regional metro service at 24 tph would use the southernmost two tracks — serving 12 tph per track, with dwell times in the range of 2 to 3 minutes.

In this operational concept, there would be two tracks that could be used flexibly for either suburban or Amtrak service, depending upon scheduled train volumes. Likewise, Empire Corridor or Hudson Line trains can be interspersed among the Amtrak trains in the middle zone of the station. This operational concept is illustrative and has not been developed to the level of detailed operations planning or subjected to computer simulation. The allocation of tracks among the various service types matches or exceeds the requirement, as indicated in Table 5-3.

Table 5-3

Penn Station Platform Tracks Required for Through Service and Provided in Design Concept 1

<table>
<tr><th>Service</th><th>Station Tracks Required*</th><th>Station Tracks Provided in Alternative 2, Design Concept 1</th></tr>
<tr><td>Regional Metro/Local</td><td>4</td><td>4</td></tr>
<tr><td>Amtrak Acela and Northeast Regional</td><td>4</td><td rowspan="3">4 Suburban
2 Swing**
7 Amtrak NEC+Empire</td></tr>
<tr><td>Suburban and Other Amtrak Northeast Corridor</td><td>6</td></tr>
<tr><td>Empire/Hudson Line</td><td>3</td></tr>
<tr><td>TOTAL</td><td>17</td><td>17</td></tr>
</table>

* Required for through service at 48 tph in each direction, plus Empire/Hudson Line at 4-5 tph.
** Swing tracks available for use by Amtrak or suburban services.

The seven station tracks allocated for Amtrak would include the four tracks required for Acela and Northeast Regional trains, supporting Acela overtakes in both directions, plus three tracks reserved for Empire/Hudson Line turnback service. The two swing tracks would be used by both suburban trains and additional Amtrak intercity trains operating on the Northeast Corridor beyond the twice-hourly Acela and Northeast Regional trains. The four suburban and two swing tracks together would need to process up to 40 tph (20 tph in each direction of travel), with an average platform re-occupation time of 9 minutes per track. The suburban services would operate as through-running trains at Penn Station, operating to or from the far side stations and storage yards. They would have dwell times at Penn Station in the range of 5-6 minutes. The additional Amtrak trains also would be through-running and are assumed to require dwell times of 8 minutes at the station.

Amtrak long-distance trains are assumed to be scheduled during off-peak periods when platform track capacity would be available to support longer dwell times. On occasions when these trains are delayed and are present at Penn Station during peak periods, the flexible-use tracks could be utilized for these trains, with adjustments to the dwell times of suburban and other Amtrak trains as necessary. There is limited residual capacity for train volumes beyond the 24 tph per tunnel track, plus the 4 to 5 tph each way through the Empire Tunnel. Train movements and passenger-handling at Penn Station would need to be managed to minimize dwell times and maximize train throughput when the system is recovering from delay conditions.

The side-by-side train flow would preserve existing and planned train movement patterns in Queens and also would preserve the infrastructure configuration that has been developed to support those train movements. The side-by-side operational concept would take advantage of the grade-separated eastbound and westbound Harold Bypass track connections that were constructed at Harold Interlocking to support the LIRR East Side Access project, leveraging those investments to benefit future regional metro service.

Based on the above assumptions, the 17 platform tracks at Penn Station in Design Concept 1 have sufficient capacity to accommodate a total of 48 tph in each direction along the Northeast Corridor route using the four Hudson River and four East River Tunnel tracks, plus an additional 4 to 5 tph in each direction using the Empire Tunnel. While this concept can meet the minimum threshhold requirement for throughput capacity of 48 tph, some of these train slots are required to support turnback service from the yards just beyond the Hudson and East River tunnels. The full complement of peak train slots therefore are not available to meet the anticipated demand for intercity and suburban service. This capacity constraint and its impacts are described in the following section.

Suburban Service Constraint

This 100% through-running concept is compatible with the ultimate long-term implementation of bi-directional regional metro service, as described in Chapter 2. When the full regional metro network is complete, frequent rush hour service would be offered in both the peak and reverse-peak directions of travel on the regional metro trunk and branch lines.

However, this operational regime is not compatible with bi-directional suburban commuter service, to and from the portions of the regional rail network that lie beyond the area served by regional metro (i.e., trunk and branch lines that extend generally more than 30 miles from Manhattan). The ridership market on most of these routes is not expected to support transit-like peak headways or warrant the capital investment to make these routes fully interoperable and free of capacity bottlenecks.

With 100% through-running at Penn Station, there would be three potential ways to operate peak period through-running suburban service in parallel with regional metro and intercity service:

A. Peak service to far-side locations for yard storage and reverse-peak turnback service. (Figure 5-22)

B. Peak service to far-side locations in the peak direction for yard storage only, with bi-directional shuttle service providing transfer connections to regional metro trains. (Figure 5-23)

C. Peak service to far-side locations for yard storage, plus through-running service connecting suburban trunk lines on both sides of the region to provide sufficient reverse-peak service. (Figure 5-24)

Figure 5-22

Potential AM Peak Service Patterns
Suburban Far-Side Turnback Service — Option A

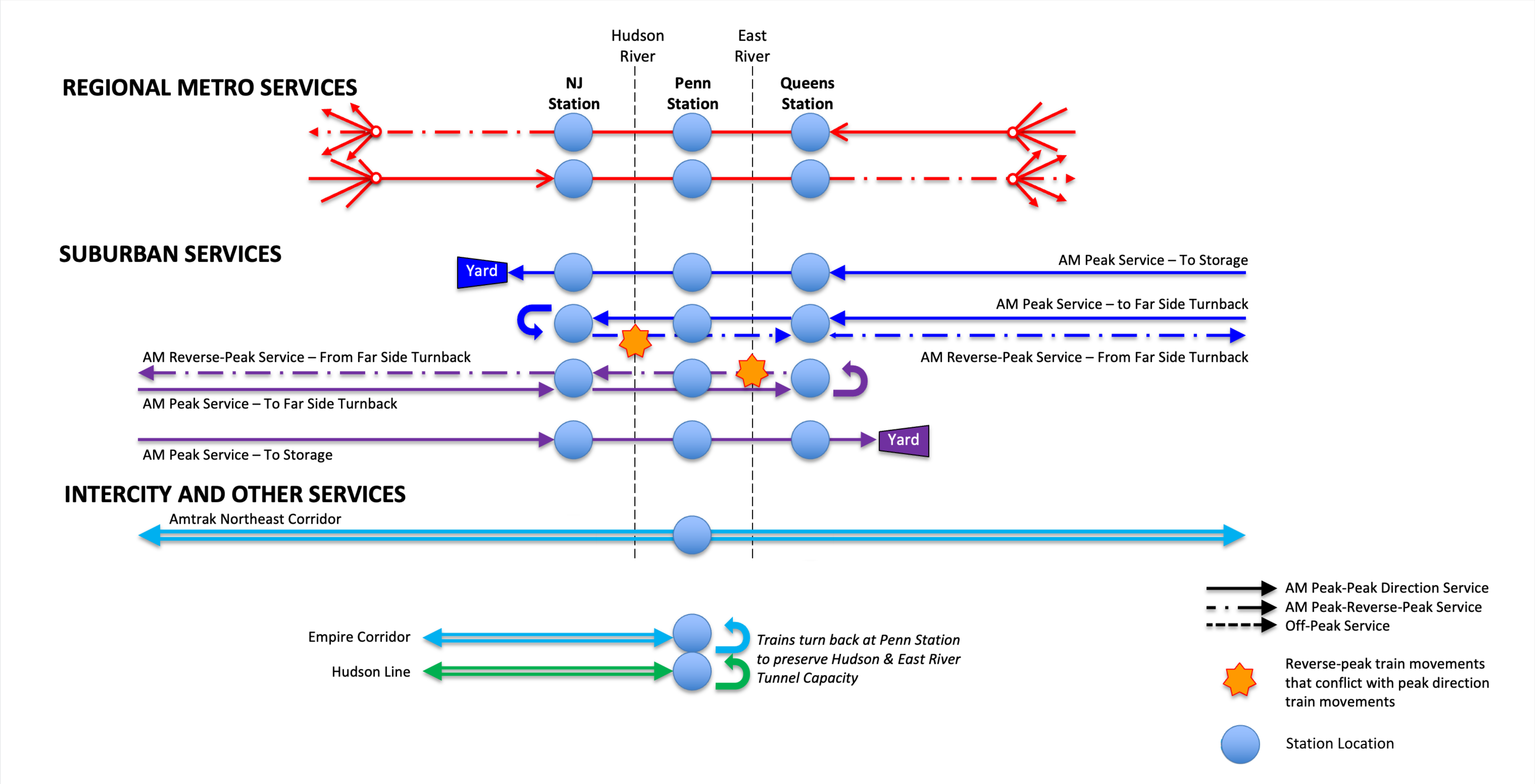


Figure 5-23

Potential AM Peak Service Patterns
Suburban Peak-Only Through Service and Shuttle Service — Option B

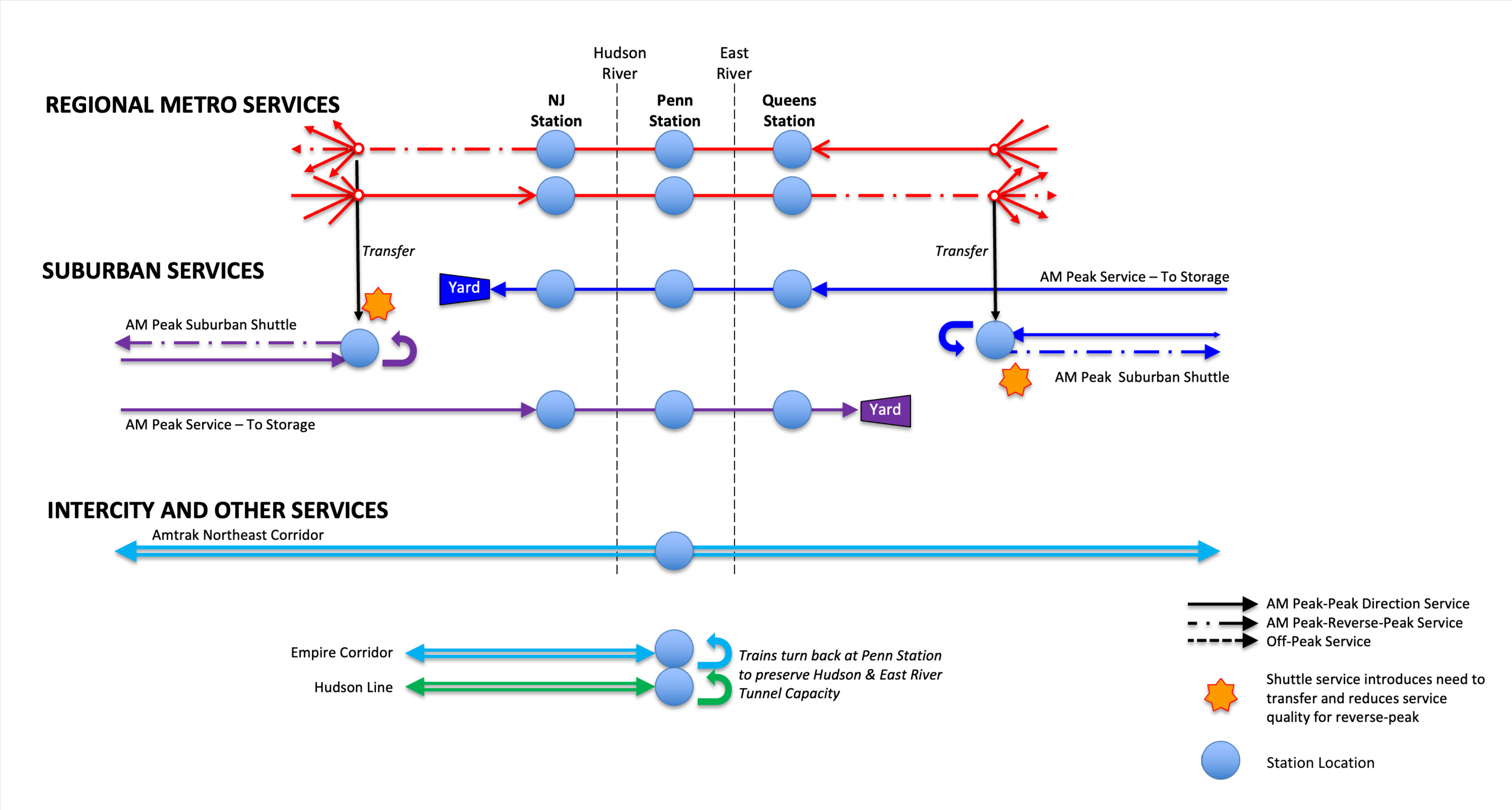
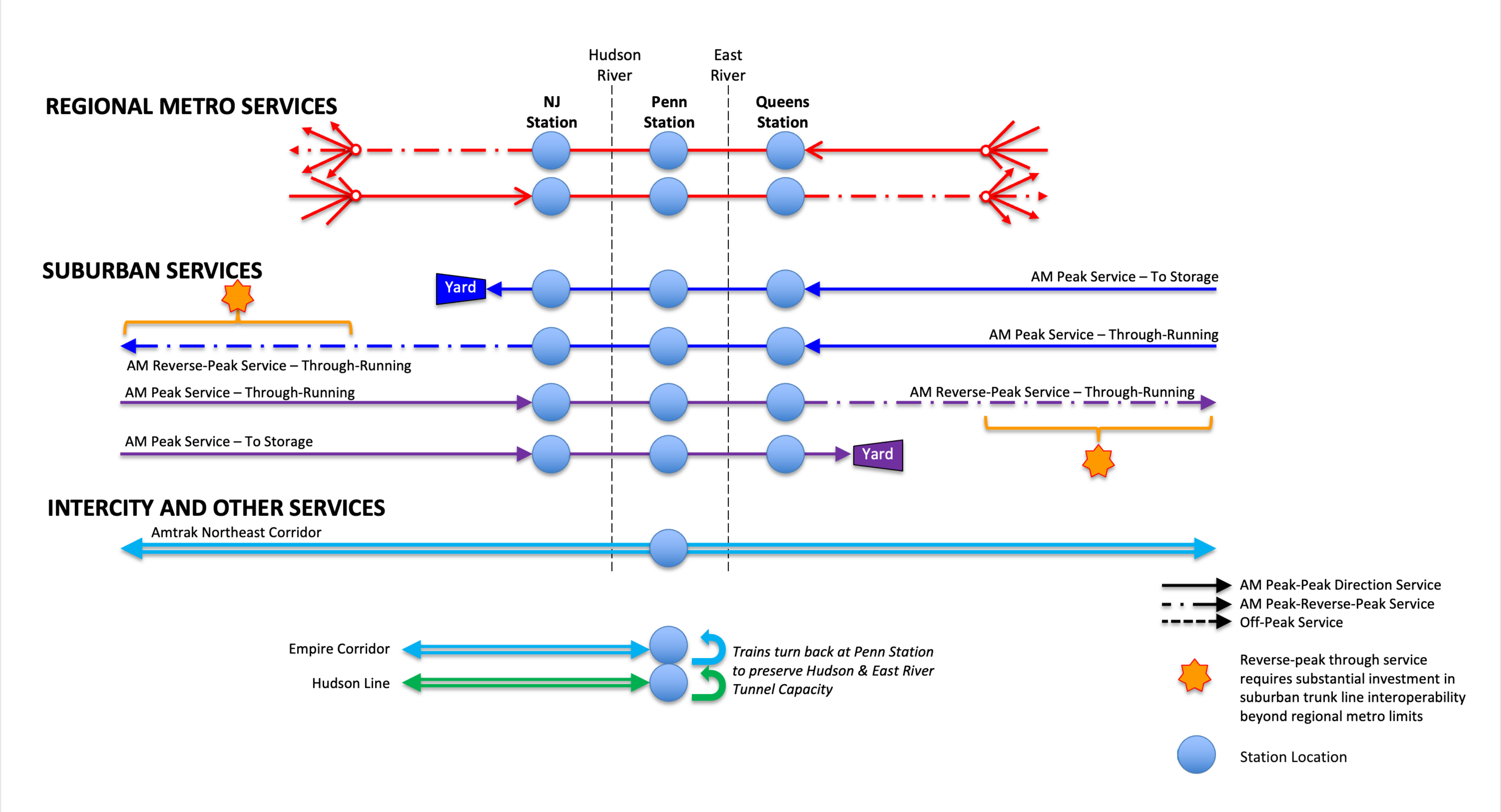


Figure 5-24

Potential AM Peak Service Patterns
Suburban Trunk Line Through Service — Option C



None of these three options meets the minimum requirements for operational performance. The operational capacity problem would exist only in the weekday peak periods, where demand for peak direction service through the Hudson and East River tunnels is expected to fully utilize the available capacity slots. During off-peak periods, tunnel capacity is expected to be available for suburban trains to operate through Penn Station in both directions, turning and laying over at the far side turnback locations.

The service patterns in Option A (far side turnbacks) are illustrated in Figure 5-22. In the AM peak, suburban express, limited-stop or outer branch trains would operate through Penn Station and both sets of tunnels to a far-side location. Some of these trains would turn at the far-side station and operate back through Penn Station and the tunnels to provide reverse-peak service to the suburban trunk lines and major branches (a reasonable estimate would be 8 tph). The remainder of the trains would proceed to a far-side yard for mid-day storage. They would return to their points of origin in the PM peak period. This mode of operation mimics existing commuter rail operations. However, unlike the current operation, these reverse-peak trains would compete with peak direction trains from the opposite side of the region for the limited available tunnel slots. AM reverse-peak trains from Queens back to the New Jersey suburban branches would compete with LIRR and New Haven Line trains for slots through the East River Tunnel, and AM reverse-peak trains from the northern New Jersey turnback point back to Long Island and the Bronx would compete with New Jersey suburban trains for slots through the Hudson River tunnels.

Every one of these reverse-peak trains would need to displace a peak-direction suburban train from the other side of the region (i.e., turning back one Long Island suburban train per hour in the AM peak to provide service to Ronkonkoma, Port Jefferson, and Babylon would displace three New Jersey suburban trains to New York City and thereby reduce trans-Hudson capacity for New Jersey to New York commuters). This option would dilute the capacity benefits for weekday peak service that were a primary rationale for both the Gateway Program and the recently opened LIRR connection to the Grand Central Madison terminal.

