New Haven Line Capacity and Speed Analysis

Final Report

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CONNECTICUT DEPARTMENT OF TRANSPORTATION

CT rail

CTrailStrategies

Table of Contents

Executive Summary

This study focused principally on the infrastructure and fleet needs of the New Haven Line. Additional analysis was performed to determine the infrastructure and fleet needs beyond the New Haven Line to support this vision. This study establishes the foundation for future studies that will further improve service on Hartford Line, Shore Line East, Waterbury Line, Danbury Line and New Canaan Line.

As part of the New Haven Line Capacity and Speed Analysis Study, the project team analyzed existing conditions of and potential future improvements to the Connecticut rail network, including infrastructural, operational, and financial considerations. The project team's review of existing conditions throughout the Connecticut rail network identified several capacity constraints including legacy infrastructure and ongoing construction and repair work, as well as operational factors that could be modified to improve service quality. An analysis of the system's capacity found that the New Haven Line (NHL) is operating at or near capacity. Ongoing and planned improvements, such as signal system upgrades and a new Stamford Station Track 7, were found to help improve capacity as well. Ridership throughout the system is expected to continue to grow as both jobs and population are projected to grow over the next several years. Ridership forecasts support these projections, with the most significant growth expected on the Hartford Line (HFL).

In order to identify potential near and mid-term improvements, the team also performed a review of programmed capital improvements and options related to fleet procurement and replacement. Based on a review of the existing conditions and future projects, service objectives were developed that would help guide future planning efforts. The project team also developed and analyzed two service concepts that would help achieve these objectives: an extension of the Amtrak Keystone Service to the HFL that would provide direct access to Penn Station New York (PSNY) and a new express train to Grand Central Terminal (GCT) that would serve the HFL and further reduce travel times. These service concepts were evaluated based on ridership, the potential impact of Transit Oriented Development (TOD) policies, and capital and operating costs. While both concepts offer improved access to New York City (NYC), they also each pose operational and institutional challenges, including agreements with other rail operators. Section 5.4.4 provides a more detailed breakdown of the tradeoffs of each concept. These concepts will be further analyzed in future planning efforts.

NOTE: The NHL Capacity and Speed Analysis Study is based on work completed in 2019 and precedes the coronavirus pandemic. Although we are now experiencing reductions in travel, the principles tested here continue to be relevant for informing when and how to restore service and support economic recovery. The project team expects that, in the medium-to-long term, the fundamentals regarding the comparative advantages of the rail mode and the demand for travel to Connecticut's urban centers and those of neighboring areas will resume their anticipated trajectory of growth.

1. Introduction

The NHL Capacity and Speed Analysis Study is focused on a complete assessment of the rail infrastructure, equipment, and service plans to identify opportunities for the Connecticut Department of Transportation (CTDOT) to create a more dynamic commuter rail network. The study includes a comprehensive look at both the commuter rail travel market in southwestern Connecticut and the role and the capability of the NHL and its branches to service that market. The HFL and Shore Line East (SLE) were also studied as their connectivity to the NHL represents a key component of the Connecticut rail network. The study is focused on examining the rail infrastructure, facilities, equipment, and services to develop a plan of near-term and long-term schedule, infrastructure, and equipment enhancements to better serve the needs of the Connecticut rail travel market. Tasks 1-5 are summarized in the below report. A summary of work for Task 9 Shops and Yards is included in a separate report.

2. Existing Conditions: Infrastructure, Facilities, Equipment and Services (Task 1)

The purpose of the initial task of the NHL Capacity and Speed Analysis Study was to document the existing infrastructure and operating conditions of the NHL and its three branches to determine the capabilities and limitations of the system. This analysis provides information regarding the existing condition of the NHL within the State of Connecticut; it does not include data for the portion of the line within the State of New York (except for information regarding access to GCT). This effort sets the framework for how to improve the NHL and its service in the future.

The Connecticut rail network is different in scope and scale from most other rail networks in the country and is rivaled only by the other New York City metropolitan area systems and other commuter services in large urban areas. The NHL in Connecticut is a 50-mile, four-track railroad between New Haven and Greenwich, Connecticut that utilizes an electric catenary power system. The New Canaan Line (NCL) is electrified while the other two branch lines, the Danbury Line (DBL) and Waterbury Line (WBL), are not.

The NHL is consistently one of the busiest commuter rail lines in the United States, with more than 40 million annual riders in 2019. However, its aging infrastructure, dated designs and alignments, and multiple crossings of large marine estuaries makes it very challenging to maintain. As part of its review of existing conditions, the project team found that while the NHL delivers a high level of service, the system is broadly constrained by five key issues:

- Capacity and speed are constrained by legacy infrastructure and current operating requirements
- Track geometry and “slow orders” contribute to reduced speeds
- State-of-good-repair & normal replacement improvements impact operating speeds
- Aging locomotive-hauled fleet limits capacity
- Service can be optimized to improve trip times

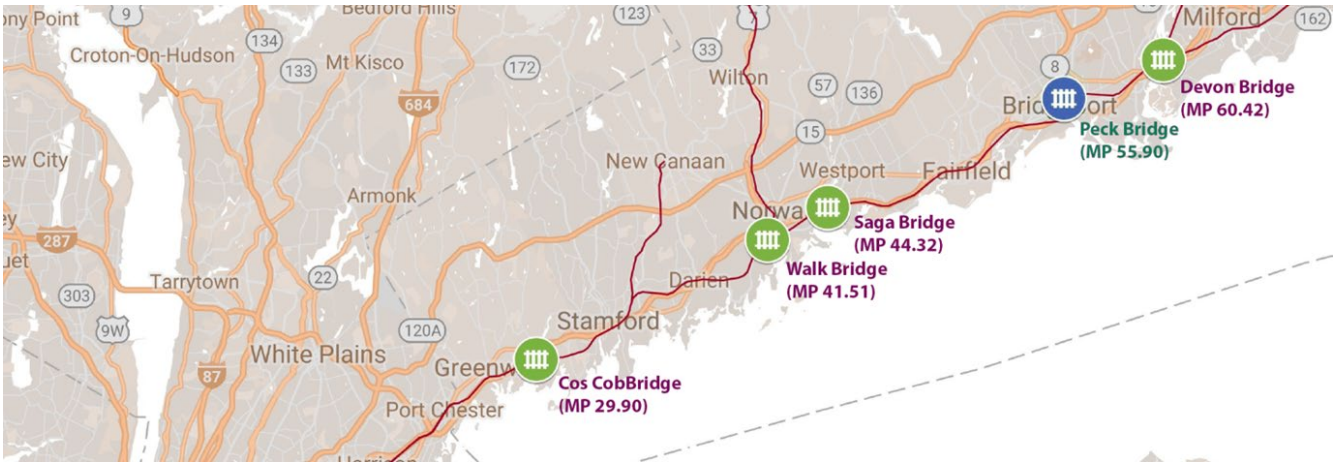
2.1. Capacity and Speed are Constrained by Legacy Infrastructure

Bridges

The existing condition of bridges has been an ongoing concern as the rehabilitation and/or replacement of bridges is not only costly but also impacts operations throughout the construction window (with "slow orders" – a restricted speed limit – being imposed on trains operating through the work area). On the NHL Main Line, 34 bridges are rated as being in poor or serious condition[1]. The existing under-grade bridges generally allow operations without restrictions, but it is likely that across a 25-year time frame many of these bridges will require significant rehabilitation or replacement, which will impact service during construction. There are 52 open deck bridges and 82 ballasted deck bridges on the NHL. Open deck timber bridges add to maintenance issues and costs as they require more frequent maintenance to ensure the structure is in good condition. By contrast, ballasted deck bridges require less maintenance by minimizing the impact load at the bridge abutment and along the structure. Replacing open deck timber bridges with ballasted deck bridges would not only reduce maintenance costs, but would also improve ride quality for passengers and provide added protection from fire damage and potential service disruptions.