In Option B, shown in Figure 5-23, suburban services operating from beyond the ends of the regional metro network would only be able to operate in the peak direction of travel through Manhattan during the height of the weekday peak period when tunnel and station capacity is fully utilized. In the morning, these trains would run through Penn Station and both sets of tunnels to the far-side station and yard, where they would be stored until the end of the peak period. This option would protect full peak-direction capacity for service from the western and eastern suburbs. However, there would be no spare capacity during the AM peak to run any of these trains back through the tunnels to the station to run reverse-peak service to their points of origin, because the tunnel capacity entering Manhattan is assumed to be fully utilized by trains originating from beyond the turnback points. In the evening, the suburban trains would operate from the far side yards back through Penn Station to the suburban branches, but again, there would be no spare tunnel capacity during the PM peak period to provide suburban service from the suburban branches to Manhattan.

Bi-directional service on the outer portions of the suburban branches would be provided by shuttle trains that would provide connections to regional metro trains outside the urban core of the region. Reverse-peak travelers in the AM peak period would need to take a regional metro train and then transfer at an outlying point to a shuttle train. This would preserve the ability to travel by rail in the reverse-peak direction but would eliminate one-seat ride reverse-peak service and force passengers traveling from Manhattan and the urban core area to transfer. Improving reverse-peak one-seat ride service on Long Island was a key objective of prior capital projects on the LIRR Main Line to add track capacity, and this option would undercut those benefits. Shuttle services are generally not well received and are typically avoided where railroad operators wish to improve service.

The third option, Option C shown in Figure 5-24, would be to fully integrate the suburban trunk line service that operates through New York Penn Station. All suburban routes where reverse-peak service is offered at Penn Station would be linked to a suburban route on the other side of the region, to enable all reverse-peak service to be operated as through-running service. This would eliminate the tunnel slot competition between peak and reverse-peak service that exists in Options A and B. Peak period, peak-direction suburban commuter trains that are not required to provide far-side off-peak service would be stored over the mid-day period at the far-side storage yards as in the other options. The through-running suburb-to-suburb trains would operate on set timetables and require longer dwell times at Penn Station than regional metro trains or suburban trains operating only to far-side yards, including a recovery time allowance.

This option would entail considerably more capital investment over a larger part of the regional rail network to extend cross regional interoperability to include the suburban trunk lines on both sides of the region. Capital projects also would be required to relieve capacity bottlenecks, such as at-grade junctions and intermediate turnback points, in order to improve the reliability of run-through trains operating through the core network. The case for these additional investments would not be ridership market-driven but would revolve around the benefits of preserving service continuity. Therefore, the incremental benefits of extending interoperability over a wider area could be more limited than if those investments were concentrated within the regional metro service area as intended. The construction required for extended interoperability would be extensive and significantly more costly that for the other options (see discussion in Chapter 2, Section 2.4.8). This additional construction would need to occur at the same time as the reconstruction of Penn Station and construction of the far-side turnback facilities and yards, which is not realistic given how infrastructure projects are funded and procured.

Phased implementation of 100% through-running, at Penn Station and within the zone in between the two turnback locations, would not be possible without degrading either peak direction service or reverse peak service.

None of these options is considered a feasible solution, either for the long-term or the interim phase of implementation. Option A would deliver peak direction throughput of only 40 tph between the regional rail network and Penn Station, less than the required 48 tph. This calculation only applies once the regional metro network is completed and operational, which could be decades away. In the interim, Option A would deliver peak-direction throughput of less than 40 tph. Additionally, each turning train would be at a Penn Station platform twice in each peak hour, canceling out the benefit of shorter dwell times. And since LIRR trains running drop-and-go service would now require a Hudson River Tunnel slot to reach the new storage yard in New Jersey, there would be another incremental loss in throughput as those trains displace through-running trains in the tunnel. Option B would not provide reverse-peak service between Penn Station and the longer-distance suburban branch lines. Option C would not be cost-effective or constructable in the timeframe when increased capacity at Penn Station will be needed. This option would require full integration of the entire suburban rail network and pairing of all suburban branch lines, which would greatly increase the requirements for investment in railroad interoperability and capacity, including outer portions of the rail network with relatively light ridership demand. This design concept, therefore, does not meet the operational performance requirements.

5.2.1.4
Compatibility with Cross-Regional Rail Vision

The vision for future rail service articulated by the FRA in NEC FUTURE and reflected in the railroads' long-range service objectives calls for the introduction of headway-based regional metro service and the continued operation of timetable-based intercity and suburban rail services along the Northeast Corridor, including the New York metropolitan region.

Design Concept 1 is not fully compatible with this vision. It is compatible with the regional metro concept, provided there is sufficient investment in infrastructure and interoperability on the network over which regional metro trains would run. However, the concept does not support reliable bi-directional suburban rail service at reasonable cost to and from points beyond the limits of regional metro service.

The fully reconstructed station, with its wide platforms with ample passenger circulation capacity, would support both regional metro with headway-based through-running service, short dwell times and high throughput, and timetable-based suburban and Amtrak intercity service. The regional metro service would be able to fully utilize two pairs of Hudson River and East River tunnel tubes and four platform tracks at Penn Station, meeting the international best practice standard for dedicated facilities. The remaining pair of tunnels and the rest of the Penn Station track and platform area would be devoted to the operation of suburban and intercity service. At Penn Station itself, the station configuration is compatible with the long-range vision for the metropolitan rail network.

Beyond the limits of the Penn Station complex, the three types of rail service — regional metro, suburban, and intercity — cannot be supported without either sacrificing reverse-peak suburban service, relegating bi-directional service on suburban lines to shuttle trains during peak periods, sacrificing peak direction capacity (in favor of direct reverse-peak service), or investing in full interoperability over the entire suburban network. The first three choices do not meet the minimum requirements for operational performance of the suburban service. The fourth choice would entail major capital investment in infrastructure and rolling stock well beyond the geographic area where a reasonable travel market would exist. This concept therefore fails the future vision compatibility test.

5.2.1.5
Engineering Feasibility

Track Geometry at Penn Station

This concept would reconstruct all of the tracks and platforms within the existing station to optimize its configuration for through-running within the existing station footprint. The northernmost track would occupy the slot of existing Track 21 and would be connected at its west end to the North River Tunnel by means of a new ladder track replacing the existing 'F' Ladder.

New tracks and platforms would be spaced from north to south to provide island platforms at least 30 feet wide and pairs of tracks that support structural columns in between the tracks. The existing station footprint could accommodate eight island platforms, with the track on the south side of the eighth platform located approximately in the slot of existing Track 3. An additional track (in the Track 2 slot) and side platform would be located at the southern edge of the station. In order to enable the new Tracks 2 and 3 to be connected directly to East River Tunnel Line 1 (for through-running), the platforms serving these tracks would be shifted westward, crossing beneath Eighth Avenue to the Moynihan block. New ladder tracks would connect the western ends of these platform tracks to the new Hudson River Tunnel tracks. The Penn Station interlockings ('A' Interlocking west of the station and 'C' and 'JO' Interlockings east of the station) would be reconfigured to feed the new station tracks. Within the station area itself, Alternative 2, Design Concept 1 provides track geometry that meets the applicable standards.

With all trains operating through the station to and from New Jersey, the LIRR West Side Yard would need to be replaced with a yard and maintenance facility capacity in northern New Jersey, and track access to the yard site could be severed. However, West Side Yard's 30 tracks of train storage capacity would need to be replaced and augmented at a new facility in New Jersey.

Design Concept 1 is feasible in terms of track geometry at Penn Station.

Track Geometry in New Jersey and Western Queens

Because this concept would require all trains to run through Penn Station, investment would be needed beyond the limits of the existing station. Far-side turnback stations and associated storage yards would be required in northern New Jersey for LIRR and Metro-North New Haven Line trains operating from the east — and in western Queens or the southeast Bronx for NJ TRANSIT trains. The northern New Jersey yard would need to replace the capacity and functionality of the existing LIRR West Side Yard and provide additional midday storage capacity. The new yard that is being planned to support the Gateway Program could be adapted for storage of trains from Long Island and the Bronx. The new or expanded yard east of the East River would supplement NJ TRANSIT's storage and maintenance capabilities at Sunnyside Yard.

Design concepts have not been developed for the far-side turnback stations and yards in northern New Jersey and in western Queens or the southeast Bronx, but these are assumed to be feasible and constructable.

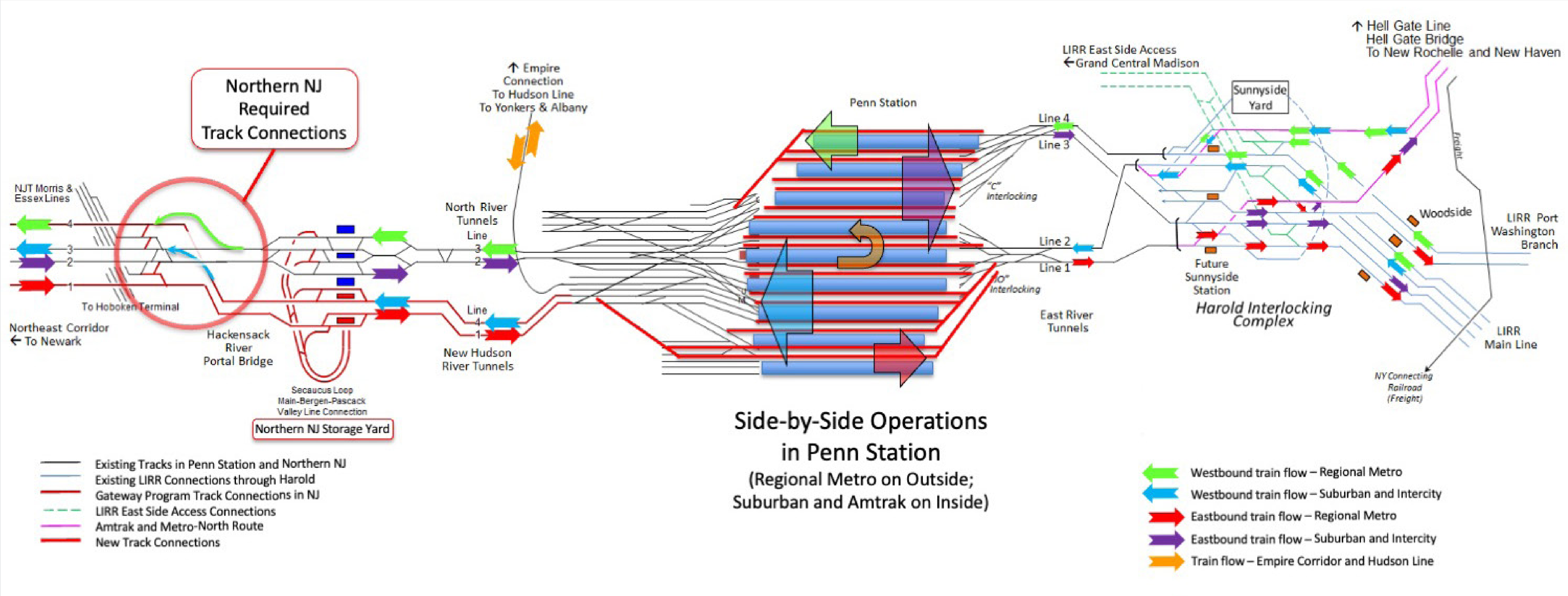
New track connections would be required in New Jersey to sort the Hudson River Tunnel traffic properly onto the

The LIRR West Side Yard would need to be replaced with a yard and maintenance facility capacity in northern New Jersey, and track access to the yard site could be severed. However, West Side Yard's 30 tracks of train storage capacity would need to be replaced and augmented at a new facility in New Jersey.

Far-side turnback stations and associated storage yards would be required in northern New Jersey for LIRR and Metro-North New Haven Line trains operating from the east — and in western Queens or the southeast Bronx for NJ TRANSIT trains.

Figure 5-25

Required Track Connections in Northern New Jersey and Western Queens for Design Concept 1



express and local tracks of the NEC heading toward Newark. Figure 5-25 shows the required track connections and illustrates the general flow of train traffic between northern New Jersey and western Queens.

The actual location and alignment of these track connections would require further engineering design and analysis. Eastbound trains on the NEC would operate as planned for the Gateway Program, with express trains (Amtrak and suburban) operating via the existing North River Tunnel south tube and local trains operating via the new Hudson River Tunnel south tube. Westbound traffic would be reconfigured to keep local traffic on the north side of the right-of-way and provide a grade-separated path for westbound express trains (Amtrak and suburban) to operate from the new Hudson River Tunnel north tube to the NEC westbound express track.

In Queens, westbound regional metro trains would operate from the LIRR Main Line westbound local track, westbound Port Washington Branch, and westbound Hell Gate Line to East River Tunnel Line 4. Conversely, eastbound regional metro trains would operate through East River Tunnel Line 1 and either run directly to the LIRR Main Line eastbound local track or use the eastbound Harold Bypass route to access the eastbound Hell Gate Line and Port Washington Branch.

Westbound suburban trains from the LIRR Main Line express track would operate directly to East River Tunnel Line 2. They would be joined by Amtrak and New Haven Line suburban trains utilizing the westbound Harold Bypass track and by Amtrak and NJ TRANSIT trains originating at Sunnyside Yard. Eastbound suburban trains would operate via Line 3 directly to the LIRR Main Line eastbound express track. Eastbound Amtrak and New Haven Line suburban trains also would utilize Line 3 and would divert to the eastbound Hell Gate Line track.

These western Queens track connections exist within the planned Harold Interlocking configuration, as illustrated in Figure 5-25. They are largely free of train crossing conflicts, though a few eastbound train movements would involve crossing conflicts, as they do today with the existing Harold Interlocking track layout:

- Eastbound trains from East River Tunnel Line 1 to LIRR Main Line express track
- LIRR from Grand Central Madison and East River Tunnel Line 3 to eastbound Port Washington Branch

No additional track connections would be required in western Queens to support train movements in Design Concept 1.

Constructability

The existing station platforms would be demolished, along with all of the vertical circulation elements that connect the platforms with the concourses above. The underside of the existing platforms and the sub-basement passageways beneath the track level are filled with utility conduits that support both train operations and station building operations. Most if not all of these utility systems would need to be completely replaced as the new platforms are constructed.

Passenger access to the new platforms would be provided from the various Penn Station and Moynihan Train Hall concourses. Virtually all of the platform vertical circulation elements would be rebuilt in new locations. All nine station platforms would be directly accessible from the Eighth Avenue side of the existing Penn Station concourse area and from the extended West End Concourse. The two southernmost platforms would not be directly accessible from the concourse level at the Seventh Avenue end of the station but would be accessed from adjacent concourses to the west. Moynihan Train Hall would provide access to the five platforms located in the middle of the station, although the existing platform escalators and elevators would need to be relocated to align with the new platform spacing. The other four platforms, on the north and south sides of the station, would be accessible indirectly via the West End Concourse.

An estimated 1,045 existing structural columns supporting all of these facilities would need to be removed, relocated or strengthened.

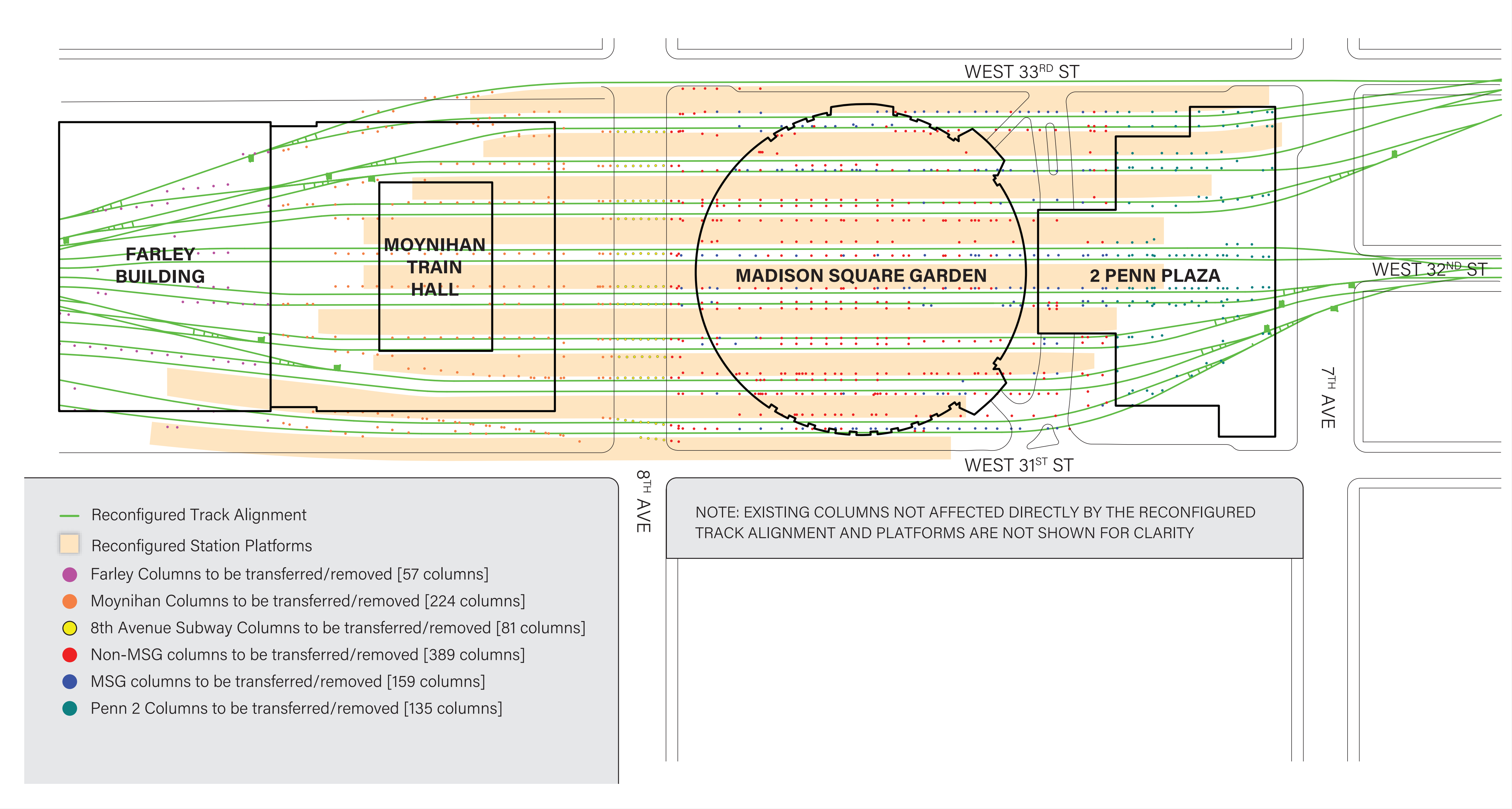
Full reconstruction of the tracks and platforms at Penn Station would entail a massive amount of complex structural work to preserve all of the infrastructure that sits above the track level between Seventh Avenue and Ninth Avenue, including the two existing station concourse levels, the Moynihan Train Hall and Annex building, the Madison Square Garden arena, the PENN 2 office building, Eighth Avenue, and the Eighth Avenue A/C/E subway lines.[7] An **estimated 1,045 existing structural columns supporting all of these facilities would need to be removed, relocated or strengthened.** Much of the work would need to be done in areas of the track level with limited headroom, and all of the work would need to be accomplished while maintaining the operations of the train station. This represents an unprecedented level of heavy construction work in a confined space, within an operating rail station, and beneath active office, entertainment, and transportation uses. The scale of disruption far exceeds the scale of disruption during the demolition of the original station headhouse, the reconstruction of the underground station and the construction of MSG and PENN 2 from 1963 to 1968, impacting more than just the footprint of Penn Station.