There are five moveable bridges along the NHL (see Figure 1 for the location of these bridges). Peck Bridge was replaced in 1998 but the four remaining moveable bridges are each over 100 years old and require replacement. Moveable bridges are complex and require significant maintenance, without which they have the potential to get stuck in the open position, preventing the passage of trains. Train operations are slowed by speed restrictions when trains pass over mitre rails (the rail connecting the moveable portion of track to the fixed portion).

Figure 1 Location of Moveable Bridges along the NHL



Signal System & Catenary

The legacy signal system has imposed and continues to impose substantial capacity constraints in the sections of the line still operating under the obsolete design. A new signal system is currently being installed on sections of the line and provides critically needed increased capacity. The timetable to install it over the entire line is not established, but is expected to occur over the next one to two decades. The current communications system does not pose significant concerns for the operation of the NHL. The WBL is the only line in the Connecticut rail

[1] Federal Highway Administration National Bridge Inventory structural ratings (NBI 67), based on CTDOT data reporting, 2017-2018

network that is not currently signalized and does not have active controlled passing sidings; this lack of signalization currently severely limits the service provided on that line. However, construction of a new signal system for the WBL is underway and scheduled for completion in 2021.

Both the catenary (i.e., overhead wire system) and traction power systems on the NHL have recently been upgraded or are nearing the completion of the upgrade process. Accordingly, concerns surrounding these facilities are relatively limited. Unlike the predecessor system, the new design does not limit speed or service volume and upgrades will allow for increased train density (e.g., 25 trains per hour from Woodlawn to Stamford and 20 trains per hour from Stamford to New Haven). While the catenary itself and traction power system can handle current service, many of the structures supporting it are close to or in excess of 100 years old and continue to need substantial repairs or replacement.

Track

The NCL, DBL, and WBL are all single-track lines. The lack of a second track limits the capacity of these lines. These lines also have few passing sidings - one limited in length on the DBL and two limited in length on the NCL. These track limitations could impact future increases in bi-directional service levels. Although the Danbury Yard has additional storage capacity, limited storage capacity at New Canaan Station could constrain future service expansion. Further analysis of shops and yards on the NHL and its branches is available in the Task 9 Shops and Yards Report.

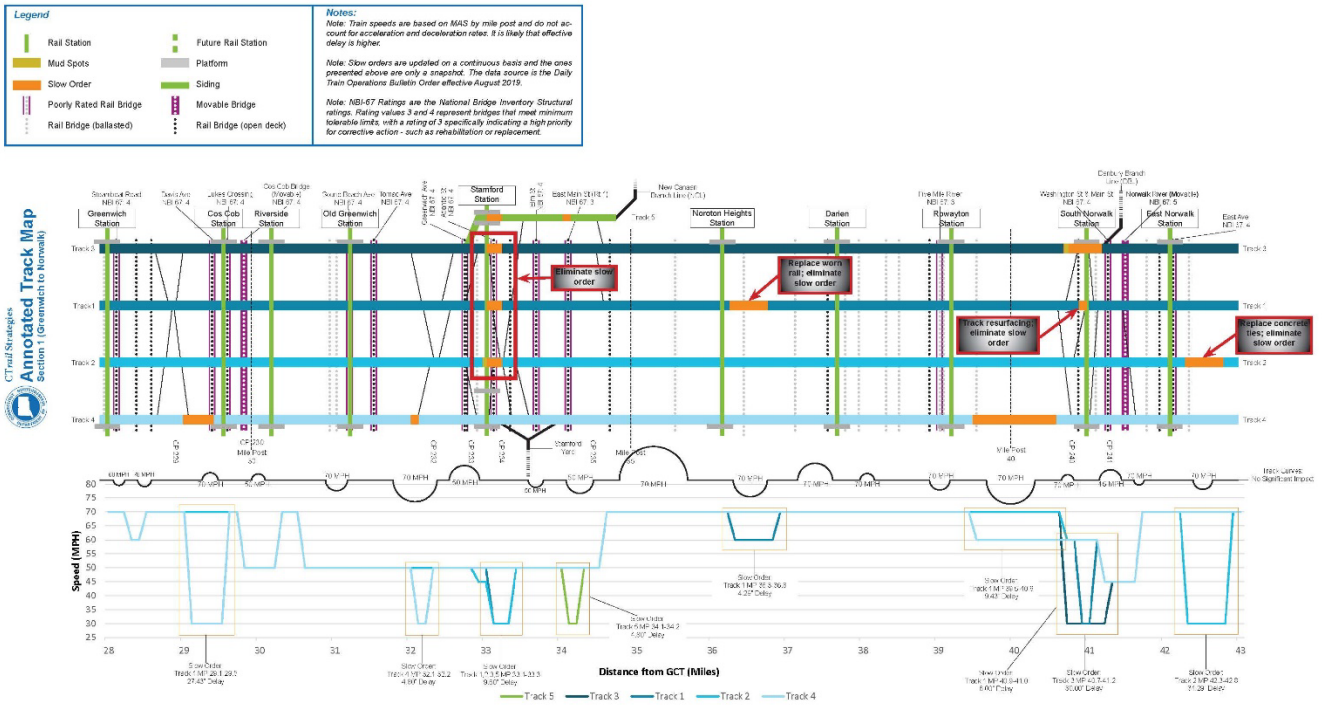
2.2. Track Geometry and Slow Orders Contribute to Reduced Speeds

Curved track alignment limits operable speeds throughout the system to varying degrees, which leads to broad fluctuations in the maximum allowable speeds, inhibiting fast journey times and the efficient operation of the rail system. This limitation is difficult to address given that straightening of track is cost prohibitive and is limited by right-of-way constraints. Permanent speed restrictions are exacerbated by slow orders that are caused by the railroad's state of good repair, particularly related to drainage, tie and track damage, and profile deviations. Metro-North Railroad (MNR) has identified 95 locations on the NHL with an estimated 5,700 ties needing replacement. Figure 2 shows an example of a damaged concrete tie resulting from a mud spot caused by poor drainage.

Figure 2 Concrete Tie Damaged Due to Poor Drainage

The team compiled a track map for the Connecticut portion of the NHL between Greenwich Station and New Haven State Street (Mile Posts 28 to 73.2) identifying key speed limitations such as mud spots and slow orders. Figure 3 displays a sample of these track maps. Complete annotated track maps are provided in Appendix A.

Figure 3 Sample of Annotated Track Maps



The team analyzed 29 slow orders effective April 20, 2018[2] and found that 10 months later approximately the same number were in effect. The overall number of slow orders stays relatively constant because while each year many are cleared, new slow orders are also added. The average duration of slow orders was found to be almost one year, with the average authorized speed on these segments reduced to 37 MPH (a reduction of 41% from the average authorized speed of 66 MPH). Table 1 provides a summary of the analysis of these slow orders. Efforts in 2019 helped reduce the total number of slow orders, but it is an ongoing process that requires a long-term, systemic solution.