Because of the need to maintain existing uses above the track level, the structural system cannot be demolished and

7 This concept would utilize existing track alignments beneath the Seventh Avenue Subway, linking Penn Station with East River Tunnel Lines 1-4 at 'C' and 'JO' Interlockings. Therefore, re-framing or underpinning of the Seventh Avenue Subway structure would not be required.

Figure 5-26

Structural Columns Within Penn Station Requiring Removal, Relocation, or Transfer Alternative 2, Design Concept 1



rebuilt from scratch to efficiently carry loads from above. Loads will need to be transferred from existing columns to be removed to a combination of new and strengthened existing columns, requiring new load transfer beams to be located within the concourse areas of the station. With transfer structures already present in the structural system supporting Madison Square Garden and PENN 2, the additional changes to the track and platform level column grid would result in even more complicated and intrusive transfer structures within the station area.

Figure 5-26 shows a plan of the track and platform level, identifying the potentially affected columns. The plan shows track centerlines and platform edges for Design Concept 1. Outlines of the major structures that sit above the track level also are shown. The columns that would need to be removed, relocated, or have their loads transferred are shown as colored circles. This includes existing columns that lie within the right-of-way of the proposed new station tracks, as well as columns that would fall along the edges of the proposed platforms or within six feet of the platform edges.

Columns along platform edges have the potential to block train doors and impede the flow of passengers boarding and alighting from trains. Columns on the platforms that are close to the platform edge potentially block passenger circulation and can impede access for passengers using wheelchairs. For this reason, the Federal Railroad Administration has established a policy that the area on a platform within six feet of the platform edge must be kept clear of obstructions to meet the accessibility requirements of the Americans with Disabilities Act.

There are existing platforms within the station that do not meet this standard that are covered by a waiver from FRA, and it is possible to seek additional waivers of this standard. However, a construction project of this magnitude will be expected to meet ADA standards, and the high density of train operations and passenger volumes that would accompany the future increase in service, particularly on regional metro through-running platforms will require unencumbered passenger circulation along the platforms. Therefore, this analysis assumes that the standard will need to be met for any of the design concepts.

In the zone between Seventh and Eighth Avenue, the footprint of Penn Station, an estimated 764 columns would need to be relocated or removed, to avoid conflicts with the proposed tracks and platform edges and to ensure proper placement of columns between tracks and on platforms sufficiently clear from platform edges. This includes 159 columns that carry loads supporting the Madison Square Garden arena, shown as blue circles, where the circular arena structure superimposed on the rectangular grid of the train station tracks and platforms already results in complex load transfers within the station concourse levels. The need to further change how these loads are carried down to the foundations would significantly increase the complexity of the resulting structure. The reconstruction concept also would remove, relocate, or modify approximately 524 other columns that support the train station structure and the PENN 2 office building.

An additional 281 columns within the Moynihan Train Hall and Farley Post Office Building block west of Eighth Avenue would need to be relocated or removed. Extensive structural modifications to add load transfer systems within the Moynihan Train Hall and West End Concourse, completed and opened in January 2021, would be required to accommodate the new track layout. Major reconstruction of an iconic new train hall so soon after it opened reasonably can be expected to cause significant, and perhaps justified, public backlash for perceived wastefulness.

Approximately 81 columns that support Eighth Avenue and the Eighth Avenue subway would need to be removed and their loads transferred to new columns, an expensive and risky process.

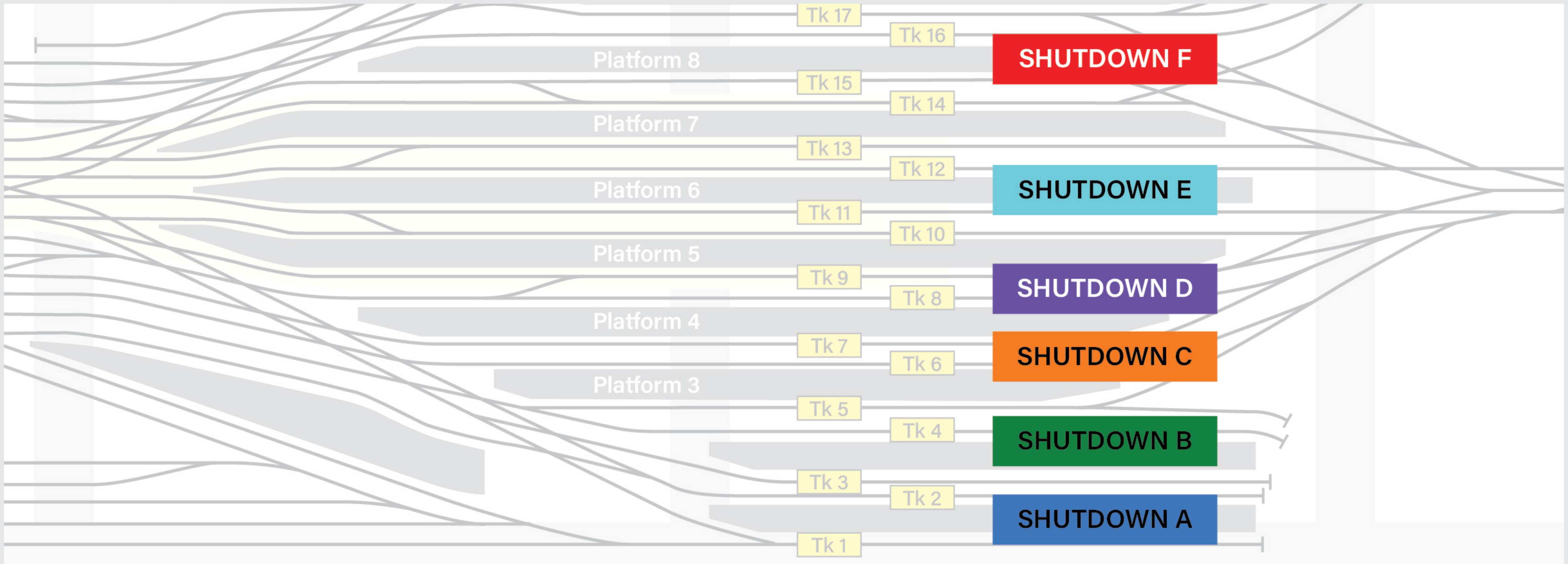
The construction of Madison Square Garden and PENN 2 required over 200 new columns in the train shed. Prior capital projects at Penn Station have removed, relocated, and strengthened columns within the track and platform area on a limited scale to enable track shifts and platform extensions. And the contemplated reconstruction of Penn Station would also require new and relocated columns as well. However, for these prior and anticipated projects — as large as they were (or will be) — the challenges of maintaining train operations were not (or would not be) even close to the massive scale required for this design concept, individually or collectively. The number and extent of required modifications would exceed the practical ability to design a rational structural system.

The total reconstruction of the Penn Station track and platform level would be a major undertaking and would have major impacts to ongoing station operations during the lengthy construction period. A high-level conceptual phasing plan has been developed for this project that demonstrates how the structural work and track and platform relocation work might be sequenced in multiple phases progressing in steps from one side of the station to the other (see Figure 5-27).

In each major phase of construction, all or portions of two platforms and up to four tracks in the station would be taken out of service for an extended time period (between 36 and 40 weeks). During these intervals, the railroads at Penn Station would have to operate on fewer station tracks, which would reduce the number of trains that could be operated during peak periods and the number of passengers that could be handled. A four-track reduction in capacity exceeds the scheduled outages that have been employed in the past to support major construction programs within the station, and the duration of these rolling permanent outages is longer. The initial phases of construction would reduce the number of available platform tracks from 21 to 17. Later phases would reduce capacity even further, to as few as 13 tracks. Partial implementation of through-running service in these later phases, once the far side turnback stations and yards have been constructed, could help increase the productive capacity of the remaining station tracks.

Figure 5-27

Construction Phasing Plan



Key

New Tracks & Platforms

Old Tracks & Platforms

Platform Tracks Available for Weekday Peak Service

	Existing	Phase A	Phase B	Phase C	Phase D	Phase E	Phase F	Complete
Narrow	2	15	12	9	6	2	-	-
Wide	19	2	5	7	9	11	13	17
Total	21	17	17	16	15	13	13	17

The impact on train schedules and passenger convenience during the construction period, however, is expected to be severe. Over the course of a multi-year construction period, with multiple station tracks out of service to support ongoing construction activity, the capacity of the station to handle weekday peak period volumes of trains and passengers would be reduced by approximately 30%.

With opportunities to take existing tracks and platforms out of service for demolition and reconstruction limited by the need to keep most of the station operational during the weekday morning and evening peaks, reconstruction of the station would take an estimated 12 years to complete. During this time, train movements through station throat areas would be restricted, and the station would have limited operational flexibility, increasing the potential for delay conditions. Passenger circulation facilities, including the existing Penn Station concourses and virtually all platform access points, would need to be rebuilt under traffic. Similarly, the newly constructed vertical access to the platforms from the Moynihan Train Hall and West End Concourse would need to be rebuilt under traffic.

The ability of the railroads to meet acceptable standards of customer service at Penn Station during the construction period would be hampered by both the extent of the required construction work and the lengthy period of time that would be required to complete the reconstruction. This construction would also negatively impact the users of Penn Station, the Moynihan Train Hall building, Madison Square Garden, and the PENN 2 office building during an extended period of construction. This level and duration of disruption to operations would be considered unacceptable.

In addition to the negative effects on station operations, the track and platform reconstruction would impact other facilities and activities within the construction zone. Staging of structural work at the Eighth Avenue subway would need to be timed to protect subway operations during construction. (The Seventh Avenue Subway structure would not be directly affected by construction.) Access and loading operations for Madison Square Garden and PENN 2 would be disrupted during the construction period.

The complexity of the required construction, which would need to be confined within very limited geographic areas and restricted to limited time periods due to the requirements to maintain station operations, would generate a high level of risk to both project schedule and cost. The level of disruption to station operations during a decade-long construction period, and the likely degradation of the reliability of service and the quality of the passenger experience at the station could have a long-term negative effect on railroad ridership.

Even with a carefully phased construction plan, reconstruction of the existing tracks, platforms, and structural systems, while maintaining existing active uses above the station and a reasonable level of train operations and passenger circulation within the station, is not feasible.

Design Concept 1 therefore fails the feasibility metric related to both design and constructability due to the extreme complexity of the required structural modifications to Penn Station, Moynihan Train Hall and Annex, PENN 2, Eighth Avenue, and the Eighth Avenue Subway, as well as the severe impact of construction on station operations at both Penn Station and Moynihan Train Hall.

Construction east of Penn Station would require a western Queens or Bronx turnback station and storage yard for NJ TRANSIT trains. Construction west of Penn Station would require a northern New Jersey turnback station and storage yard for LIRR and Metro-North trains, along with track connections to re-sort directional train traffic. These improvements beyond the limits of Penn Station are considered to be feasible from a constructability standpoint.

Fire/Life Safety

This design concept would reconstruct the entire track and platform level and would provide platforms with significantly more circulation and egress capacity. Station infrastructure would be able to be designed to meet the requirements of NFPA 130 for emergency egress and other design standards related to fire protection and life safety.

5.2.1.6

Overall Assessment

Table 5-4 summarizes this concept's assessment.

Alternative 2, Design Concept 1 passes the track geometry feasibility assessment, since it resolves the track geometry constraint in western Queens and meets the requirements for train throughput at Penn Station at 48 tph per direction though both the Hudson and East River tunnels and 4-5 tph through the Empire Tunnel.

However, Design Concept 1 cannot fully utilize the available 48 tph in the peak direction, because of the need to claim approximately 8 peak-direction slots to operate reverse-peak suburban service. In this concept, weekday morning reverse-peak suburban trains would need to originate either in northern New Jersey or Queens or the southeast Bronx instead of at Penn Station, in order to maintain 100% through-running at Penn Station. Regional metro service can provide bi-directional service to the inner suburban branches, but not the full network.

This concept therefore can deliver only 40 tph for peak direction service, less than the required 48 tph, if suburban reverse-peak service is preserved. On the other hand, if full peak-direction were offered at the expense of suburban reverse-peak service, then this design concept would be incompatible with the future vision for regional rail, which includes robust, bi-directional regional rail and suburban rail services.

Table 5-4

Step 1 Performance Results

Alternative 2 (Through-Running)

Design Concept 1: Full Reconstruction with Side-by-Side Operations

Step 1 (Pass / Fail)

Track Geometry	Constructability	Fire-Life Safety	Operational Performance	Future Regional Rail
Pass	Fail	Pass	Fail	Fail

Alternative 2, Design Concept 1 also would generate unacceptable levels of risk and disruption while track and platform reconstruction is occurring over a period of a decade or more. This concept fails to meet the operational performance requirements for this project. It can deliver 24 tph through each Hudson River and East River tunnel tube, but it would not provide a reasonable way to deliver reverse-peak service to the suburban branch lines, without either sacrificing peak direction capacity or requiring up-front investment in full network interoperability.

Alternative 2 Design, Concept 1 therefore fails the constructability, operational performance, and future vision compatibility tests, and the concept does not advance for further study.

5.2.2
Alternative 2 **Through-Running**

Design Concept 2: **Limited Track and Platform Reconfiguration**

Key Takeaways

1. Platform widening is feasible to construct with manageable construction-related service disruption.
2. Quality of the passenger environment and the capacity for passenger circulation is lower for this configuration than for purpose-built new platforms, given the irregular and substandard placement of columns on many existing station platforms.
3. Insufficient number of tracks to support Amtrak NEC, suburban and Empire/Hudson Line service
4. Cannot meet the operational requirement to increase service to 48 tph in each direction and still maintain reverse-peak-direction service on suburban routes.
5. Fails operational performance requirements — **concept does not advance.**

5.2.2.1
Design Concept Summary

Alternative 2, Design Concept 2 addresses the extreme constructability impacts of Design Concept 1. The objective of this concept, based on proposals put forward by ReThinkNYC, is to enable 100% through-running service between New Jersey and Queens through Penn Station, while minimizing the amount of capital investment required at Penn Station. The least capital-intensive approach to creating wider platforms at Penn Station would be to widen the existing platforms by decking over or eliminating the existing track on one side of each island platform. This would widen each platform by approximately 11 feet, to at least 30 feet. It would also cut the number of available tracks approximately in half. The wider platforms in the reconstructed station would help reduce platform dwell times for through trains by allowing boarding passengers to assemble on the platform ahead of the arrival of their train and enabling passenger alighting and boarding to occur simultaneously.

Design Concept 2 would retain 12 existing Penn Station tracks and would eliminate 9 existing station tracks. The design concept would widen 10 of the 11 existing station platforms either to the north or to the south, covering an adjacent track, to provide greater platform area and vertical circulation capacity. Only existing Platform 6 would be retained at its existing width. This platform would be used by alighting passengers to ascend to concourse level but would not be used by boarding passengers. The premise of the ReThinkNYC concept is that through-running would enable the station to accommodate twice the existing service with one-half the number of tracks. Or, put another way, all-through-running in Penn Station would be four times as efficient as the current hybrid concept of operations in which one-half of peak hour trains already run through the station.

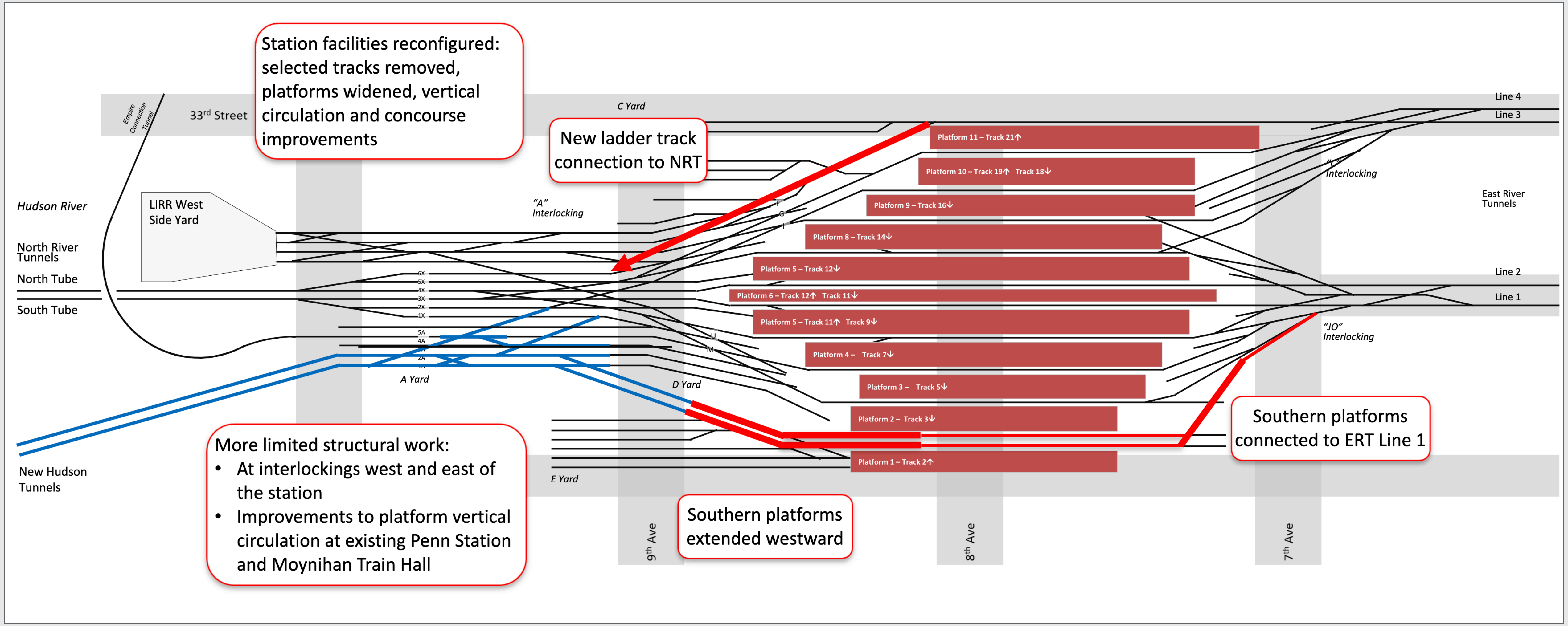
Passenger access to all platforms would be provided from the various Penn Station and Moynihan concourses. The existing stairs, escalators, and elevators down to the current station platforms could be retained. Additional vertical circulation capacity could be added adjacent to these existing access points where desirable or needed for passenger capacity or to improve the quality of access for mobility-impaired passengers. Passenger access to and from the platforms would be improved over the existing station configuration.