Table 1 Slow Order Analysis Summary

Slow Order Speed (mph)		Duration of Slow Order at Effective Date (Days)	
Average	37 mph	Average	348 days
Minimum	30 mph	Minimum	1 day
Maximum	60 mph	Maximum	1079 days

[2] Metro-North Daily Train Operations Bulletin Order, April 2018

2.3. State-of-Good-Repair & Normal Replacement Improvements Impact Speed

The high density of train traffic currently operating makes it difficult to take on large scale capital improvements on the NHL Main Line without impacting service. Development along the NHL and its branches geographically constrains the railroad and the four-track configuration. To accommodate regular maintenance as well as state-of-good-repair and normal replacement improvements, much of the four-track NHL typically operates with only three tracks. These construction-related impacts affect travel time on a daily, long-term basis. As with drainage issues, this generally requires slow orders that reduce operating speeds for the safety of the construction work force. Temporary platform bridges, generally necessary due to the improvement work, increase dwell time, also increasing trip times. The impact of track work is also significant on the single-track branch lines where track work requires service disruptions or complete shut-downs, diverting customers to a substitute bus service.

2.4. Aging Diesel-Hauled Fleet Limits Capacity

The Connecticut rail network utilizes two different equipment propulsion types: self-propelled Electric Multiple-Unit rail cars (EMUs) and locomotive-hauled push-pull coaches.

Figure 4 EMUs

Figure 5 Locomotive-hauled Push-pull Coaches

The EMUs operate exclusively in in the electrified territory of the NHL Main Line and NCL. They utilize either 750V Direct Current (DC) third rail between Pelham and GCT or a 12.5kV, 60Hz Alternating Current (AC) overhead catenary system between New Haven and Pelham. These EMUs are classed as "M8" by the operating railroad and follow in a series of similar, previous designs developed for the Metropolitan Transportation Authority (MTA) and its MNR services on the NHL. As shown in Table 2, CTDOT owns 275 of the fleet of 405 M8s, with an additional 66 M8s pending delivery.

Service on the other lines in the Connecticut rail network (DBL, WBL, HFL, and SLE) is operated with a fleet of locomotive-hauled push-pull coaches. Diesel service on the DBL and WBL is operated by MNR utilizing either diesel or dual-mode locomotives (i.e., capable of operating in diesel or electric mode) hauling push-pull coaches. MNR, in coordination with CTDOT, recently took steps to procure new diesel/dual-mode locomotives to support these branch line services. In the near-future, MNR expects to replace and supplement the existing locomotive-hauled coaches with new multi-level push-pull coaches. CTDOT and MNR coordinate closely on these procurements.

CT*rail* service on the HFL is operated with diesel locomotive-hauled push-pull coaches under contract with TASI. While the SLE territory is electrified, service on the SLE is operated with diesel locomotive-hauled push-pull coaches operated under contract with Amtrak. For service on the HFL and SLE, CTDOT operates a fleet of 49 push-

pull coaches[3]. A summary of rail rolling stock operating on the Connecticut rail network is summarized in Table 2 below.

Table 2 Rail Rolling Stock Operated on the Connecticut Rail Network

Line	Operated By	Assigned Equipment			
		MUs (Electric)	Dual-mode Locomotives	Diesel Locomotives	Coaches
New Haven Line/New Canaan Branch (MNR Owned)	**MNR**	130	N/A	N/A	N/A
New Haven Line/New Canaan Branch (CTDOT Owned)		275 + 66 *[on order]*			
Shore Line East	**CT*rail* - Amtrak**	N/A		18	33
Hartford Line	**CT*rail* - TASI**				16
Danbury/Waterbury Branches	**MNR**		4	6	48
TOTAL		**471**	**4**	**24**	**97**

Note: Amtrak owned fleet that CTDOT utilizes for state supported service includes 4 Regional trainsets and 3 Shuttle trainsets

Much of the diesel-hauled fleet is aging and/or in need of replacement. The HFL CT*rail* service is operated with 16 coaches (MBB) that are leased from the Massachusetts Department of Transportation and scheduled to be returned within the next three years. Amtrak shuttle service on the HFL is operated with 40-year old "Amfleet" equipment that is also at the end of its useful life. SLE trains operate with a fleet of 33 thirty-year old "Mafersa" cars (named after their Brazilian manufacturer). While they have provided good service, their age and unique design make it difficult to continue to maintain them for reliable operation.

Beyond the age and condition of the fleet, neither the HFL nor SLE coaches are equipped for automatic door operation, making their operation less efficient and contributing to longer station dwell times. The fleet is also currently sized to operate existing CT*rail* HFL and SLE services only, meaning the existing fleet cannot support future service expansion. This varied, aging fleet limits the performance and reliability of service across the system. Section 5.2 provides more detail on these needs and recommended solutions, including coach and locomotive procurement plans.

2.5. Service Can Be Optimized to Improve Trip Times

The NHL is operated using a sophisticated zone schedule structure that offers faster trips to NYC than is achievable utilizing other stopping pattern strategies. While these patterns vary across the day, the zone schedule strategy is in effect for both peak and off-peak operations and offers NHL riders a scheduled service experience found only on a very few other commuter rail lines in the nation. However, growing ridership demand, especially along the eastern end of the line, changed infrastructure design standards, heightened construction activities to address a large backlog of deferred maintenance elements, and new safety-related systems have each contributed to lengthened travel times and reduced reliability compared to historic operations. The service schedule is also not

[3] Push-pull coaches allow for a locomotive-hauled consist to operate in the reverse direction with a 'cab car' for reverse operations. The CTDOT rail car fleet consists of both trailer and cab cars which are collectively referred to as coaches.

designed to always facilitate travel within Connecticut between its major business centers. Passengers wishing to travel to and from NHL stations to the respective connecting route stations can often experience long waits to make connections or simply to ride a train due to the limited number of frequencies operated, even during the peak periods. Section 5 will examine infrastructure and service concepts that can offer improved trip times to NYC and enhanced connectivity for travel to and from Connecticut's business centers.

2.6. Operating Costs and Revenue

The NHL is operated and maintained by MNR. The physical rail line and accompanying right-of-way in New York is owned by the State of New York while the Connecticut portion of the line is owned by the State of Connecticut. The Amended and Restated Service Agreement (ARSA) governs the rights and responsibilities of the MTA, MNR, and CTDOT in funding and operating the NHL Main Line and branch line services. Although the NHL has among the highest recovery ratios of any commuter rail line in the nation, it is not capable of being sustained through ticket sales alone. The three parties subsidize operating expenses (operating costs minus revenue) on an apportioned basis: 65% CTDOT and 35% MTA/MNR. The NCL, DBL, and WBL services are funded 100% by CTDOT. In terms of capital expenditures, non-moveable assets such as stations and facilities are capital-funded according to the state in which they are located. Moveable assets such as rolling stock are funded according to the 65-35 split described above. Administrative assets, such as field vehicles and office equipment, are allocated to CTDOT according to the ARSA NHL operating cost share formula of the entire MNR system. This includes the Harlem and Hudson Lines as well the NHL and its three branches.