All station tracks would be aligned to connect directly to both a Hudson River tunnel and an East River tunnel, enabling through-running. This is not the case today, where Tracks 1 through 4 do not connect with the East River Tunnel, and Tracks 20 and 21 do not connect with the existing tunnel under the Hudson River. The platforms and connecting tracks along the north and south edges of the station box would need to be shifted to enable through-running on all station tracks.

The result of eliminating every other track to widen the existing platforms would be a station that retains 12 of the existing 21 station tracks. The Penn Station track and platform configuration for this concept is shown in **Figure 5-28**. The station in its final configuration would have five fewer platform tracks than Design Concept 1.

Figure 5-28

Illustrative Penn Station Track and Platform Configuration — Design Concept 2 — Limited Track and Platform Reconfiguration



As with Alternative 2, Design Concept 1, investment would be needed to accommodate regional metro and suburban trains beyond the limits of the existing station to enable run-through service. To make through-running at Penn Station work, this concept requires far-side turnback stations and storage yards both west of the Hudson River and east of the East River. The turnback stations and yards are necessary for through-running at Penn Station and support the implementation of regional metro service and better-integrated regional rail service. The configuration, size, and cost of the turnback stations and far-side yards would be similar to those that would be required for Alternative 2, Design Concept 1.

Once the Penn Station reconstruction and far-side turnback stations and yards are constructed — along with the institutional changes and capital investments needed for regional metro service interoperability (e.g., to enable through-running trains from Long Island to operate through Penn Station to points in New Jersey), the station would be able to support 100% through-running. The station would not be able to operate at its full capacity until the full program of associated capital investments has been completed.

Operational constraints and challenges would remain. The station would be able to support regional metro service, fully utilizing four platform tracks. However, the eight remaining tracks would not be sufficient to accommodate Amtrak NEC service, Empire/Hudson Line service, and longer-distance suburban service. With suburban trains running through both sets of tunnels to the far-side stations, and the station operating at its full capacity to support peak demand during rush hours (towards Penn Station on weekday mornings and away from Penn Station on weekday afternoons), there would be no spare capacity available to offer reverse-peak service to and from suburban trunk lines and branches that serve areas beyond the reach of the regional metro network.

This Design Concept would present the same choices as Design Concept 1 with respect to the operation of suburban rail services with 100% through-running at Penn Station:

A. Peak service to far-side locations for yard storage and for reverse-peak turnbacks at 8 tph.

B. Peak service to far-side locations in the peak direction for yard storage only, with bi-directional shuttle service providing transfer connections to regional metro trains.

C. Peak service to far-side locations for yard storage, plus through-running service at 8 tph in each direction, connecting suburban trunk lines on both sides of the region to provide sufficient reverse-peak service.

None of these options is considered a feasible solution, either for the long-term or the interim phase of implementation.

This design concept does not meet the operational performance requirements for this project, in terms of both station throughput capacity and the ability to deliver reverse-peak suburban service. It is not recommended to carry this concept forward for further analysis.

This design concept is evaluated in detail in the sections below.

5.2.2.2
Service Concept

Alternative 2, Design Concept 2 is based on the same future service assumptions as Design Concept 1. It would allow for through-running regional metro service at Penn Station, fully utilizing one set of Hudson and East River tunnels and operating at dedicated platform tracks at Penn Station. Additional suburban rail service would be provided to and from the portions of the regional rail network beyond the limits of regional metro service. Suburban service also would be through-running at Penn Station, utilizing far-side stations and yards. Amtrak Acela and Northeast Regional service would operate at half-hourly intervals during peak periods and occupy four platform tracks two times each peak hour. Other Amtrak Northeast Corridor services, Amtrak Empire Corridor service, and Metro-North Hudson Line service would also operate at Penn Station. Empire/Hudson Line trains are assumed to turn back at the Penn Station platforms to preserve Northeast Corridor through-running capacity. The Amtrak and suburban services are assumed to use the Penn Station tracks and tunnel tracks not used by regional metro service. These trains may use specific platforms or groups of platforms at Penn Station, but they will operate in mixed traffic in the tunnels and on the main line tracks feeding the Penn Station complex.

Under Design Concept 2, the anticipated track usage within the Penn Station complex would be as follows (as shown in Figure 5-29):

Northern Side of Penn Station (4 platform tracks) — Regional Metro Service
- Westbound regional metro trains from East River Tunnel Line 4 via northernmost two station tracks to the North River Tunnel north tube
- Eastbound regional metro trains from the North River Tunnel south tube via two station tracks to East River Tunnel Line 3

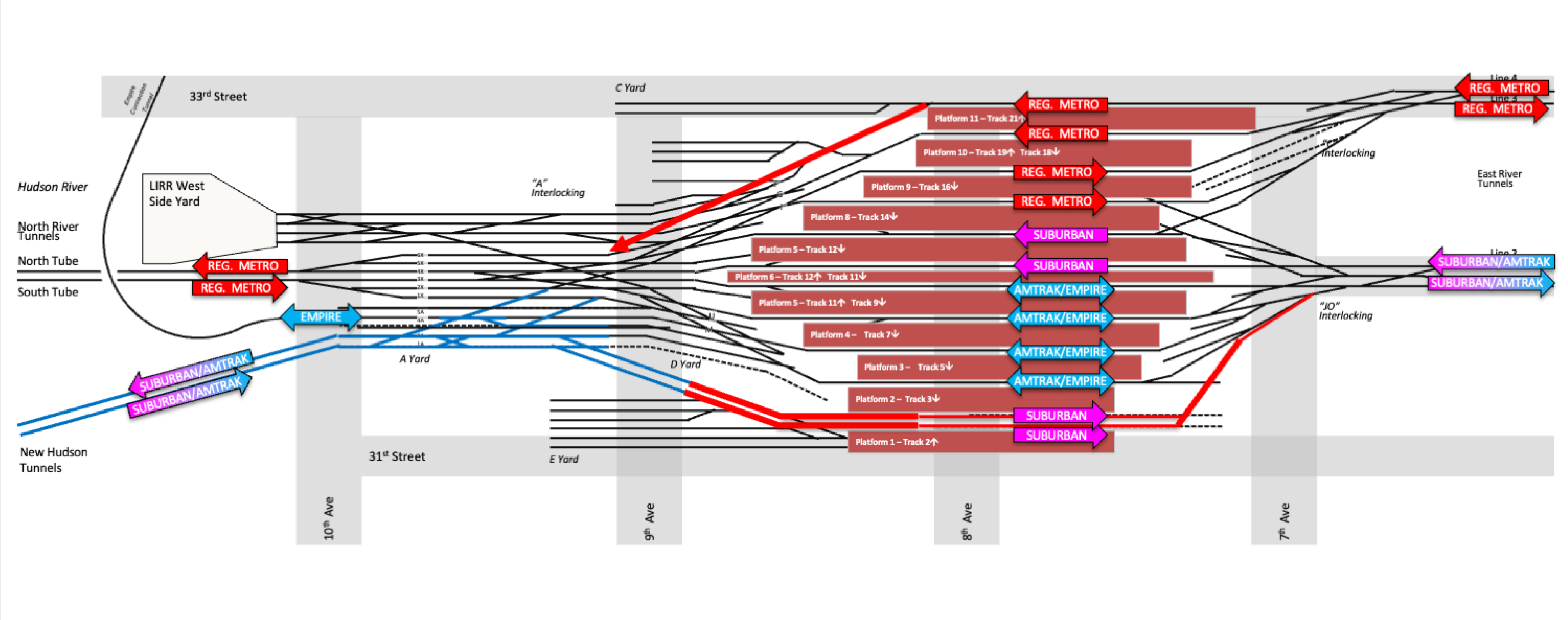
Middle and Southern Side of Penn Station (8 platform tracks) — Suburban and Intercity Services
- Westbound trains from the East River Tunnel Line 2 via the middle station tracks to new Hudson River Tunnel north tube
- Eastbound trains from the North River Tunnel south tube via the southernmost station tracks to East River Tunnel Line 1
- Empire/Hudson Line trains from the Empire Tunnel would utilize the middle station tracks — these trains could either turn back at the Penn Station platforms or run through to Sunnyside Yard in Queens

Within the middle and southern zone of the station, eight station tracks would need to be shared by:
- Suburban trains from New Jersey, Long Island, the New Haven Line, and the Hudson Line
- Amtrak Northeast Corridor trains
- Amtrak Empire Corridor trains

For operational flexibility, the tracks on the north side of this zone would be used by westbound through-running suburban trains and the tracks on the south side of this zone would be used by eastbound through-running suburban trains. The tracks in the center of this zone would be available for use by Amtrak for through-running trains. Empire/Hudson Line trains also would need to use these tracks, either to run through to or from Queens or to turn at Penn Station. In either case, the number of tracks available for Amtrak Northeast Corridor and Empire Corridor train movements is limited. This constrains the station’s capacity for intercity service. If more station tracks are devoted to intercity trains, then the capacity available for suburban service would be reduced. This operational concept is illustrative and has not been evaluated or approved by the operating railroads at Penn Station.

Figure 5-29

Track Usage
Concept 2 — Limited Track and Platform Reconfiguration



5.2.2.3

Operational Performance

Penn Station Throughput Capacity

In Design Concept 2, two tracks would be available in each direction for regional metro service, or for suburban local service prior to full implementation of regional metro. This service would use the four northernmost tracks in the station, the existing North River Tunnel, and East River Tunnel Lines 3 and 4. A total of 24 tph could be delivered in each direction, with 12 tph per track. This would provide trains at each track at five-minute intervals during peak periods, supporting dwell times in the range of two to three minutes, which is considered within the acceptable range for regional metro service operating at wide station platforms.

All other suburban and intercity service would use the middle and southern sides of the station, utilizing the new Hudson River Tunnel, the existing Empire Line Connection tunnel, and East River Tunnel Lines 1 and 2. Eight platform tracks would be available for these services in Design Concept 2. Four of these eight tracks would be required to support Amtrak Acela and Northeast Regional service, with Acela through trains able to overtake Northeast Regional through trains in both directions of travel at Penn Station, potentially twice each hour during peak travel periods.

With four station tracks allocated to regional metro service and a minimum of four tracks allocated to Amtrak Acela and Northeast Regional service, the remaining four tracks in the central and southern portion of the station would need to be able to support:

- Suburban trains serving New Jersey, Long Island, the southeast Bronx, and the New Haven Line
- Amtrak Northeast Corridor or long-distance trains that require platform space in addition to the tracks occupied by Acela and Northeast Regional trains
- Empire/Hudson Line trains accessing the station via the Empire Tunnel

In Design Concept 2, the suburban trains are assumed to run through Penn Station using the new Hudson River Tunnel and East River Tunnel Lines 1 and 2. Ideally, six tracks would be allocated for the suburban services and Amtrak Northeast Corridor service beyond the half-hourly Acela and Northeast Regional trains, and another three tracks would be allocated to Empire/Hudson Line trains, as indicated in Table 5-5. However, Design Concept 2 would only make four tracks available for these services. This poses a severe constraint on the ability of the station to handle reliably the planned volume of trains.

The capacity of these four tracks is insufficient to support bi-directional suburban and intercity service, plus Empire/Hudson Line service, with reasonable dwell times that protect the reliability of the service.

The limited available capacity on these four tracks would be maximized by running through service on all of them. If it is assumed that Empire/Hudson Line service would be limited to 3 tph and would run through to Sunnyside Yard in Queens, then an additional 10 tph would be available for suburban trains crossing both the Hudson River and the East River. Total trans-Hudson capacity would be 40 tph through both pairs of tunnels. However, as in Concept 1, an allowance needs to be made for reverse-peak suburban service from the New Jersey turnback station to Long Island and the New Haven Line in the AM peak, and returning from Long Island and the New Haven Line to the New Jersey turnback station in the PM peak. With a reasonable allowance of 8 tph for suburban reverse-peak service, this would reduce the number of peak direction Hudson River train slots to 32 tph (6 Amtrak and 26 suburban/regional metro). This is significantly below the 48 tph that is required to meet operational needs, and only an additional 8 tph more than the capacity of the existing tunnel.

Table 5-5

Penn Station Platform Tracks Required for Through Service and Provided in Design Concept 2

Service	Station Tracks Required*	Station Tracks Provided in Alternative 2, Design Concept 2**
Regional Metro/Local	4	4
Amtrak Acela and Northeast Regional	4	4
Suburban and Other Amtrak Northeast Corridor	6	4
Empire/Hudson Line	3	
TOTAL	17	12

* Required for through service at 48 tph in each direction, plus Empire/Hudson Line at 4-5 tph.

** These 12 tracks would only enable 32 tph in the peak direction of travel under the Hudson River, once provision is made for Empire/Hudson Line service and for reverse-peak service to/from LIRR branch lines and the New Haven Line.

Assuming that two platform tracks in each direction would be allocated to regional metro service, and another two tracks in each direction would be allocated to Amtrak NEC services (including Acela, Northeast Regional and Keystone service), the remaining two platform tracks in each direction would then be available for use by suburban trains from New Jersey, Long Island, the New Haven Line, and the Hudson Line, along with Amtrak Empire service. Based on the estimated dwell time requirements contained in **Appendix B** for through-running timetable-based service at wide platforms (in the range of 6-7 minutes), platform re-occupation time on these tracks would be approximately 9 minutes, permitting 6.7 tph per track. The two tracks in each direction could accommodate approximately 13 tph. Planned Empire/Hudson service would claim three of these hourly slots and would need to run through to Sunnyside Yard in Queens to minimize dwell times at Penn Station on these suburban/Empire tracks. The remaining 10 slots per hour could be filled by suburban trains operating to or from New Jersey. This would be significantly lower than the estimated demand for peak suburban train service from trunk and branch lines beyond the limits of the regional metro network — and lower than the 18 tph for suburban service that would be provided in Alternative 1, and in Alternative 2, Design Concept 1.

It therefore would not meet the operational performance requirement to increase trans-Hudson capacity by 24 tph, to at least 48 tph.

If the railroads were to try to operate the planned peak level of train service on 12 station platform tracks, dwell times for Amtrak and suburban trains would have to be shortened to levels below the minimums identified for through-running with wide station platforms. This could result in crowding at platform level for suburban and intercity passengers during the train alighting and boarding process. Intercity passengers in particular would be rushed into quicker-than-desired boarding intervals and would have less time available for handling luggage. The reduced recovery time embedded in station dwell times at New York also would tend to increase the likelihood of departure delays for Amtrak and suburban trains operating on set timetables.

In summary, in this concept, there is no combination of platform allocations or operating concepts that simultaneously supports Amtrak Acela overtakes, Empire/Hudson Line service, and suburban express service from New Jersey, Long Island, and the New Haven Line. As a result, Design Concept 2 is not operationally feasible. **Appendix B** documents the assumptions related to dwell time and train throughput per track that support this conclusion.

Suburban Service Constraint

Like Alternative 2, Design Concept 1, Design Concept 2 would not provide a reasonable way to operate reverse-peak suburban service once regional metro service is implemented. There are three possible ways to provide bi-directional suburban service in the morning and evening peak periods:

1. Turn back selected suburban trains at the far-side stations. These returning trains would claim tunnel slots that then would not be able to be used by peak direction trains from the suburban branches in the morning and to the suburban branches in the evening. This would reduce peak direction capacity and service, which is considered unacceptable.

2. Limit reverse-peak service to regional metro lines, with transfers required to reach suburban locations on the trunk lines and suburban branches beyond the extent of the regional metro network via shuttle services (e.g., change trains at Jamaica or Hicksville for points east, or at Secaucus or Newark for points west). This would eliminate one-seat ride reverse-peak service from Manhattan to the suburban trunk lines, forcing reverse commuters from the urban core to transfer.

3. Make suburban trunk lines fully interoperable and convert a limited number of suburban trains to cross-regional through-running to support reverse-peak service. This would significantly increase the cost and time to implement through-running and force early decisions about investment in the cross-regional rail network.

None of these options is considered acceptable. Therefore, Design Concept 2 does not meet the overall operational performance requirement.

5.2.2.4
Compatibility with Cross-Regional Rail Vision

The vision for future rail service articulated by the FRA in NEC FUTURE and reflected in the railroads' long-range service objectives calls for the introduction of headway-based regional metro service and the continued operation of timetable-based intercity and suburban rail services along the Northeast Corridor, including the New York metropolitan region.

Design Concept 2 provides for dedicated regional metro operations on the north side of Penn Station and through the existing Hudson River Tunnel and East River Tunnel Lines 3 and 4. This service would be a key part of the future vision for cross-regional service. However, the remainder of the station would have insufficient capacity for the anticipated future level of suburban and intercity rail service. Since all three service types are integral to the long-range vision, the design concept is not compatible with the vision.