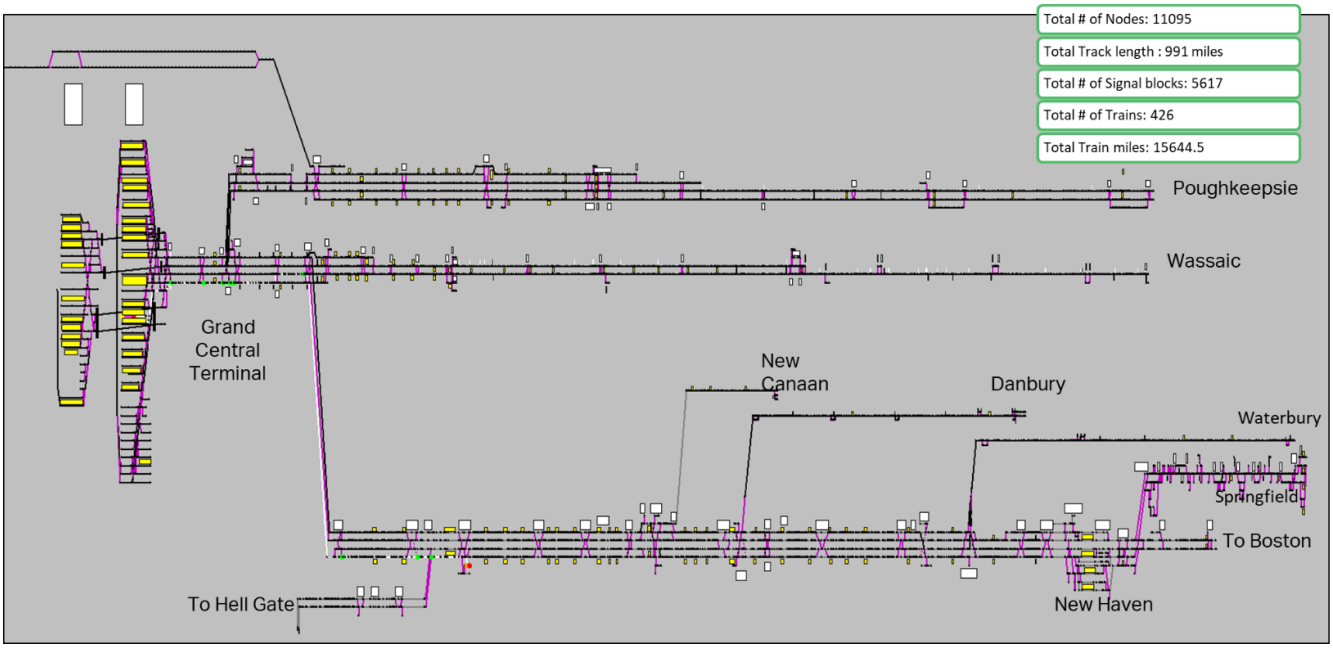
Changes in the budget are chiefly driven by service changes, equipment acquisition/fleet growth, and labor and materials inflation. Between state fiscal years 2016-2017 expenses grew 5.8%, while revenues grew only 2%; the result of this is that the deficit and the CTDOT subsidy grew by 15%. The largest increase in cost was for operating and maintenance, equaling $13.8 million; this increase was largely due to an increase in fleet size and an expansion of services. Over a 20-year period, the NHL CTDOT subsidy payment has risen at an average rate of less than 7% per year.

3. Capacity of the NHL (Task 2)

In order to better understand its capacity, the project team used the trademarked "Rail Traffic Controller" (RTC) train simulation model to evaluate the NHL. The RTC model is nationally regarded as being capable of accurately simulating actual railway operations with realistic conditions and operational constraints. The work was coordinated with MNR to use available RTC model 'cases' the agency had previously developed to simulate the NHL capacity with the proposed Penn Station Access infrastructure and service enhancements.

Work efforts in Task 2 focused upon validation of the performance of previously developed model network sections, calibration of more recent infrastructure changes made and modifying the weekday schedule to reflect base line operations. The completed analysis established a base line that could then be compared against alternative scenarios to understand the potential benefits of infrastructure and service enhancements proposed in Tasks 4 & 5 as described in Section 5. Figure 6 is a graphic representation of the model. Additional simulations detail may be found in Appendix B.

Figure 4 Step 1: MNR East of Hudson Baseline Model – Adjusted to Initial Project Scope



Key findings from the modeling efforts are:

- The rail line effectively operates above practical capacity between Stamford and New Rochelle, especially when any construction work requiring track outages may be taking place in the section.
- Relatively generous "Recovery Time" built into train schedules allow trains to achieve acceptable levels of on-time performance.
- While the ability to add train frequencies in peak hours is significantly constrained, continued coordination with MNR may provide future opportunities to increase peak or shoulder-of-the-peak service.
- Schedule modifications and/or infrastructure improvements may enable additional frequencies in off-peak times.
- Adding new service concepts, such as the proposed Penn Station Access Service, that would operate on typical commuter rail peak frequencies is not possible between Stamford and New Rochelle without substituting selected new service trains with existing trains to GCT (slot diversion), or through very substantial new increases in infrastructure.
- The operating practice to reverse the movement of non-revenue trains (informally known as "Zippers" due to their non-stop operation) on one of the main NHL tracks during peak periods consumes much capacity that would otherwise be available for other train movements. Elimination of these trains is not recommended nor practicable as they provide essential seat capacity during their revenue trips. Special turnback facilities not on a main track could serve the same purpose with reduced impacts to operations.
- Installation of a new signal system, now underway on portions of the NHL, has clear benefits in terms of reducing travel times during higher-speed switching movements. These speed benefits would be realized

on the main track following divergent train movements and during station stops. Specific benefits vary by location, but all sections would see some improvement.

- Capacity is not reduced on the express tracks (Tracks 1, 2) with higher operating speeds and with the new signal system installed. Peak period capacity is not materially affected on the local tracks (Tracks 3, 4) with either higher speeds or installing the new signal system due to required dwell times at station stops. Off-peak operations on the local tracks can benefit from the signal system improvements and, to a lesser extent, higher speeds.
- Train movements through capacity-constrained Stamford Station will benefit from the construction of new Station Track 7. However, completion of the track may not be sufficient to meet all the demand for additional trains, especially for potential new intra-Connecticut terminations and originations. An additional station track (Track 6) may be necessary to provide the necessary station capacity.
- Current capacity constraints between the South Norwalk and Bridgeport area are materially the result of extra-ordinary construction activities (catenary renewal, bridge construction). It is anticipated that future constraints/delays will be generated at a rate consistent with other sections of the NHL and have more manageable delay impacts.

4. Market Assessment (Task 3)

The project team performed a market assessment to examine the existing rail service and current travel demands, as well as to identify future travel demands and patterns. While the Existing Conditions analysis focused on the NHL, the Market Assessment looked at service in Connecticut more broadly. The assessment included a review of existing travel demand models to estimate future ridership for the purposes of this study. The models identified will be used to estimate future travel demand for services developed later in this study. See Appendix C for the full technical memoranda describing the market assessment work.

4.1. Model Selection and High-Level Validation

The team first reviewed available travel demand models in Connecticut and New York and provided recommendations for use in subsequent market assessment and in developing forecasts. The team considered the MTA's Regional Travel Forecasting Model (RTFM), the Connecticut Statewide Model (CTSWM), and the Federal Railroad Administration's NEC FUTURE Interregional Ridership Model. At the time of this study, the CTSWM was still in the process of being prepared for forecasting and not ready to be used as part of this analysis[4].

The project team conducted a series of sensitivity tests on the RTFM and NEC FUTURE models in order to test the effectiveness of the models in capturing changes in the market area. Tests included decreasing headways to increase one-seat rides on various services, reducing and increasing in-vehicle travel time (IVTT), increasing fares, and through-running potential New Jersey Transit (NJT) trains through PSNY to Stamford. Test 3, reduced In-Vehicle Travel Time (IVTT), was found to have the biggest impact on ridership while test 8, NJT through-running to Stamford, had the smallest impact. Figure 7 and Figure 8 show the results of these sensitivity tests.

[4] As of August 2020, this model was still undergoing development and calibration

Figure 5 Results of RTFM Sensitivity Tests

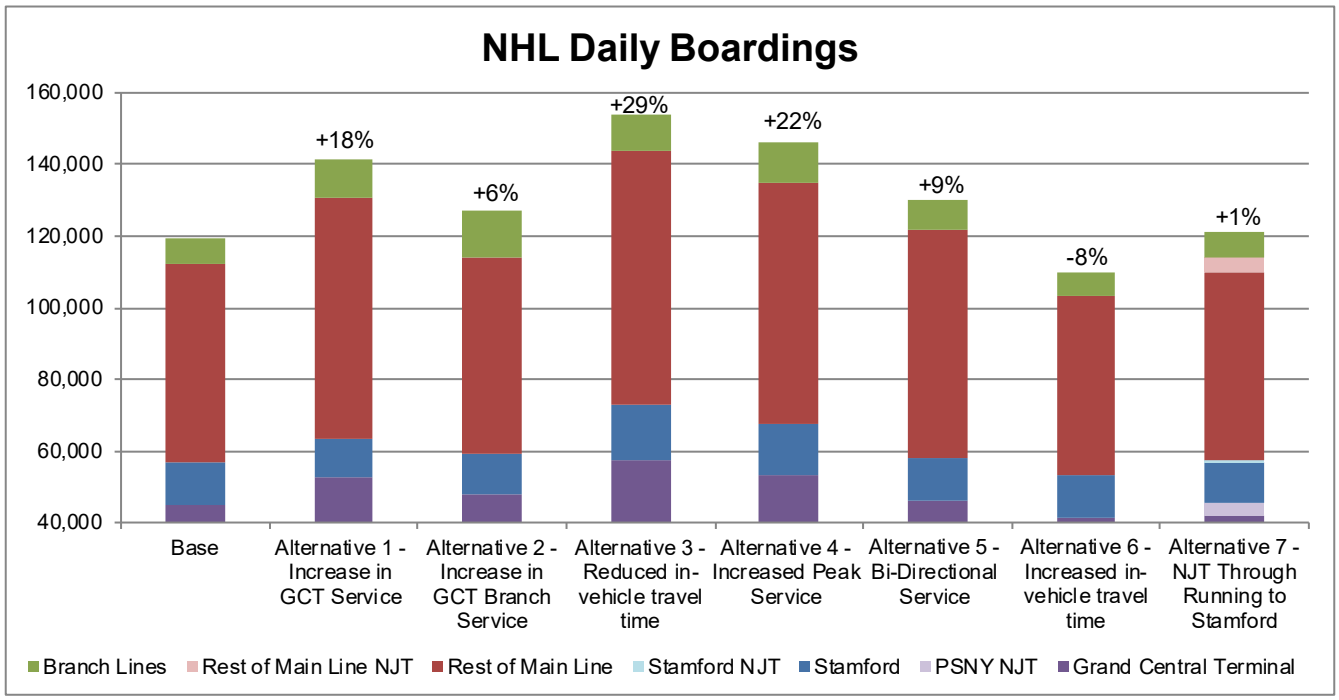
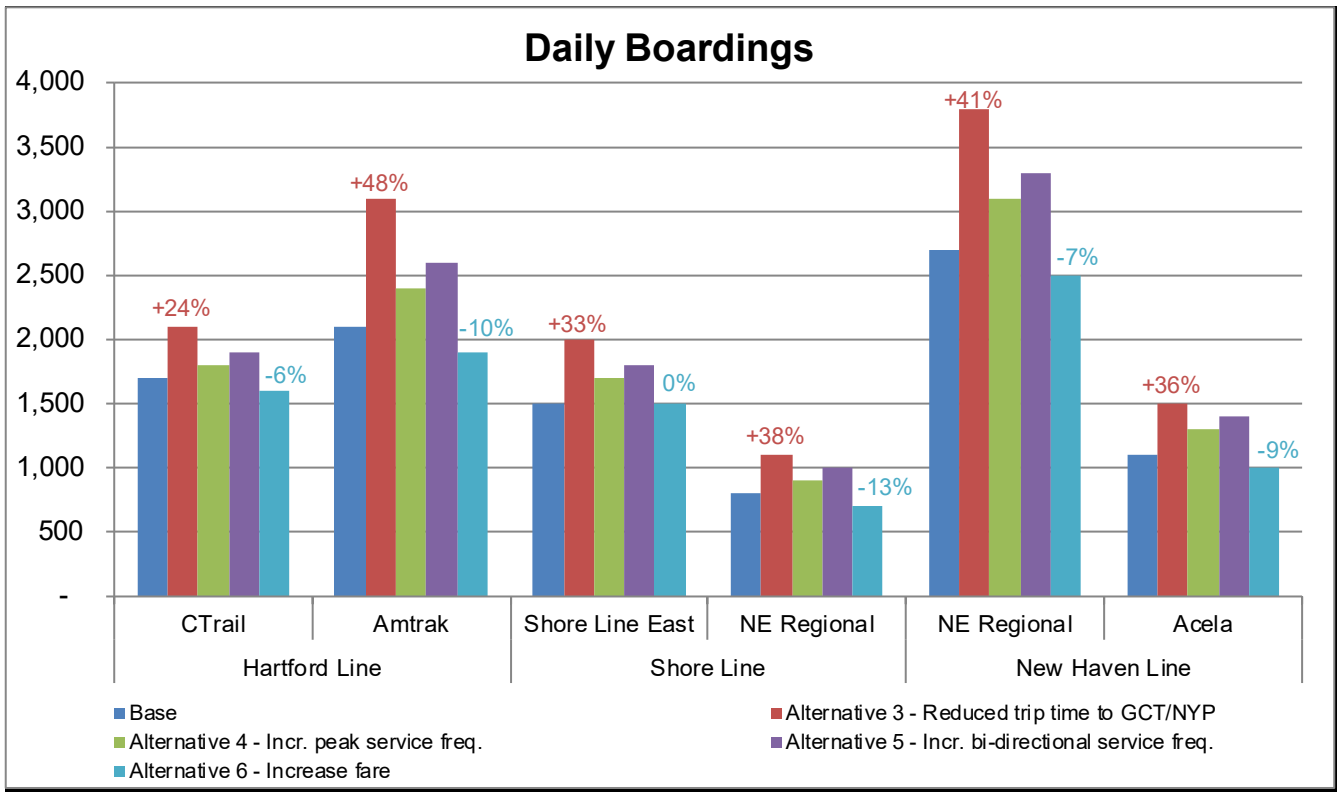


Figure 6 Results of NEC FUTURE Sensitivity Tests



The RTFM sensitivity tests indicated that changing the model inputs created a change in ridership that varied from -8% to +20%. The NEC FUTURE test results varied from -13% to +48%. These tests found both models to be

reasonably sensitive to changes in service. Consequently, the RTFM was selected to capture the commuter market for trips between New York City and New Haven on the NHL and its branches while the NEC FUTURE model was used to forecast both intercity and commuter trips along the SLE and HFL. The NEC FUTURE model was modified slightly to ensure that the reporting across both models was consistent.