5.2.2.5
Engineering Feasibility

Track Geometry at Penn Station

Design Concept 2 would retain the geometry of 10 of the 12 station tracks that remain. The two southernmost tracks would be shifted to the west to accommodate feasible track connections to both the new Hudson River Tunnel and existing East River Tunnel Line 1. The alignment of the new connecting tracks on both the north and south sides of the station meet the applicable track design criteria. With fewer station tracks to connect, the existing ladder tracks and interlockings potentially could be modified to improve the geometry and increase speeds for certain train movements.

In summary, the track geometry at Penn Station is considered feasible, but would require further study during a subsequent phase of design, if this concept is advanced.

Platform Geometry at Penn Station

The existing platforms at Penn Station include a mixture of original platforms from the 1910 station and platforms that have been lengthened or modified over the years. Some existing platform edges at the ends of the platforms are curved as a result of the underlying track geometry. This can result in gaps between the platform edge and train doors that exceed the 3-inch standard for ADA-compliant level boarding.

The structural columns that land on the platforms include original Penn Station columns and new columns that support structures that supplemented or replaced the original station. Many of these columns are situated close together or close to or along the edges of existing platforms, which can obstruct the smooth flow of passengers as they board or alight from trains. These locations also do not meet the ADA standard, which calls for maintaining a 6-foot clear zone for passenger circulation between platform edges and any obstructions on the platform, such as columns or stair/escalator/elevator enclosures.

Alternative 2, Design Concept 2 would retain and expand the existing station platforms, largely retaining the non-compliant elements of the existing station. At most of the widened platforms, one side of the platform will have a line of columns located close to the platform edge, hindering circulation along the platform edge and potentially blocking access to train doors in some locations. This non-compliant condition could be addressed by erecting a barrier along these platform edges, essentially converting the platforms into wide side platforms serving a single track (as opposed to island platforms serving two tracks). Passenger access then would be limited to one side of each track. This concept also would not address directly the various impediments to smooth passenger circulation that are present on the existing station platforms.

With the focus of through-running on minimizing dwell times and maximizing the throughput of trains at each platform track, smooth passenger circulation on the platforms is of critical importance, including the ability of passengers to alight from and board trains relatively quickly. Given the level of investment needed to enable through-running at Penn Station and regional metro service for the New York metropolitan region, retaining or creating substandard conditions for passenger circulation at Penn Station would not be logical or practical. However, replacing or modifying the columns and other impediments that create those substandard conditions would introduce the same type of construction complexities and constructability issues that render Design Concept 1 infeasible.

Track Usage and Geometry in New Jersey and Western Queens

Alternative 2, Design Concept 2 requires construction of the far-side turnback stations and associated yards in northern New Jersey and either western Queens or the southeast Bronx. These stations and yards would be configured similarly to those assumed in Design Concept 1. Because the usage of tracks in the existing tunnels and new Hudson River Tunnel would change in this through-running concept, capital investment would be required in new grade-separated track connections in northern New Jersey to re-sort the directionality of train traffic and align the tunnel tracks properly with the NEC express and local tracks.

The Gateway Program intends to connect the express tracks of the NEC at Newark to the existing North River Tunnel and extend the NEC local tracks to connect to the new Hudson River Tunnel. Alternative 2, Design Concept 2 would reverse the usage of tracks within the Hudson River tunnels. Local service, including future regional metro, would use the existing North River Tunnel, while Amtrak trains and longer-distance suburban trains (which tend to operate as express trains during peak periods) would use the new Hudson River Tunnel. Consequently, track connections would need to be re-designed and built somewhere between the tunnel portals and Newark to properly sort express and local traffic. The required connections are shown diagrammatically in **Figure 5-30** and would be designed to meet track geometry standards. The actual location and alignment of these track connections would require further engineering design and analysis. They are considered to be feasible and constructable.

Under Alternative 2, Design Concept 2, the East River Tunnel would operate similarly to the way they do today. Amtrak trains would use Lines 1 and 2, which provide access to Sunnyside Yard and to the Hell Gate Line via the Harold bypass tracks. "Local" services, including future regional metro service, would use Lines 3 and 4 and require connections to the Hell Gate Line, the local tracks of the LIRR Main Line and the LIRR Port Washington Branch. Suburban express trains from Long Island and from the New Haven Line would use Lines 1 and 2, sharing the use of those tracks with Amtrak and with New Jersey suburban trains (**Figure 5-30**).

As in Alternative 2, Design Concept 1, these train movements are largely free of train crossing conflicts, though eastbound train movements to the LIRR Port Washington Branch from both East River Tunnel Line 1 and the connecting track from Grand Central Madison would involve crossing conflicts, as is the case with the existing Harold Interlocking track layout.

With the side-by-side operational assumptions described above, no additional track connections would be required in western Queens to support train movements in Design Concept 2. If this concept were implemented with right-hand running operations, it would face the same insurmountable obstacle of requiring additional grade-separated track connections in western Queens, for which space is not available.

Constructability

This concept generally retains the existing track layouts within the Penn Station interlockings, including the existing ladder tracks, though it would be possible to remove the switches and tracks that feed station tracks that would be eliminated.

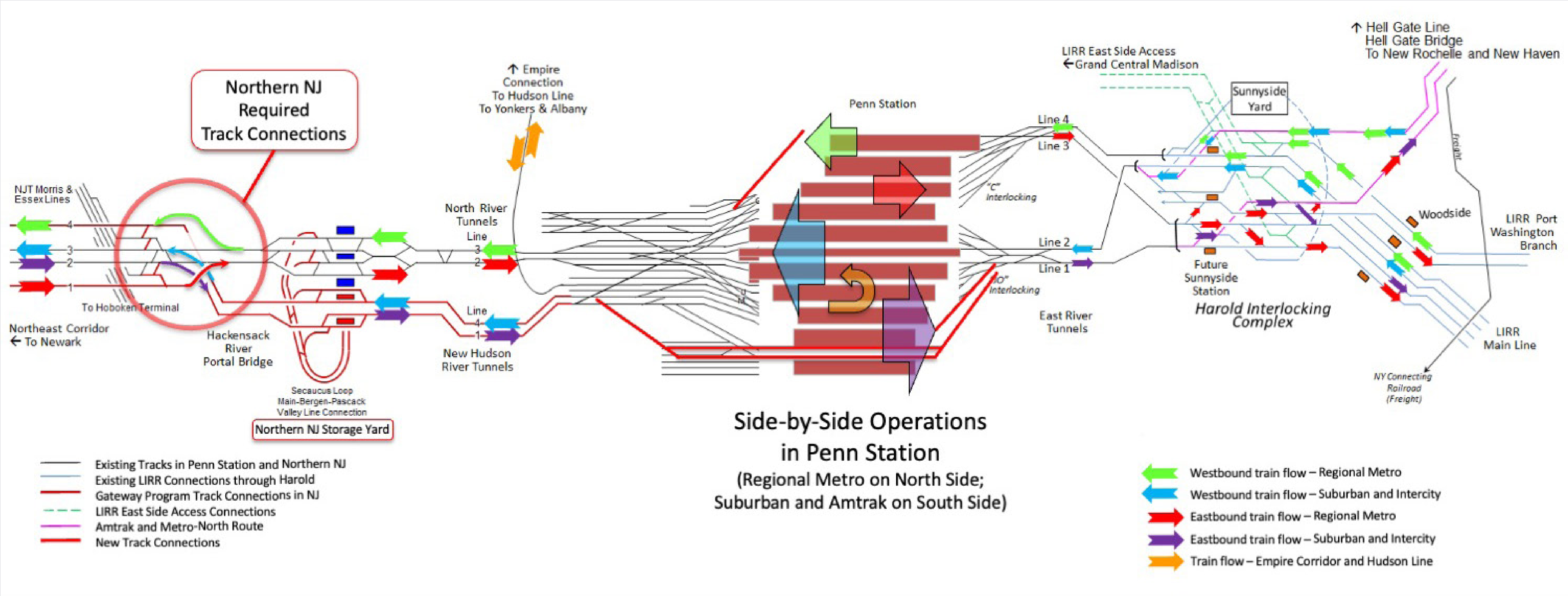
Additional trackwork would be needed west and east of the station platforms to allow all of the remaining station tracks to connect to tunnels on both sides of the station, thereby supporting through-running. The northernmost track would occupy the slot of existing Track 21 and would be connected at its west end to the North River Tunnel by means of a new ladder track designated as the 'G' Ladder, replacing the existing 'F' Ladder. Significant column relocation and other structural work within the Moynihan Train Hall block would be required to create the new ladder track. With all trains from Long Island, the Bronx, and the New Haven Line operating through Penn Station to and from New Jersey, the LIRR West Side Yard would become functionally obsolete. Its capacity for the storage and maintenance of LIRR trains would need to be replaced and expanded with new yard and maintenance facilities in northern New Jersey. Existing track access from Penn Station to the West Side Yard site would not need to be preserved.

The two southernmost station tracks in this concept, in the alignments of existing Tracks 2 and 3, would need to be realigned on both the west and east sides of the station to provide platforms long enough to support 12-car trains and through-running track connections to both the new Hudson River Tunnel and existing East River Tunnel Line 1. In order to connect Tracks 2 and 3 directly to East River Tunnel Line 1, which is not possible today, the platforms serving these tracks would be shifted westward, crossing beneath Eighth Avenue to the Moynihan block. New ladder tracks would connect the western ends of these platform tracks to the new Hudson River Tunnel tracks. Significant column relocation and other structural work within the Moynihan Train Hall block would be required to create these new ladder tracks. The Penn Station interlockings ('A' Interlocking west of the station and 'C' and 'JO' Interlockings east of the station) would be reconfigured to feed the new station tracks.

Some structural work within the station would be required to frame widened vertical circulation elements and to shift columns away from platform edges where necessary to ensure adequate passenger circulation along the platforms and safe and ADA-compliant access to trains on every remaining station track. The existing columns that support

Figure 5-30

Required Track Connections in Northern New Jersey and Western Queens for Design Concept 2



Moynihan Train Hall, the Eighth Avenue subway, existing Penn Station, Madison Square Garden, and PENN 2 could be retained. Selective column relocation along the edges of the widened existing platforms could allow the new platforms to access trains on both sides of the platform, but this would not be required along every platform edge for feasible operations, since almost all of the remaining tracks would be accessible from at least one platform edge without obstructions. If necessary, one side of a track could be fenced off to allow boarding only from the other platform to ensure ADA-compliant access.

Figure 5-31 shows a plan of the track and platform level, identifying the potentially affected columns, with the columns that would need to be removed, relocated, or have their loads transferred shown as colored circles. This includes existing columns that lie within the right-of-way of the proposed new station tracks, as well as columns that would fall along or close to the edges of the proposed platforms or within six feet of the platform edges, which have the potential to block train doors and impede the flow of passengers boarding and alighting from trains.

The required demolition, trackwork, concourse and platform vertical circulation improvements could be implemented in phases, one platform at a time, minimizing disruption to train movements and station operations. Much of the structural work within the station could be concentrated during overnight and weekend periods. The amount of required column relocation or reframing would be relatively limited. This work might entail taking more than one station track out of service, but this work generally could be scheduled to minimize construction-related impacts to operations.

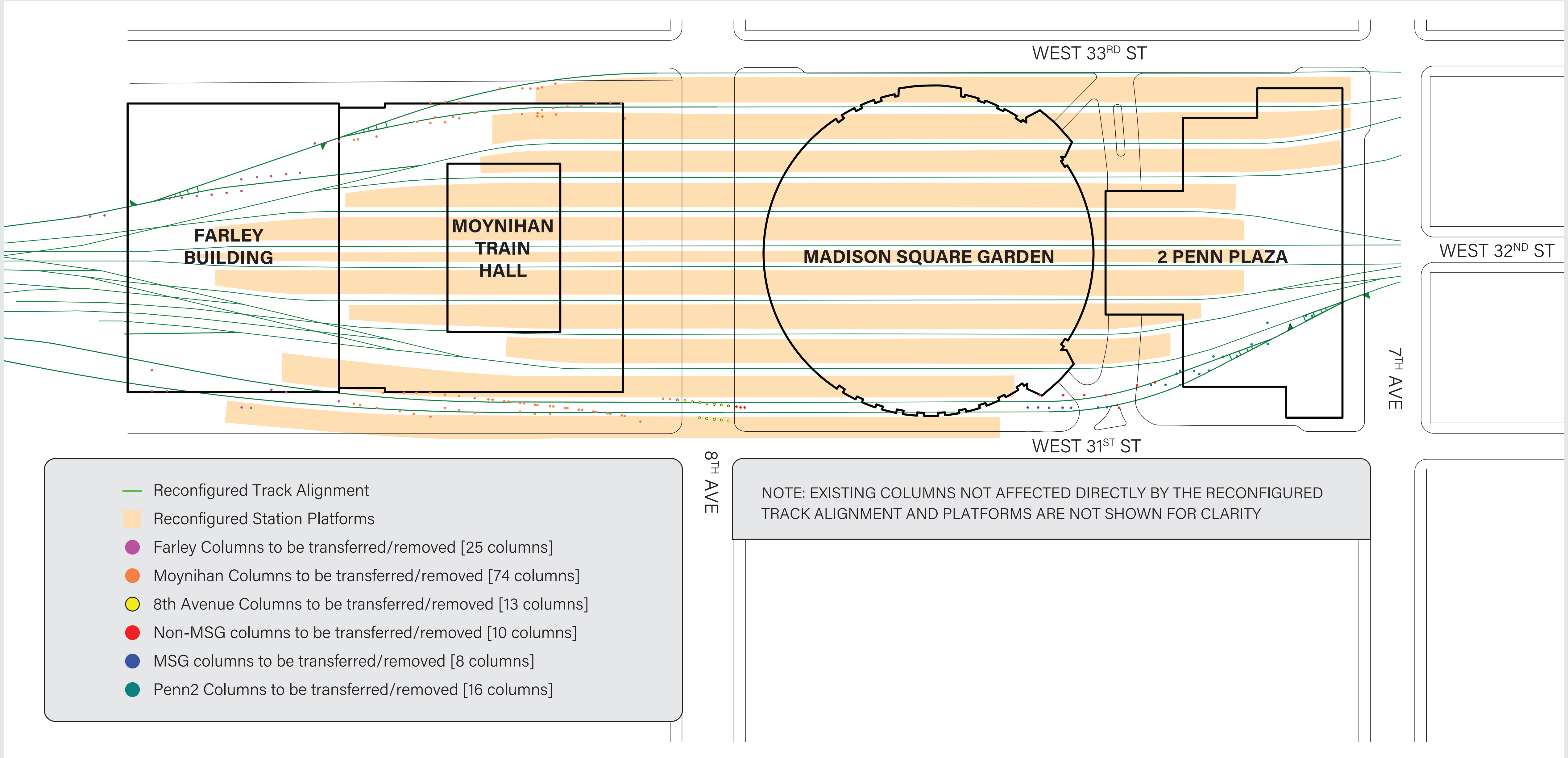
In summary, this concept is considered feasible from a constructability standpoint, although it would entail an extensive amount of construction work within the station complex. Further study would be required to confirm feasibility during a subsequent design phase if this concept is advanced.

Fire/Life Safety

This design concept would retain most of the existing rail and systems infrastructure at the track and platform level and would enable improved egress capacity from the platform level. Station infrastructure would be able to be designed to meet the requirements of NFPA 130 for emergency egress and other design standards related to fire protection and life safety.

Figure 5-31

Structural Columns Within Penn Station Requiring Removal, Relocation, or Transfer Alternative 2, Design Concept 2



5.2.2.6
Overall Assessment

Table 5-6 summarizes this concept's performance for each of the Step 1 screening criteria.

This concept passes the engineering feasibility assessment, based on both the track geometry and constructability metrics. Design Concept 2 would be a large and complex construction project within the existing station envelope and would entail significant structural work at Moynihan Train Hall to provide track connections to the northernmost and southernmost station tracks. Major track realignment within the station platform area would be limited to the southern edge of the station and the tracks abutting the two southernmost platforms. Construction within the station area would affect the areas of the station where work is being done, but the impacts on station operations during construction could be mitigated by sequencing the work in multiple phases.

However, this concept fails to meet the operational performance requirements for this project. It does not have the ability to reliably deliver 24 tph through each Hudson River and East River tunnel tube (48 tph total in each direction of travel). Alternative 2, Design Concept 2 could reasonably deliver through-running regional metro service on the north side of the station at peak volumes of 24 tph in each direction. However, the center and southern portion of the station would not be able to provide enough capacity to accommodate the remaining suburban services, Amtrak's planned growth in Northeast Corridor intercity service, and rail service from the Empire Corridor or Metro-North Hudson Line. The relatively long dwell times required for Amtrak trains (compared with regional metro and suburban trains), the need to accommodate Acela-Northeast Regional overtakes at Penn Station, and the requirement to turn back Empire/Hudson Line trains at Penn Station in order to balance Hudson and East River tunnel volumes result in demand for platform track space that exceeds the supply by three to five tracks. Appendix B documents the assumptions related to dwell time and train throughput per track that support this conclusion.

This design concept also would not provide a reasonable way to deliver reverse-peak service to the suburban branch lines, without either sacrificing peak direction capacity (i.e., using peak-direction tunnel slots for reverse-peak trains) or requiring up-front investment in the infrastructure, rolling stock, and institutional changes needed for interoperable bi-directional service on the full regional network, including both the suburban trunk lines and the regional metro network.

Alternative 2, Design Concept 2 therefore fails the operational performance test, and the concept does not advance for further study.

Table 5-6
Step 1 Performance Results
Alternative 2 (Through-Running)
Design Concept 2: Limited Track and Platform Reconfiguration

Step 1 (Pass / Fail)

Track Geometry	Constructability	Fire-Life Safety	Operational Performance	Future Regional Rail
Pass	Pass	Pass*	Fail	Fail

* While not analyzed in depth, the assumption is that since this design concept re-uses the existing station and does not add new tunnels, the fire-life safety regulations can be met.

5.2.3

Network Investment Requirements to Implement a Regional Metro Service through New York Penn Station

Numerous challenges would need to be overcome to implement a through-running regional metro service and better integrate the regional rail network. Matching up branch lines on both sides of Penn Station requires assessment of relative travel market size, as well as overcoming physical constraints that currently limit maximum train lengths on certain branches. To enable a through-running regional metro service — even one focused on a limited area as shown in Figure 5-32 — several operational and infrastructure investments above and beyond the Gateway Program are necessary on the NEC, as well as the LIRR, MNR, and NJ TRANSIT systems.