In order to validate the models for trips in the travel market, the model base year[5] no build[6] ridership on each line and each service was compared with recent observed ridership. The observed ridership is based on Fall 2016 New Haven Line On-Off counts, September 2018 CT*rail* and Amtrak Hartford Line counts, October 2017 Shore Line East counts, and FY 2013 Amtrak Intercity and Northeast Corridor counts[7]. Table 3 shows the results of this comparison.

Table 3 Model Validation Results

Scenario	Observed (Boardings)	Model Base Year No Build (Boardings)	Observed – Model Base Year (Difference)	Observed – Model Base Year (% Difference)
Line Totals				
Hartford Line (HFL - HFL/NHL/PSNY)	**1,673**	**1,620**	**53**	**3%**
CT*rail* Operated	526	520	6	1%
Amtrak Operated, CT*rail* Fare	270	270	0	0%
Amtrak Intercity (HFL - NHL/PSNY)	877	830	47	5%
New Haven Line (NHL-NHL/PSNY)	**139,769**	**143,230**	**-3,461**	**-2%**
Metro-North Railroad (MNR)	139,220	142,560	-3,340	-2%
Amtrak Intercity (NHL - PSNY)	549	670	-121	-22%
Shore Line East (SLE-NHL/SLE/PSNY)	**2,074**	**1,990**	**84**	**4%**
MNR Operated	283	280	3	1%
Amtrak Operated	1,516	1,490	26	2%
Amtrak Intercity (SLE - NHL/PSNY)	275	220	55	20%
Amtrak Northeast Corridor (SLE/HFL/NHL-NEC)	**2,832**	**4,010**	**-1,178**	**-42%**

The difference between the observed number of boardings and the number predicted by the model base year was small, falling within a 5% difference for most lines. Lines that did have a larger discrepancy (the Amtrak Intercity along the NHL, Amtrak Intercity along the SLE, and Amtrak Northeast Corridor along SLE/HFL/NHL) generally had low ridership numbers: 549; 275; and 2,832, respectively. The modeled ridership was thus found to be largely consistent with observed data and the models determined to be appropriate for use in further analysis.

With the models determined to be sensitive and validated at a high-level, they were combined to form a hybrid model that would be used to test service concepts in Tasks 4 and 5. The RTFM would capture the commuter

[5] The model base year is 2018. The model includes 2015 trip tables (i.e., trips making patterns from zone to zone from 2015) and 2018 service plans.
[6] The "No Build" scenario assumes the existing transportation network plus the completion of planned improvements scheduled for implementation by the build year
[7] The latest data available at the time of this analysis

market for trips between New York City and New Haven on the NHL and its branches while the NEC FUTURE model would be used to forecast both intercity and commuter trips along the SLE and HFL.

4.2. Market Analysis

The project team analyzed travel markets by examining population and employment projections as well as travel patterns. A better understanding of these trends and projections can provide a better understanding of factors that underpin trip making within the region and how demand for rail will change with expanded CT*rail* service.

A review of demographic forecasts indicated that both jobs and population are expected to experience continual growth in Connecticut, with the growth of jobs (8.3%) outpacing the growth of population (4.3%). While more densely populated counties like Fairfield and New Haven will add more people and jobs, less populated counties like Litchfield and Windham are expected to grow at a faster pace (both in terms of population and jobs). Table 4 provides additional detail.

Table 4 Demographic Growth Projections

	Total Population (in 000s)			Total Employment (in 000s)		
AREA NAME	**2015**	**2025**	**2025/2015 Growth**	**2015**	**2025**	**2025/2015 Growth**
NEW YORK CITY	8,315.6	8,684.7	4.4%	4,776.8	5,239.9	9.7%
MID-HUDSON	2,369.5	2,534.7	7.0%	1,279.5	1,435.8	12.2%
CONNECTICUT	**3,628.0**	**3,783.2**	**4.3%**	**1,984.6**	**2,150.1**	**8.3%**
Fairfield	944.7	985.5	4.3%	591.4	645.5	9.1%
Litchfield	198.2	220.8	11.4%	105.4	115.7	9.8%
New Haven	873.6	912.6	4.5%	487.2	531.2	9.0%
Hartford	898.9	923.0	2.7%	517.0	549.2	6.2%
Middlesex	166.5	172.3	3.5%	67.8	73.1	7.8%
New London	275.0	282.4	2.7%	131.1	142.5	8.7%
Windham	119.2	127.0	6.6%	42.4	46.8	10.3%
Tolland	152.0	159.7	5.1%	42.4	46.2	9.1%

Table 5 shows modeled ridership for the Model Base Year No Build and the 2025 No Build, as well as the rate of anticipated growth between these time frames. The RTFM forecasted a 5-6% increase on each line's ridership from the base year to the 2025 No Build scenario.

Table 5 Ridership Growth Projections

Line Totals	Model Base Year No Build (Boardings)	2025 No Build (Boardings)	2025 No Build – Model Base Year No Build (% Change)
Hartford Line (HFL - HFL/NHL/PSNY)	**1,620**	**1,710**	**6%**
CT*rail* Operated	520	560	8%
Amtrak Operated, CT*rail* Fare	270	280	4%
Amtrak Intercity (HFL - NHL/PSNY)	830	870	5%
New Haven Line (NHL-NHL/PSNY)	**143,230**	**150,980**	**5%**
Metro-North Railroad (MNR)	142,560	150,260	5%
Amtrak Intercity (NHL - PSNY)	670	710	6%
Shore Line East (SLE-NHL/SLE/PSNY)	**1,990**	**2,100**	**6%**
MNR Operated	280	290	4%
Amtrak Operated	1,490	1,570	5%
Amtrak Intercity (SLE - NHL/PSNY)	220	240	9%
Amtrak Northeast Corridor (SLE/HFL/NHL-NEC)	**4,010**	**4,250**	**6%**

As Table 4 and Table 5 show, the demographic forecasts (roughly 4% population growth and 8% employment growth for Connecticut) are consistent with modeled ridership growth (5-6% along the various lines).

This projected ridership is also consistent with the recent historical pattern of ridership growth along the NHL since 2007. Table 6 shows the ridership activity reported by MNR in 2007 and 2016 along the NHL as measured by boardings and alightings (i.e., ons and offs) in both the inbound and outbound direction. Ridership has grown substantially along the line (19%) with growth on the Main Line (20%) significantly outpacing that of the Branch Lines (8%).

Table 6 Historical NHL Ridership Growth

	Weekday Ridership Activity (On + offs; Inbound + Outbound)		
Service	**2007**	**2016**	**% Change**
Branch Line Stations	7,698	8,307	**8%**
Grand Central Terminal	83,869	97,745	**17%**
Main Line Stations	226,150	270,693	**20%**
New Haven Line Stations	233,848	279,000	**19%**

The project team also analyzed trip ends, trip productions, and trip attractions to better understand market flows and travel patterns across the network. This analysis highlights the importance of the connection to New York City both as a destination for Connecticut residents and as an origin for reverse peak commuters to Connecticut. The HFL, SLE, and Amtrak trips are primarily connecting Connecticut passengers with the New York City metropolitan (NY Metro) area. HFL trips primarily connect areas around Hartford with the NY Metro area and, to a lesser extent, Springfield, Massachusetts. SLE trips primarily connect the westernmost stations of the SLE with the NY Metro area. Amtrak Intercity trips primarily connect southwestern Connecticut with the NY Metro area, and to a lesser extent, Boston, Massachusetts. The NHL Main Line hosts many trip attractions and productions along the entire length of the line, with major urban areas such as Stamford, Norwalk, Bridgeport, and New Haven

generating robust trip patterns in both peak and counter-peak directions. Figure 9 and Figure 10 are two examples of maps produced as part of this analysis. See Appendix C for a more complete set of maps.

Figure 7 NHL Peak Direction Attractions

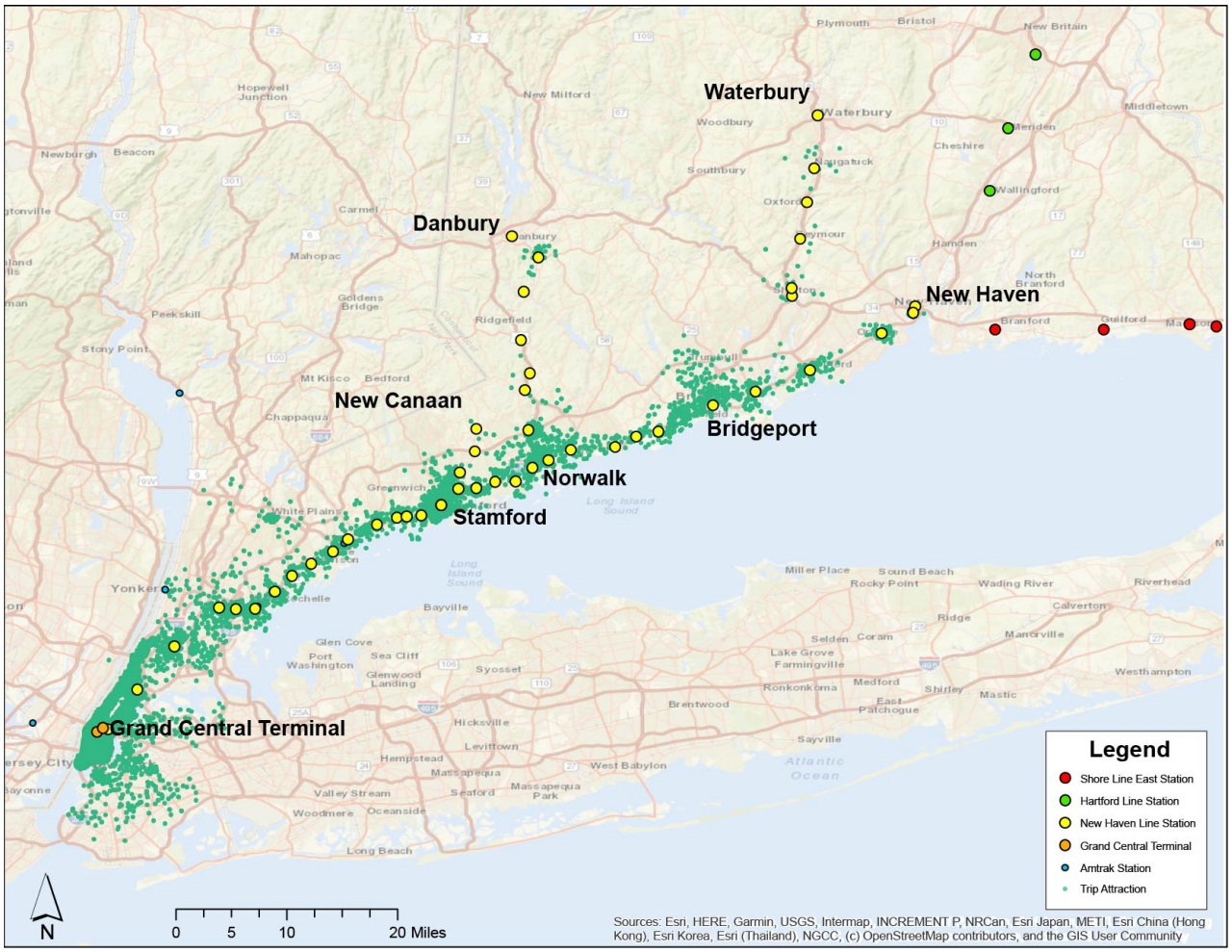
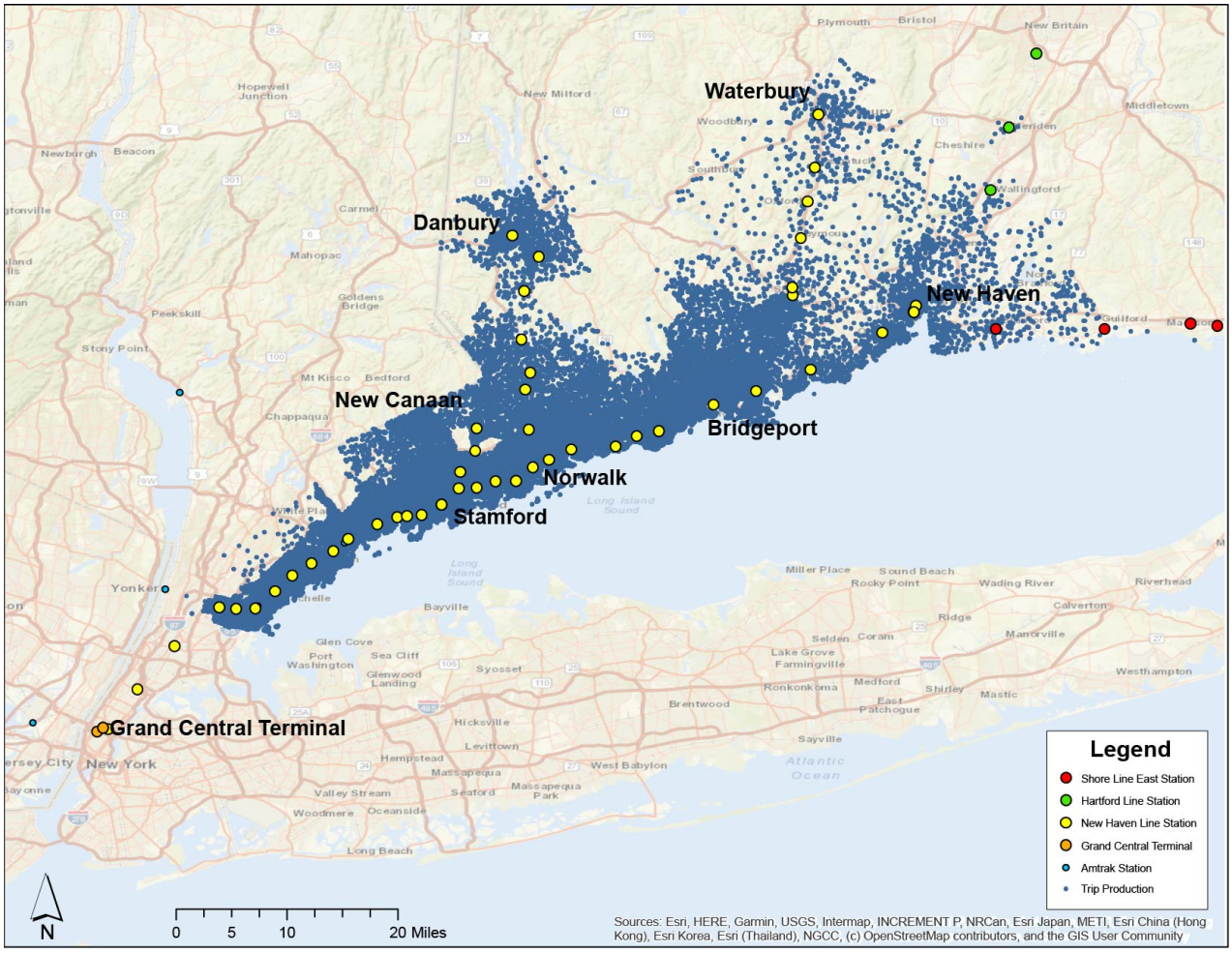