Necessary capital investment in rail infrastructure, systems, and facilities would include the types of items enumerated below. The scope of these improvements has not been developed, and detailed capital cost estimates have not yet been calculated for these required investments, but costs can be expected to be in the range of tens of billions of dollars, even for the limited area served by regional metro. This list serves to illustrate the extent and magnitude of capital investment that would be required to fully implement regional metro service as part of a comprehensive, high-quality, reliable regional rail network. These specific investments are currently not included in the capital programs of any of the regional transportation agencies. **All are investments that would not be required for traditional operations — they would only be required for a through-running regional metro service.**

Northeast Corridor Investments

East River Tunnel

- New double-tracked (Line 5 & 6) tunnel between Penn Station and Queens, with grade-separated tie-ins to the LIRR Main Line, LIRR Port Washington Branch, and Hell Gate Line east of the limits of Harold Interlocking.

Hell Gate Line

- Full four-track line. While the Penn Station Access project is building third and fourth tracks in limited segments, the full length of the Hell Gate Line between Harold Interlocking (near Sunnyside) and New Rochelle (approximately 15.2 miles) must be expanded to four tracks to facilitate both intercity and commuter service without affecting reliability (regional metro serving Port Chester would use the full length of the Hell Gate Line).
- Electrification (traction power substations and overhead catenary system [OCS]). The Penn Station Access project is building limited expansion of traction power substations; however, through-running regional metro service would require further expansion of traction power substations.

MNR Network Investments

Where no grade-separated junctions exist and are not planned in the future, through-running regional metro service would require:

- Grade separation of tracks at Control Point (CP) 216 (also referred to as Shell Interlocking) adjacent to New Rochelle where the Hell Gate Line and New Haven Line connect at a flat junction (regional metro serving Port Chester would pass through this major junction).

Station/terminal modifications:

- Terminal capacity improvements like additional platform tracks for terminating or originating trains, as well as addition of interlockings (crossover/turnout switches) for quick turnaround of regional metro service, at Port Chester.

New yards and service and inspection (S&I) facilities where no yards currently exist and are not currently planned in the future:

- The origin (westbound) or termination (eastbound) of through-running regional metro service would necessitate a yard and S&I facilities at Port Chester.

LIRR Network Investments

Where limited grade-separated routings exist but more are not planned in the future, through-running regional metro service would require:

- Expansion of grade-separated tracks at Jay and Hall Interlockings adjacent to Jamaica. Due to the complexity and enormity of train traffic (nearly 1,000 train movements on a typical weekday) passing through Jamaica — serving multiple terminals such as Grand Central Madison, Penn Station, Long Island City, and Atlantic Terminal — the regional metro routings must be unencumbered from the operating variability of the other suburban services, and vice versa.

Where no grade-separated junctions exist and are not planned in the future, through-running regional metro service would require:

- Grade-separation of tracks at Nassau Interlocking adjacent to Mineola, where the Oyster Bay Branch and LIRR Main Line connect at a flat junction (regional metro serving Hicksville would pass through this major junction).
- Grade-separation of tracks at Queens Interlocking adjacent to Elmont, where the Hempstead Branch and LIRR Main Line connect at a flat junction (regional metro serving Hempstead would pass through this major junction).
- Grade-separation of tracks at Divide Interlocking adjacent to Hicksville, where the Huntington/Port Jefferson Branch and Ronkonkoma/Central Branch connect at a flat junction (regional metro serving Hicksville would pass through this major junction).
- Grade-separation of tracks at Lynbrook, where the Long Beach Branch and Babylon Branch connect at a flat junction (regional metro serving Long Beach would pass through this major junction).
- Grade-separation of tracks at Valley Interlocking adjacent to Valley Stream, where the West Hempstead Branch and Far Rockaway Branch connect at a flat junction (regional metro serving Far Rockaway would pass through this major junction).

Station/terminal modifications:

- Terminal capacity improvements like additional platform tracks for terminating or originating trains, as well as the addition of interlockings (crossover/turnout switches) for quick turnaround of regional metro service, would be required at the following locations (based on Figure 5-32):
  - Port Washington
  - Hicksville
  - Hempstead
  - Long Beach
  - Far Rockaway

Figure 5-32

Potential Regional Metro Network

New yards and S&I facilities where no yards currently exist and are not currently planned in the future:

- The origin (westbound) or termination (eastbound) of through-running regional metro service would necessitate a yard and S&I facilities at Hicksville.

Additional tracks and expansion of electrification (traction power substations and third rail) at locations where not currently planned in the future:

- Fifth track approximately seven miles long between Harold Interlocking and Jamaica.
- Double-tracking between Island Park and Long Beach, including the single-track "Wreck Lead" Moveable Bridge on the Long Beach Branch.
- Double-tracking between Garden City and Hempstead on the Hempstead Branch.
- Double-tracking between Great Neck and Port Washington on the Port Washington Branch, including Manhasset viaduct.

NJ TRANSIT Network Investments

Where limited grade-separated routings exist but more are not planned in the future, through-running regional metro service would require:

- Expansion of grade-separated tracks at Union Interlocking, adjacent to Rahway. Due to the complexity and enormity of train traffic at Union Interlocking, the regional metro routings must be unencumbered from the operating variability of intercity and other suburban services, and vice versa.

Where no grade-separated junctions exist and are not planned in the future, through-running regional metro service would require:

- A new grade separation at Roseville Ave Interlocking, where the Morris & Essex Line and Montclair-Boonton Line connect at a flat junction (regional metro serving Montclair State University as well as Summit would pass through this major junction).
- A new grade separation at Laurel Interlocking, where the Main Line/Port Jervis Line and Bergen County Line/Pascack Valley Line connect at a flat junction (regional metro serving Hawthorne would pass through this major junction).

Station/terminal modifications:

- Terminal capacity improvements like additional platform tracks for terminating or originating trains, as well as the addition of interlockings (crossover/turnout switches), for quick turnaround of regional metro service, would be required at the following locations (based on Figure 5-32):
  - South Amboy
  - North Brunswick
  - Plainfield
  - Summit
  - Montclair State University
  - Hawthorne

New yards and S&I facilities where no yards currently exist and are not currently planned in the future:

- The origin (eastbound) or termination (westbound) of through-running regional metro service would necessitate yards and S&I facilities at the following locations (based on Figure 5-32):
  - South Amboy
  - Plainfield
  - Summit
  - Hawthorne

Additional tracks and expansion of electrification (traction power substations and OCS) at locations where not currently planned in the future:

- Third track approximately 10 miles long between Graw Interlocking (near Rahway) and Rare Interlocking (near South Amboy), including adding the third track to the double-tracked Raritan Moveable Bridge, which is in construction and nearing completion of structural and civil elements as of June 2024.

Electrification (traction power substations and OCS) at locations where electrification currently does not exist and is not currently planned in the future:

- Hunter Interlocking (near Newark Penn Station) to Plainfield on the Raritan Valley Line
- Secaucus Lower Level to Hawthorne on the NJ TRANSIT Main Line

Regional Investments

Interoperable fleet

- Rolling stock/train equipment that can traverse LIRR, MNR, and NJ TRANSIT systems with respect to traction power/electrification change of third rail (LIRR), third rail/OCS (MNR New Haven Line), and OCS (NJ TRANSIT).
- FRA-compliant rolling stock/train equipment with a sufficient number of appropriately sized doors and wide vestibules like subway trains, to permit faster egress than current train equipment (for very short 2- to 3-minute dwells in New York Penn Station). This would substantially reduce the seating area/number of available seats on each of the regional metro trains, even if there is an increase in total passenger carrying capacity from the area served by the regional metro.

Interoperable traction power system

- The LIRR, MNR, and NJ TRANSIT traction power systems are very different. MTA's railroads use third rail, and NJ TRANSIT uses OCS. Within the MTA system, LIRR direct current third-rail systems are over-running, while MNR's system is under-running using 750 V. In addition, the alternating current OCS on the MNR New Haven Line is 12.5 kV, 60 Hz, whereas the alternating current OCS is 12.5 kV, 25 Hz on Amtrak's NEC and 25 kV, 60 Hz on NJ TRANSIT's electrified branch lines.

To accommodate through-running regional metro service, traction power systems must be standardized to the extent practicable to minimize the complexity of dual-power or dual-mode rolling stock and minimize the number of types of rolling stock required.

Interoperable signaling system

- LIRR and MNR signaling systems do not conform to the requirements of the Northeast Operating Rules Advisory Committee (NORAC). Technically specialized, highly complex, interoperable signaling is currently in service in the common territory of Penn Station "A" Interlocking to Harold Interlocking.

  To accommodate through-running regional metro service, this interoperable signaling would have to be installed in the entirety of the regional metro service area.

Station improvements

- For standardized passenger experience and improved ADA accessibility, all regional metro stations must have high-level platforms, as well as the ability to accommodate full-length trains (just like any typical subway station) to enable level boarding of trains and minimize passenger unloading and loading times.

New yards and S&I facilities

- Through-running service would necessitate yards and S&I facilities very close to Penn Station's main core (i.e., within a 5- to 6-mile radius), in addition to the farther outlying locations. Required locations for these inner yards would be:
  - The vicinity of Secaucus/Kearny, NJ
  - Southeast Bronx
- Plans for the Gateway Program include a yard in the vicinity of Secaucus/Kearny, but an additional new yard would be required in Southeast Bronx. This yard must be capable of storing at least 30 trainsets, each trainset being 12 cars long (1,200 feet), to replicate LIRR's West Side Yard, and must include a full service and inspection facility.

  MTA LIRR's West Side Yard, a facility that is only about 35 years old, would no longer be used.

Practices, Procedures, and Governance

In addition to the investments in fleet and system interoperability and rail network infrastructure described above, further changes to the institutional, labor, and governance framework of the region's transit operators would be required.

Operating procedures and labor agreements would need to be standardized. Train crews, train dispatchers, and other operations staff would need to be trained, managed, and supported across the entire regional network. Operational rules, dispatching protocols, failure-recovery procedures, and maintenance practices for regional metro service would need to be integrated with the rest of the suburban services. Fare payment systems and passenger information dissemination would need to be coordinated.

Conclusion

To enable through-running regional metro service, the investments enumerated above in infrastructure, fleet, and rail systems and institutional changes involving labor agreements, work rules, governance, ticketing and passenger information systems, and cost and revenue sharing would be implemented on the inner portions of the trunk and branch network where regional metro trains would operate. These investments would be capital-intensive, require long and sustained track and service outages during construction (not just in Penn Station but throughout the limits of the regional metro service), and require specialized Force Account (i.e., railroad workers for flagging, traction power, communications, signaling, and track disciplines), which are limited at all agencies. The cost of these investments is expected to be in the range of tens of billions of dollars systemwide, above and beyond the costs of the Gateway Program and its identified supporting projects.

6 Summary

At the conclusion of this screening process, neither alternative for adapting Penn Station within its existing footprint emerged as a feasible option for doubling trans-Hudson rail capacity at the station. These alternatives are not recommended for further study.

The results of this analysis are summarized in Table 6-1. Alternative 1 (Under Penn Station) was determined to be infeasible during Step 1 of the alternative screening process because both design concepts failed one or more of the technical feasibility fatal flaw criteria. Alternative 1, Design Concept 1 (Underpinning - Single Level) would require underpinning more than 1,000 existing columns west of Penn Station, an unprecedented task that is not considered technically feasible. Alternative 1, Design Concept 2 (Mined — Single Level) avoids this pitfall, but still has a critical remaining fatal flaw: the required operational capacity could not be achieved due to the configuration of the interlocking west of the existing station.

With several fatal flaws, Alternative 1 is deemed not technically feasible and is not recommended for further study.

For Alternative 2, there is no combination of through-running tracks and platforms that can meet the operational performance needs and still be constructed without massive and unacceptable disruption to service; and there is no lesser modification plan that can be constructed within acceptable limits of disruption of service and still meet the operational performance needs.

Alternative 2, Design Concept 1 provides acceptable track geometry, but the need to realign virtually every station track and reconstruct every platform renders it unbuildable. The reconstruction would require relocating or modifying more than 1,000 structural columns and transferring loads from four different overbuild structures, each of which superimpose different structural systems on top of the original Penn Station structure. The resulting level of structural complexity, the confined space within which the structural work would need to occur, the impacts of the resulting structure on the public space at concourse level, and the need to maintain operations of the station and all of the overbuild uses during a construction period lasting more than a decade, all lead to the finding that this concept is not constructable. Construction, even if phased over an extended time period, would result in unacceptable negative impacts to station operations and reduce the station's peak capacity to below the level needed to sustain reasonable commuter and intercity service. This concept also would not provide a reasonable way to deliver reverse-peak service to the suburban branch lines, without either sacrificing peak direction capacity (a shortfall of 8 tph) or requiring up-front investment in full network interoperability. Alternative 2, Design Concept 1 therefore fails both the constructability test and the operational performance test, and the concept does not advance for further study.

Alternative 2, Design Concept 2, like Concept 1, would be incompatible with the future vision for regional rail, since it would not be able to deliver robust regional rail and suburban rail services during peak periods in both the peak and reverse-peak directions through both the Hudson and East River tunnels at the required level of service frequency.

Alternative 2, Design Concept 2 would be constructible, but fails to meet the operational performance requirements for this project. It does not have the ability to reliably deliver 24 tph through each Hudson River and East River tunnel tube (48 tph total in each direction of travel). Like Design Concept 1, this design concept also would not provide a reasonable way to deliver reverse-peak service to the suburban branch lines, without either sacrificing peak direction capacity (a shortfall of 16 tph) or requiring up-front investment in full network interoperability. Alternative 2, Design Concept 2 therefore fails the operational performance test, and the concept does not advance for further study.

Conclusion

International best practice for achieving high-density cross-regional rail service includes building purpose-built tunnels and station expansions. Through this study, focused on the specific characteristics of New York Penn Station and its associated infrastructure, it has been found that achieving the needed doubling of trans-Hudson capacity and accommodating regional metro service entirely within the envelope of existing Penn Station is not feasible, so it will be necessary to evaluate the construction of an expansion of Penn Station beyond its existing footprint and provide additional tracks and platforms to meet the operational performance needs.

A separate, future analysis will evaluate alternatives that expand the footprint of Penn Station.

Table 6-1

Assessment Summary

		Step 1 (Pass / Fail)					Step 2*	
		Track Geometry	Constructability	Fire-Life Safety	Operational Performance	Future Regional Rail Vision	Construction Cost	Construction Schedule
Alternative 1: **Under Penn Station**	Design Concept 1: **Underpinning — Single Level**	Pass	Fail	Fail	Fail	Pass	-	-
	Design Concept 2: **Mined — Single Level**	Pass	Fail	Fail	Fail	Pass	-	-
Alternative 2: **Through-Running**	Design Concept 1: **Full Reconstruction**	Pass	Fail	Pass	Fail	Fail	-	-
	Design Concept 2: **Limited Track and Platform Reconfiguration**	Pass	Pass	Pass	Fail	Fail	-	-

* None of the design concepts evaluated in this report passed the Step 1 technical feasibility screening.

Appendix A

Alternative 1
Under Penn Station Supporting Documentation

Appendix A.1

Alternative 1
Under Penn Station

Design Concept 1:
Underpinning - Single Level

Engineering Drawings

UNDER PENN STATION – DESIGN CONCEPT 1 – UNDERPINING – SINGLE LEVEL – LIST OF DRAWINGS	
DWG. NO.	DESCRIPTION
	GENERAL
G-002	UNDER PENN STATION - DESIGN CONCEPT 1- UNDERPINING - SINGLE LEVEL - LIST OF DRAWINGS
	TRACK
TK-109	UNDER PENN STATION ALTERNATIVE - UNDERPINNING SINGLE LEVEL CONCEPT - TRACK PLAN AND PROFILE - SHEET 1
TK-110	UNDER PENN STATION ALTERNATIVE - UNDERPINNING SINGLE LEVEL CONCEPT - TRACK PLAN AND PROFILE - SHEET 2
	STRUCTURAL
ST-008	UNDER PENN STATION ALTERNATIVE - UNDERPINNING SINGLE LEVEL CONCEPT - TUNNEL PLAN AND PROFILE - SHEET 1
ST-009	UNDER PENN STATION ALTERNATIVE - UNDERPINNING SINGLE LEVEL CONCEPT - TUNNEL PLAN AND PROFILE - SHEET 2

CURVE DATA							
CURVE	Dc	Rc (ft)	Lc (ft)	Ls (ft)	Ea (in)	Eu (in)	V (MPH)
C2-1	3°0'0"	1910.08	229.45	155	2.50	1.75	45
C2-2	3°0'0"	1910.08	333.39	155	2.50	1.75	45

HORIZONTAL SCALE: SCALE IN FEET 80' 40' 0 80' 160'

VERTICAL SCALE: SCALE IN FEET 16' 8' 0 16' 32'

CURVE DATA							
CURVE	Dc	Rc (ft)	Lc (ft)	Ls (ft)	Ea (in)	Eu (in)	V (MPH)
C3-1	3°45'0"	1528.16	214.34	186	3.00	2.32	45
C3-2	6°0'0"	955.37	325.01	124	2.00	1.78	30
C3-3	6°0'0"	955.37	427.98	124	2.00	1.78	30

LEGEND:

- NEW TRACK
- TRACK INSTALLED UNDER HUDSON RIVER TUNNEL PROJECT

NOTES

1. FOR TUNNEL PROFILE LIMITS AND RELATIONSHIP OF NEW TO EXISTING STRUCTURES, SEE STRUCTURAL DRAWINGS.

MTA AMTRAK NJ TRANSIT

PENN STATION, NY EXPANSION
FEASIBILITY OF ALIGNMENT ALTERNATIVES

fxcollaborative • wsp

FEASIBILITY STUDY

UNDER PENN STATION ALTERNATIVE
UNDERPINNING SINGLE LEVEL CONCEPT
TRACK PLAN AND PROFILE
SHEET 1

DWG. No. TK-109

PLATFORM TABLE		
PLATFORM	LENGTH (FEET)	WIDTH (FEET)
1	1020	30
2	1020	30
3	1020	30
4	1020	30
5	1020	30

CURVE DATA							
CURVE	Dc	Rc (ft)	Lc (ft)	Ls (ft)	Ea (in)	Eu (in)	V (MPH)
C2-3	8°0'0"	716.78	71.56	0	0	1.26	15
C2-4	8°49'24"	650.00	64.88	0	0	1.39	15

CURVE DATA							
CURVE	Dc	Rc (ft)	Lc (ft)	Ls (ft)	Ea (in)	Eu (in)	V (MPH)
C3-4	8°0'0"	716.78	71.56	0	0	1.26	15
C3-5	8°49'24"	650.00	64.88	0	0	1.39	15

NOTES

1. FOR TUNNEL PROFILE LIMITS AND RELATIONSHIP OF NEW TO EXISTING STRUCTURES, SEE STRUCTURAL DRAWINGS.

MTA AMTRAK NJ TRANSIT

PENN STATION, NY EXPANSION
FEASIBILITY OF ALIGNMENT ALTERNATIVES

fxcollaborative • wsp

FEASIBILITY STUDY

UNDER PENN STATION ALTERNATIVE
UNDERPINNING SINGLE LEVEL CONCEPT
TRACK PLAN AND PROFILE
SHEET 2

DWG. No. TK-110

MTA · AMTRAK · NJ TRANSIT

PENN STATION, NY EXPANSION
FEASIBILITY OF ALIGNMENT ALTERNATIVES

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FEASIBILITY STUDY

UNDER PENN STATION ALTERNATIVE
UNDERPINNING SINGLE LEVEL CONCEPT
TUNNEL PLAN AND PROFILE
SHEET 1

DWG. No. ST-008

MTA · AMTRAK · NJ TRANSIT

PENN STATION, NY EXPANSION
FEASIBILITY OF ALIGNMENT ALTERNATIVES

fxcollaborative • wsp

FEASIBILITY STUDY

UNDER PENN STATION ALTERNATIVE
UNDERPINNING SINGLE LEVEL CONCEPT
TUNNEL PLAN AND PROFILE
SHEET 2

DWG. No. ST–009

Appendix A.2

Alternative 1
Under Penn Station

Design Concept 2:
Mined - Single Level

Engineering Drawings

UNDER PENN STATION – DESIGN CONCEPT 2 – MINED – SINGLE LEVEL

DWG. NO.	DESCRIPTION
	GENERAL
G-002	UNDER PENN STATION - DESIGN CONCEPT 2 - MINED - SINGLE LEVEL - LIST OF DRAWINGS
	TRACK
TK-111	UNDER PENN STATION ALTERNATIVE - MINED SINGLE CONCEPT - TRACK PLAN AND PROFILE - SHEET 1
TK-112	UNDER PENN STATION ALTERNATIVE - MINED SINGLE CONCEPT - TRACK PLAN AND PROFILE - SHEET 2
	STRUCTURAL
ST-010	UNDER PENN STATION ALTERNATIVE - MINED SINGLE LEVEL CONCEPT - TUNNEL PLAN AND PROFILE - SHEET 1
ST-011	UNDER PENN STATION ALTERNATIVE - MINED SINGLE LEVEL CONCEPT - TUNNEL PLAN AND PROFILE - SHEET 2
	RIGHT-OF-WAY
RW-002	UNDER PENN STATION ALTERNATIVE - MINED SINGLE CONCEPT - PARCELS POTENTIALLY AFFECTED

CURVE DATA

CURVE	Dc	Rc (ft)	Lc (ft)	Ls (ft)	Ea (in)	Eu (in)	V (MPH)
C2-1	3°0'0"	1910.08	229.45	155	2.50	1.75	45
C2-2	3'0'0"	1910.08	333.39	155	2.50	1.75	45

CURVE DATA

CURVE	Dc	Rc (ft)	Lc (ft)	Ls (ft)	Ea (in)	Eu (in)	V (MPH)
C3-1	3°45'0"	1528.16	214.34	186	3.00	2.32	45
C3-2	6°0'0"	955.37	325.01	124	2.00	1.78	30
C3-3	6°0'0"	955.37	427.98	124	2.00	1.78	30

HORIZONTAL SCALE: SCALE IN FEET 80' 40' 0 80' 160'

VERTICAL SCALE: SCALE IN FEET 16' 8' 0 16' 32'

NOTES

1. FOR TUNNEL PROFILE LIMITS AND RELATIONSHIP OF NEW TO EXISTING STRUCTURES, SEE STRUCTURAL DRAWINGS.

MTA AMTRAK NJ TRANSIT

PENN STATION, NY EXPANSION
FEASIBILITY OF ALIGNMENT ALTERNATIVES

fxcollaborative • wsp

FEASIBILITY STUDY

UNDER PENN STATION ALTERNATIVE
MINED SINGLE LEVEL CONCEPT
TRACK PLAN AND PROFILE
SHEET 1

DWG. No. TK-111

PLATFORM TABLE		
PLATFORM	LENGTH (FEET)	WIDTH (FEET)
1	1020	30
2	1020	30
3	1020	30
4	1020	30
5	1020	30

CURVE DATA							
CURVE	Dc	Rc (ft)	Lc (ft)	Ls (ft)	Ea (in)	Eu (in)	V (MPH)
C2-3	8°0'0"	716.78	71.56	0	0	1.26	15
C2-4	8°49'24"	650.00	64.88	0	0	1.39	15

CURVE DATA							
CURVE	Dc	Rc (ft)	Lc (ft)	Ls (ft)	Ea (in)	Eu (in)	V (MPH)
C3-4	8°0'0"	716.78	71.56	0	0	1.26	15
C3-5	8°49'24"	650.00	64.88	0	0	1.39	15

NOTES

1. FOR TUNNEL PROFILE LIMITS AND RELATIONSHIP OF NEW TO EXISTING STRUCTURES, SEE STRUCTURAL DRAWINGS.

MTA AMTRAK NJ TRANSIT

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FEASIBILITY STUDY

UNDER PENN STATION ALTERNATIVE
MINED SINGLE LEVEL CONCEPT
TRACK PLAN AND PROFILE
SHEET 2

DWG. No. TK-112

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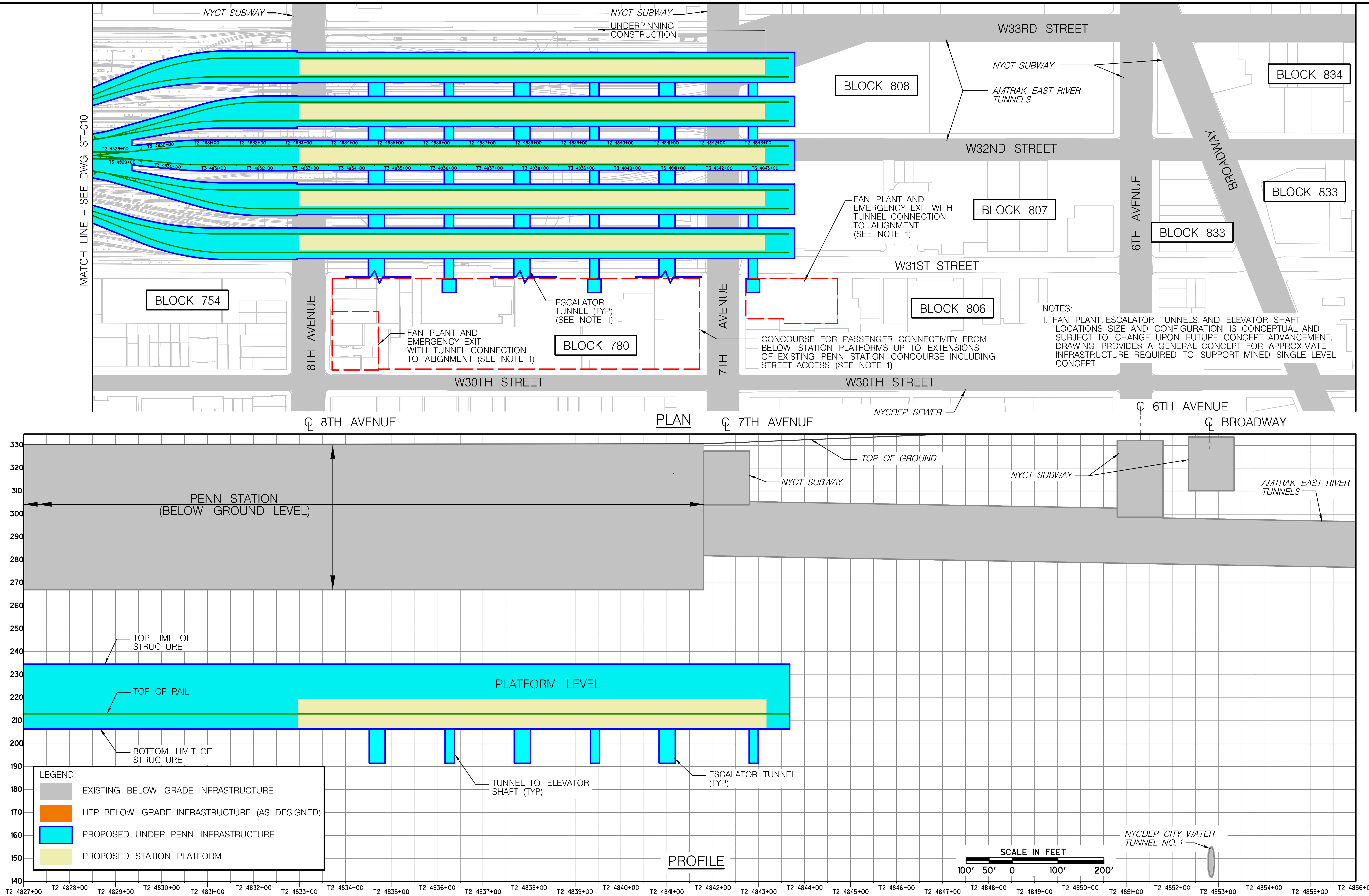
FEASIBILITY STUDY

UNDER PENN STATION ALTERNATIVE
MINED SINGLE LEVEL CONCEPT
TUNNEL PLAN AND PROFILE
SHEET 1

DWG. No. ST-010



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PENN STATION, NY EXPANSION
FEASIBILITY OF ALIGNMENT ALTERNATIVES

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FEASIBILITY STUDY

UNDER PENN STATION ALTERNATIVE
MINED SINGLE LEVEL CONCEPT
TUNNEL PLAN AND PROFILE
SHEET 2

DWG. No. ST-011

GRID NORTH

NOTES:

1. FINAL LOCATION, SIZE AND CONFIGURATION OF FAN PLANTS WITH EMERGENCY EXIT TO STREET LEVEL AND STREET LEVEL PASSENGER HEADHOUSES WITH CONNECTIVITY TO THE STATION MEZZANINE LEVEL ARE TBD. EXACT PARCELS AFFECTED AS ILLUSTRATED ARE SUBJECT TO CHANGE.
2. IMPACTS FOR THESE PROPERTIES ARE IDENTIFIED AS SUBSURFACE IMPACTS BASED ON PRELIMINARY CONTRACTIBILITY REVIEWS. COLLECTION OF EXISTING BUILDING CONDITIONS INFORMATION AND FURTHER ENGINEERING DESIGN IS REQUIRED TO CONFIRM FEASIBILITY OF TUNNEL CONSTRUCTION BELOW GRADE WITHOUT DEMOLITION OF EXISTING BUILDINGS.

LEGEND:

- HUDSON TUNNEL PROJECT TRACK ALIGNMENT
- TRACK ALIGNMENT

ANTICIPATED IMPACT

- SURFACE
- SUBSURFACE

AMTRAK
TRANSIT

PENN STATION, NY EXPANSION
FEASIBILITY OF ALIGNMENT ALTERNATIVES

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FEASIBILITY STUDY

UNDER PENN STATION ALTERNATIVE
MINED SINGLE LEVEL CONCEPT
PARCELS POTENTIALLY AFFECTED

DWG. No.
RW-002

Appendix B

Alternative 2: **Through-Running Supporting Documentation**

Doubling Trans-Hudson Train Capacity at Penn Station –
An Engineering Feasibility Study of Alternatives Within the Existing Station Footprint

Appendix B

Alternative 2: Through-Running Supporting Documentation

Contents

Penn Station Capacity

The Penn Station complex has multiple components, each of which potentially limits the throughput capacity of the station:

- Station platform tracks
- Station platforms
- Passenger circulation elements, including vertical circulation elements, waiting areas, concourses, station entrances/exits, and transit connections to and from other modes of transportation
- Tunnel tracks feeding the station
- Interlockings, comprising the tracks and switches that connect the tunnel tracks to the station platform tracks
- Train storage yards that serve the station.

The station complex operates as an integrated system, and the overall capacity of the system is limited by the element that has the least capacity. As a matter of policy and good system design practice, system capacity should be governed by the throughput capacity of the tunnel tracks, so that utilization of the tunnels can be maximized at peak travel periods to obtain greatest value from the investment in the tunnels and connecting railroad assets. This means that the station elements and interlockings should be designed with a capacity that meets or exceeds that of the connecting tunnels, so that the station itself does not become the element that constrains the capacity of the system. This appendix focuses on the station's track and platform capacity.

Station Dwell Times

Dwell time, or the length of time that a train remains stopped at a station platform, is a major determinant of the capacity of a station platform track.

Train Type Factors Affecting Dwell Time

Required dwell times are different for different types of trains and train movement patterns. Commuter rail trains have different performance characteristics than Amtrak intercity trains. Within the set of Amtrak train types, Acela, Northeast Regional, and long-distance trains each have different requirements. Regional metro trains, which are part of the long-range vision for service through Penn Station, but which do not currently operate at the station, perform more like transit trains than traditional commuter trains and generally have shorter dwell times, because the service is headway-based rather than timetable-based, which eliminates the need to build recovery time allowances into the required dwell times. The three types of train movements also have different dwell time requirements:

- Revenue to non-revenue – trains arrive loaded with passengers but depart empty
- Non-revenue to revenue – trains arrive empty and only load passengers at the station
- Revenue to revenue – trains operate with passengers both arriving and departing, with passengers both alighting and boarding at the station.

Dwell time characteristics also depend on whether the train continues operating in the same direction of travel (through-running) or changes direction in the station (turnback operations). Turnback movements require train crews to undertake certain actions to allow the train to change its direction of travel. Through-running trains generally have shorter dwell time requirements, therefore.

Components of Dwell Time

A major component of dwell time is the time needed for passengers to disembark from the train and/or board the train. For revenue to non-revenue and non-revenue to revenue trains, passengers are either only alighting or boarding. For revenue-to-revenue operations, the platform needs to handle both alighting and boarding passenger loads. During weekday peak periods, these passenger loads can be in excess of 1,000 passengers in the peak direction of travel. The existing narrow platforms at Penn Station do not permit large volumes of boarding and alighting passengers to be present on the platforms simultaneously, because of concerns about crowding and the limited available vertical circulation capacity on the platforms. On Amtrak through-running trains, passenger alighting and boarding happen sequentially. Boarding passengers are held at concourse level until all arriving passengers have left the platform, which lengthens the required dwell time.

With wider platforms that are able to comfortably accommodate boarding passengers queued on the platform, alighting passengers exiting the trains, and passengers circulating along the platform, it would be possible to allow boarding passengers to descend to platform level in advance of the train's arrival. This shortens the time required for passenger alighting and boarding. This is the mode of operation at 30th Street Station in Philadelphia, which has significantly wider platforms than Penn Station.

Passenger alighting and boarding is not the only factor controlling dwell time. For through-running trains that change crews while the train is at the platform in Penn Station (which is the case for Amtrak through trains and could be the case for through-running commuter trains), the following activities must be factored into the dwell time:

- Engineer operating position close-up
- New engineer operating position set-up
- Engineer/conductor job briefing

For trains that turn back at station platforms, there are a larger number of operational support activities that must be factored into the dwell time:

- Engineer operating position close-up
- Conductor walk time for train safety review
- Engineer walk time
- Engineer operating position set-up
- Terminal departure brake test
- Cab signal test
- Positive train control (PTC) test[1]
- Engineer/Conductor job briefing

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[1] Future requirement for the Advanced Civil Speed Enforcement System (ACSES II), the PTC and train control system deployed on the Northeast Corridor.

In current practice, these activities can consume up to 14 minutes for revenue-to-revenue turns. They require less time for non-revenue turns. Passenger alighting and boarding generally occurs in parallel with these activities.

For trains that operate on a set timetable (which covers all existing train service at Penn Station), dwell times for revenue-to-revenue service include an additional time buffer to allow for slight delays to arriving trains without affecting the on-time departure of the outgoing train. This recovery time generally provides an extra few minutes, added to the required minimum dwell time. For purposes of this analysis, through-running timetable-based suburban train dwell times are assumed to include two minutes of recovery time.

In addition to passenger alighting/boarding, crew-related activities, train servicing activities, and recovery time, some additional time is needed for opening and closing of the train doors, for the engineer to receive confirmation that the train doors are closed and the train is ready to depart, and for the engineer to react upon receiving a clear signal to proceed.

Estimated Dwell Times for Purposes of Penn Station Through-Running Analysis

Based on prior studies and analyses of train dwells at Penn Station and at stations elsewhere that serve regional metro trains and operate in through-running mode, planning criteria were developed for station dwell times for the various types of train movements that might occur at Penn Station in the future, with either narrow or wide station platforms. These criteria are listed in Table B-1.

Table B-1
Dwell Time Criteria for Penn Station Through-running Analysis
(Time in Minutes)

	Timetable-Based Service		Headway-Based Service
	Existing Narrow Platforms	Wide Platforms*	Wide Platforms
Commuter/Suburban Turnback Operations			
Revenue to Non-Revenue	15	14	--
Non-Revenue to Revenue	15	14	--
Revenue to Revenue	22	17	--
Commuter/Suburban Run-Through Operations			
Revenue to Non-Revenue	7	6*	--
Non-Revenue to Revenue	15	6*	--
Revenue to Revenue	--	7*	--
Intercity Operations			
Revenue to Revenue – Run-Through	15-30	8*	--
Revenue to Revenue – Run-Through trains being overtaken in station	--	15-20	--
Revenue to Revenue – Turnback (Empire Service)	--	40	--
Regional Metro Run-Through Operations			
Revenue to Revenue	--	--	3

* Changes to current operating procedures also will be needed to achieve reduced dwell times.
Source: WSP

Amtrak long-distance trains handle checked baggage and generally require more platform dwell time to support passenger-handling and operational needs than Acela or Northeast Regional trains. These trains are limited in number and are assumed to operate outside of the weekday peak periods, so their performance and requirements were not analyzed for the peak periods. Sufficient capacity in the station is assumed to be available during off-peak periods to accommodate these trains and their longer dwell times.

In order to achieve the reductions in dwell time shown in Table B-1 for through-running revenue-to-revenue suburban and intercity service, the operational factors that partially contribute to existing dwell times would need to be mitigated. First, the existing narrow station platforms are assumed to be widened or replaced with wider platforms, which is considered a prerequisite for through-running service with reasonably short dwell times. For suburban revenue-to-revenue service, departing passengers should be allowed to descend to platform level prior to the arrival of the train, to shorten the time required for alighting and boarding. Eliminating the need for crew changes at Penn Station, or shifting them to an alternate location, may also help shorten dwell time. Revenue-to-revenue services should utilize rolling stock that enables rapid passenger alighting and boarding, which might necessitate the acquisition of new rail cars with more loading and unloading capacity for these services.

For intercity services, shifting crew changes and food car re-stocking to alternate locations may also enable shorter dwell times at Penn Station. No analysis was done as part of this work effort to quantify these potential changes in operating procedures, including assessments of their feasibility, costs, and cost-effectiveness.

The information provided herein provides a sense of the degree of dwell time savings that could be accomplished with wider platforms, through-running, and the conversion of a portion of the service to regional metro. Its purpose was to support this analysis of through-running at Penn Station and should not be taken as specific guidance for service planning in general.

Throughput Capacity per Track

The throughput capacity of a station platform track is a function of the inter-arrival time between successive trains at a station platform track, which is defined as Platform Reoccupation Time. Platform Reoccupation Time is measured from the time a train arriving at a platform comes to a stop. The following equations show how track capacity is measured and identify the components that make up Platform Reoccupation Time:

$$C_{Trk} = \frac{60}{T_{Reocc}}$$

Where…

C_{Trk} = Platform Track Throughput Capacity (trains per hour per track)

T_{Reocc} = Platform Reoccupation Time (in minutes)

$$T_{Reocc} = T_{Dwell} + T_{Outbound} + T_{Reset} + T_{Buffer} + T_{Inbound}$$

Where…

T_{Dwell} = Dwell Time – time when train is stationary at the station platform

$T_{Outbound}$ = Outbound Movement Time – time for the initial departing train to clear the platform signal block upon exiting the station

T_{Reset} = Interlocking Reset Time – time needed for the train control system to establish a route through the approach interlocking into the station platform for a following train and display a clear signal

T_{Buffer} = Buffer Time – time between when a clear signal is displayed and when the subsequent train enters the platform signal block

$T_{Inbound}$ = Inbound Movement Time – time for the subsequent arriving train to move through the interlocking and come to a stop at the station platform.

(All times measured in minutes)

Generally, the latter four elements of Platform Reoccupation Time adds in the range of two to four minutes to the station dwell time.

Amtrak Acela and Northeast Regional trains represent a special case in terms of track occupancy. Both Amtrak services are assumed to operate along the Northeast Corridor (NEC) in the future at half-hourly intervals during peak periods. Amtrak is expected to continue its current practice of having high-speed Acela trains pass or "overtake" the Northeast Regional trains at Penn Station. Typically, the regional train arrives at Penn Station first, followed by the Acela train. After discharging and boarding passengers (some of whom receive assistance from "Red Cap" porters with their luggage), changing crews, and servicing the food and beverage car, the Acela train departs first, followed by the regional train. The Acela trains have scheduled dwell times of 15 minutes, and the regional trains being overtaken can have dwell times of 30 minutes. With wide platforms in the future station, these dwell times potentially could be reduced to 8 minutes for Acela and 15 to 18 minutes for Northeast Regional trains, but these trains still would consume considerable track capacity within the station.

These overtakes can be accomplished more efficiently at the station than on the railroad, where commuter trains generally consume the capacity available on the local tracks and Amtrak trains generally are confined to the express tracks on portions of the NEC with four main tracks. Planned future Amtrak service includes semi-hourly Acela express service and semi-hourly Northeast Regional (or equivalent) service, so these overtakes are assumed to continue to occur at Penn Station at the top and bottom of the hour during peak periods in both directions of travel – simultaneously occupying four station platform tracks.

Basis for Station Capacity Estimates

In the through-running concepts for Penn Station, the station is assumed to require platform track capacity sufficient to be able to handle 48 trains per hour (tph) in each direction, for service operating between the NEC in New Jersey and the Harold Interlocking complex in western Queens. These trains would fully utilize two pairs of tunnel tubes beneath the Hudson River and two pairs of tunnel tubes beneath the East River. In addition, the station is assumed to need to accommodate additional service through the Empire Tunnel into the west side of Penn Station. This track connection is located in-between the existing North River Tunnel and the planned portal of the new Hudson River Tunnel. The through-running concepts analyzed for Penn Station assume future peak service at 4-5 tph in each direction through the Empire Tunnel. Service is expected to include a combination of Amtrak Empire Corridor service and Metro-North Hudson Line service. The actual volume and mix of trains will be determined in the future. These trains are assumed to turn back at Penn Station, in order to retain balanced flows through the other sets of tunnels.

A review of international best practice examples showed that the regional metro concept works best when this transit-style headway-based service can be provided on dedicated tracks and platforms, with the relatively uniform operations of the regional metro service separated from the more variable operations of longer-distance suburban and intercity trains. With the future provision of two separate tunnel tracks in each direction between New Jersey and Queens, Alternative 2 from the main body of this feasibility study assumes that future operations would dedicate one pair of tunnel tracks to regional metro ("local service"), with the suburban and intercity services sharing the other pair of tracks ("limited-stop and express service"). While this allocation of tunnel capacity slots between regional metro and suburban trains is one among many possible service scenarios, it is the one that best matches international best practice and, therefore, was used as the basis for analyzing Alternative 2. This concept would be workable if six or seven branch lines on each side of the region can be converted to regional metro, generating demand to fully utilize the dedicated tunnel tracks at the 24 tph capacity of the tunnels. At Penn Station, these regional metro services potentially can be assigned to specific dedicated platform tracks within the station, aligned with the tunnels that regional metro trains would use. The regional metro service in each direction could be evenly divided between two platform tracks in each direction, with each track handling 12 tph, equivalent to a Platform Reoccupation Time of 5 minutes. This would allow for dwell times in the range of 2-3 minutes, consistent with transit-style operations with rolling stock designed to permit rapid alighting and boarding of passengers.

The remainder of the station would be devoted to suburban and Amtrak intercity services (such as Acela, Northeast Regional, Keystone, Empire, North Carolina, and Vermont services and long-distance trains that may arrive during the peak period), as well as Hudson Line suburban service. Two tracks in each direction would be utilized by Amtrak Acela and Northeast Regional trains. At the top and bottom of each hour during peak periods, all four trains (two in each direction) would occupy these tracks. The Northeast Regional trains would arrive first, followed by the Acela trains. After an 8-minute dwell time for the Acela trains, they would depart, followed by the Northeast Regional trains. There would be room on the platform tracks used by Acela to accommodate an extra suburban train or other Amtrak train in-between the half-hourly Acelas. The remaining tracks in the station would be used primarily by suburban trains.

Alternative 2, Design Concept 1 — a through-running concept with 17 tracks and side-by-side operations — provides an example of how these trains would be allocated to station platform tracks, with the assumed train throughput and dwell time assumptions. The Amtrak NEC services, at 6 tph in each direction, would require four tracks (two in each direction). The suburban services, totaling 18 tph in each direction, are estimated to require six tracks (three in each direction), with all trains operating as through-running trains. Empire Corridor and Hudson Line trains would turn at the station platforms and require a total of three dedicated platform tracks.

Alternative 2, Design Concept 1, as described in Section 5 of the feasibility report, results in the following allocation of trains among the 17 tracks served by wide platforms within Penn Station:

Regional Metro Service – 24 tph in each direction

- Westbound Regional Metro service (24 tph)
  - Fully utilizing East River Tunnel Line 4
  - Northernmost two tracks in the station
  - Fully utilizing North River Tunnel North Tube
- Eastbound Regional Metro service (24 tph)
  - Fully utilizing North River Tunnel South Tube
  - Southernmost two tracks in the station
  - Fully utilizing East River Tunnel Line 1
- 12 tph per track; 5 min. re-occupancy time; 3 min. dwell time

Amtrak Acela and Northeast Regional Service –6 tph in each direction[2]

- Eastbound service (6 tph)
  - North River Tunnel South Tube
  - Tracks in north-central zone of station
  - East River Tunnel Line 3
- Westbound service (6 tph)
  - East River Tunnel Line 2
  - Tracks in south-central zone of station
  - North River Tunnel North Tube
- 2 tracks required in each direction, for overtake operations at 30-min. intervals

Suburban Service – 20 tph in each direction

- Eastbound service (20 tph)
  - North River Tunnel South Tube
  - Tracks in north-central zone of station
  - East River Tunnel Line 3
- Westbound service (20 tph)
  - East River Tunnel Line 2
  - Tracks in south-central zone of station
  - North River Tunnel North Tube
- 2 tph in each direction assumed to fit in-between the Acela trains on the same station platform tracks used by Acela
- 3 additional tracks required in each direction, to support 18 tph
- 6 tph per track; 10 min. re-occupancy time; 7-8 min. average dwell time

[2] Includes Amtrak NEC service and routes feeding New York City other than the Empire Corridor (e.g., Keystone Service and trains to Scranton, PA; Allentown, PA; Long Island; Virginia; North Carolina; and Springfield, MA)

Amtrak Empire Service and Hudson Line Suburban Service – 4-5 tph in each direction

- Option 1
  - Empire Service at 2 tph (uses 2 tracks, with turn times of approx. 40 mins.)
  - Hudson Line at 2 tph (uses 1 track, with turn times of approx. 17 mins.)
  - All trains turn back at Penn Station platforms
- Option 2
  - Empire Service at 1 tph (uses 1 track, with turn times of approx. 40 mins.)
  - Hudson Line at 4 tph (uses 2 tracks, with turn times of approx. 17 mins.)
  - All trains turn back at Penn Station platforms
- Both options require three dedicated platform tracks
- Firm future plans for increased Empire Corridor service and the introduction of Hudson Line service have not been developed; these options present two potential service levels but do not represent the full range of potential options.

Table B-2 summarizes the allocation of tracks to the various types of rail service for each of the two Alternative 2 through-running design concepts and compares them to the platform track requirements. Design Concept 1 meets the requirement, while Design Concept 2 — a through-running concept that would deck-over every other track in the existing Penn Station configuration so that platforms could be widened to support simultaneous boarding and alighting — falls short.

Table B-2
Penn Station Platform Track Requirements To Support Through-Running C

<table>
<tr><th>Service</th><th>Station Platform Tracks Required*</th><th>Station Platform Tracks Provided in Alternative 2, Design Concept 1</th><th>Station Platform Tracks Provided in Alternative 2, Design Concept 2</th></tr>
<tr><td>Regional Metro/Local Service</td><td>4</td><td>4</td><td>4</td></tr>
<tr><td>Amtrak Acela and Northeast Regional</td><td>4</td><td rowspan="3">4 Suburban
2 Swing**
7 Amtrak NEC + Empire</td><td>4</td></tr>
<tr><td>Suburban and Other Amtrak Northeast Corridor</td><td>6</td><td rowspan="2">4***</td></tr>
<tr><td>Empire/Hudson Line</td><td>3</td></tr>
<tr><td>TOTAL</td><td>17</td><td>17</td><td>12</td></tr>
</table>

* Required for through service at 48 tph in each direction, plus Empire/Hudson Line at 4-5 tph. Potential additional track requirements to support reverse-peak suburban service are not included in this table.
** Swing tracks available for use by Amtrak or suburban services.
*** Number of available tracks insufficient to meet requirement.

Infrastructure and Service Implications at Penn Station

Regional metro service through Penn Station would make sense in the trunk and branch line configuration, with six to seven branch lines at 15-minute peak headways fully utilizing two tunnel tracks under the Hudson River, two tunnel tracks under the East River, and a zone at Penn Station with platform tracks dedicated exclusively to regional metro. This service would depend on efficient through-running at Penn Station. Wide station platforms (30 feet instead of the existing 20 feet) would be required, with ample vertical circulation capacity and sufficient space on the platforms for both passenger waiting and circulation.

Regional metro service would operate best as a self-contained transit line, rather than as a type of service that is blended with other types of service sharing the same tracks and station platforms. The Paris RER and London Crossrail systems operate this way at several stations in the urban core, notably at Gare du Nord on the RER B and D Lines and Paddington Station on the Elizabeth Line.

By definition, Amtrak service and the suburban services other than regional metro should be separate from the regional metro service to the maximum extent possible. These services will need to continue to operate via Penn Station. These services could operate as they do today (Amtrak in through-running mode and suburban services in a hybrid mode of operation), utilizing the existing track and platform configuration at Penn Station. Alternatively, the Amtrak and other suburban services could be adapted to a station operating plan that entirely supports through-running to maximize throughput capacity and operational efficiency, wider platforms to enable more efficient passenger movement, and shorter station dwell times. The alternatives analyzed in this document include both of these modes of operation.

In theory, it may be possible to consider operational changes that could potentially reduce Amtrak dwell time at Penn Station, but any such changes would not achieve uniform dwell times for all train services at the station. Dwell times for Amtrak trains would still be significantly longer than for regional metro trains because of the need for Amtrak porters (Red Cap personnel) to assist some passengers with their luggage and the need to build recovery time into the dwell time to help ensure on-time departures for timetable-based Amtrak trains at Penn Station.

At Penn Station, converting existing suburban commuter rail trains from turnback operations to through-running operations would reduce dwell times but would not automatically enable the recovery time allowances to be reduced or eliminated, since these services would remain timetable-based. Converting selected services from traditional commuter rail to regional metro would allow these trains to operate differently at Penn Station. Regional metro services would run at frequent enough intervals to enable conversion of these train services from timetable- to headway-based scheduling. This would allow recovery time allowances to be eliminated for those trains, significantly reducing station dwell times.

However, the regional metro concept does not apply universally to all rail services operating to and through New York City.

Regional metro service is not a total, universal solution for Penn Station, because the station must serve more than just regional metro trains. Only the main lines with both local and express tracks, plus the inner branch lines located relatively close to New York City, are suitable for regional metro service. Longer-distance suburban services operate on longer headways (30 minutes or greater) and must be timetable-based. Amtrak intercity and long-distance trains would continue to operate at Penn Station with different operational characteristics and requirements. Amtrak cannot operate like regional metro without radical changes to operations and passenger expectations at Penn Station. Long-distance trains require extra time at the platform for handling passengers and checked baggage.

The limited number of peak train slots through the tunnels into and out of Penn Station will require allocation of those capacity slots among the types of service and among the 20 different branch lines that will feed Penn Station. This allocation will be based on estimated future regional travel demand and policy choices about the type of service on the main lines and each branch line that best meets the economic, social, and travel needs of the areas served. The through-running alternative documented in the main body of this feasibility study (Alternative 2) assumes peak-direction service with intercity trains at 6 tph, regional metro trains at 24 tph and suburban service at 18 tph. Other combinations of regional metro and suburban service may better meet future needs, such as increasing the quantity of suburban service and reducing the quantity of regional metro service (by reducing the number of regional metro branch lines and/or increasing peak headways from 15 to 20 minutes). Blending regional metro service and through-running suburban service (operating to and from far-side storage yards) could be feasible through the Hudson and East River tunnels, while retaining dedicated platform tracks by service type at Penn Station. Additional platform tracks at Penn Station likely would be necessary, due to the variable dwell times. Further analysis, informed by scenarios of future travel behavior and estimates of regional travel demand, would be needed to more fully assess the potential for a more blended network of regional metro and suburban service.

Through-running is different from integrated regional rail. At Penn Station, through-running cannot be accomplished by simply merging the operations of the three commuter railroads. Through-running at Penn Station is not sufficient by itself to enable cross-regional rail integration. The complexity of the rail network, lack of interoperability between the Long Island and New Jersey rail networks, and mismatches in the size of potential rail ridership markets outside the central city make implementation of integrated cross-regional rail difficult. Achieving better integrated service is possible, but it carries a relatively high cost to achieve full interoperability and requires a complicated multiparty decision-making process. As a result, fully integrated cross-regional rail is considered a long-term prospect, while fixing conditions at Penn Station and increasing its capacity to accommodate growth in train service must happen sooner.

Penn Station's capacity must be increased to enable the new Hudson River Tunnel to operate at its full capacity. This capacity would be needed sooner than the timeframe for implementing regional metro. The long-term introduction of regional metro is a concept worthy of implementation and is supported as a concept by the railroad operators serving the New York region and Penn Station. It has the potential to improve the reliability of operations by minimizing the potential for train movement conflicts along the trunk line. It also enables efficient growth in future rail service, by avoiding the need to expand storage yard capacity at or immediately adjacent to Penn Station. Regional metro is also an idea that has proven successful at enhancing regional connectivity in major cities around the world.

Train operations at Penn Station should reflect the specific needs of the different types of rail service that will continue to serve the station. Regional metro trains should operate on dedicated tracks and platforms at the station. The transit-like characteristics of this service support close-headway operations, short station dwell times, and high throughput on a small number of platform tracks. These operations would be most efficient if regional metro service is able to fully utilize two tunnel tubes under the Hudson River and two tubes under the East River.

The remaining tunnel and station capacity would be utilized by longer-distance suburban trains and Amtrak intercity trains, operating timetable-based service. Dwell times would be longer and more variable for these services compared with regional metro, requiring a greater number of platform tracks and more flexibility in assigning trains to tracks. The trains in this part of Penn Station would operate in a hybrid manner, similar but not necessarily identical to the current way the station operates, with some trains running through the station and others turning back.

The separation of regional metro from other services at the station would match the station configurations that exist in the international best practice examples that are discussed in the main body of this feasibility study. The station complex, including station platform tracks, connecting tracks to the tunnels, station platforms, and passenger circulation elements, would be configured to efficiently handle the relatively uniform performance characteristics of regional metro and accommodate the more varied operations of suburban, intercity, and long-distance trains.