Figure 8 NHL Peak Direction Trip Productions



5. Near- & Long-Term Enhancements (Tasks 4 & 5)

Initially, the project team planned to analyze the proposed enhancements within a near-term and long-term time horizon. However, after consultation with CTDOT, it was decided to focus on near- and mid-term enhancements. As the rail network faces increasing issues related to lengthening trip times and diminished reliability, addressing the more immediate need to reverse these trends takes priority. Longer-term enhancements will be part of a larger statewide discussion incorporated into new planning initiatives led by the administration of Governor Lamont. The near-term and mid-term enhancements discussed below also lay the groundwork for more extended, expanded planning analysis to be undertaken in future planning efforts.

5.1. Programmed Capital Improvements

The project team performed a review of the 2017-2021[8] CTDOT Rail Capital Plan and found it to be centered around essential needs related to state-of-good-repair work. The plan contained regular program funds for state-

[8] The capital plan review was performed in 2018; funding levels referenced in this section are from fiscal year 2018 to fiscal year 2021
Transportation Infrastructure Capital Plan source: https://portal.ct.gov/DOT/Bureau-of-Policy/Transportation-Infrastructure-Capital-Plans

of-good-repair maintenance items such as bridge timbers, track, grade crossing, interlocking/drainage, etc. Bridge repair and replacement was one of the more costly programs with over $700 million programed for the Walk Bridge replacement and another $45 million for repairs to the Cos Cob and Saugatuck Bridges. Replacement/expansion of rolling stock was another large program with funding over $600 million. There was also over $400 million programmed to continue improvements to the HFL. The plan also had initiatives for improvements such as new station platforms, MOE shop and yard improvements at New Haven, real time information displays, and the completion of the Signal Replacement Program. The capital plan would give CTDOT and its operators the capability to continue to operate the current rail services adequately.

5.2. Review of Fleet Replacement Options

The project team provided technical support for CTDOT's evaluation of new equipment options and contributed to the dimensioning of overall fleet needs for future service expansion. As a first step, the full range of alternatives for replacement of the aging SLE and HFL push-pull coaches (described in Section 2.4) was considered. This analysis focused on the operating environment, service requirements, facilities, and passenger boardings on the locomotive-hauled services: the SLE, HFL, WBL, and DBL.

The analysis considered both locomotive-hauled coaches as well as Diesel Multiple-Unit (DMU) equipment. DMU equipment is different than locomotive-hauled equipment in that each coach is a self-propelled diesel unit. A thorough analysis of the pros and cons of either DMU or conventional locomotive-hauled service was completed prior to recommending locomotive-hauled coaches. Beyond concerns with maintenance requirements associated with DMU equipment, the primary reason for selecting locomotive-hauled coaches was their inter-operability on the CTrail network and the future flexibility they provide to operate direct service into Manhattan with dual-mode locomotives (see Section 2.4).

5.2.1. Procurement Plans

Coach Procurement

For service on the CT*rail* operated lines (HFL and SLE) the decision was made to purchase single-level push-pull coaches that would be a better fit for the estimated ridership, longer trip lengths, and opportunities for NY Direct one-seat-ride service into Manhattan. Opportunities to partner with MNR will continue to be explored as MNR advances procurement of multi-level coaches for their service on the DBL. This analysis informed the decision to procure a customized "Connecticut Car" (released in April 2020) offering state-of-the-art travel experiences along any rail line in Connecticut and beyond to New York.

With the car design determined, the project team performed a fleet dimensioning exercise to consider various service enhancement scenarios and estimate the total number of new push-pull coaches required to support those scenarios. Additional consideration was given to incrementally implementing service enhancements in conjunction with the phased delivery of new coaches. The decision to move forward with a locomotive-hauled push-pull coach fleet will support a wide range of services and meet the specific operational or regulatory needs of each without compromise to its design or performance. Each of the service concepts was also evaluated with respect to identifying overnight storage, layover, and maintenance requirements. The equipment requirements to support the service concepts was coordinated with a stand-alone Task 9 Shops and Yards Report to identify new and/or expanded shops and yards locations to support the expanded fleet required to deliver enhanced service. Importantly, the accompanying decision to also procure new dual-mode locomotives further supports improved connections to Manhattan with more one-seat rides from each of the diesel lines (WBL, DBL, and HFL).

Locomotive Procurement

The current CTDOT fleet of eighteen locomotives used on the SLE and HFL is being overhauled. The six GP-40 units (built in 1971 and remanufactured in 1996) received a top deck overhaul, including the inspection and replacement or conditioning of major engine parts and other components, as well as repainting. The overhauled GP-40s were returned to service in 2018. The twelve P40s (built in 1992) are undergoing a complete overhaul that involves a rebuild of major systems including the prime mover, main alternator, traction motors, and automatic train control, as well as a repainting. The first group of six P40s are expected to begin delivery testing in 2020-21. These overhauls will extend the life of the P40s by 12 years and the GP40s by six years. Figure 11 is an example of an overhauled GP40 in the new CT*rail* paint scheme.

Figure 9 Example of a GP40 Locomotive in the new CT***rail*** **paint scheme**

Beyond this overhaul, CTDOT will advance plans for procurement of additional locomotives to expand service opportunities with the new "Connecticut Cars." The analysis related to the new car design also highlighted the value of a push-pull coach that could be powered with a diesel, dual-power, or dual-mode locomotive.

Dual-power locomotives can draw electric current for propulsion from both electrical current systems: from overhead catenary utilizing Alternating Current (AC) and from third rail utilizing Direct Current (DC).

Dual-mode locomotives can operate in diesel or electric mode and are critical to offering more one-seat ride service from the diesel branches into Manhattan. These dual-mode locomotives can be one of two types:

- Diesel and DC third rail (e.g., dual-mode locomotives operated by MNR), or
- Diesel and AC overhead catenary (e.g., dual-mode locomotives operated by NJ TRANSIT)

The extended service plans described in this report (Section 5.3) connecting non-electrified territory and GCT or PSNY are dependent upon procurement of two differing locomotive types. Hartford-GCT direct service would require a diesel-3rd rail dual-mode locomotive, while Hartford-PSNY service would require a diesel-catenary dual-

mode locomotive. Based upon these potential service plans, 6-8 locomotives of each type would be required. Procurement would likely take 5-6 years from specification development to in-service dedication, dependent upon supply-chain and other market conditions. Both locomotives would require expanded yard and shop facilities, with attendant parts and special systems maintenance support.

5.3. Service Objectives

Building on the assessment of existing conditions, speed and capacity limitations and capabilities, as well as on the market assessment, a set of service objectives was established to guide the development of potential service concepts to both improve travel times and enhance the overall connectivity and convenience of the Connecticut rail network. These initial objectives were reflected in and consistent with inputs to the Commission on Fiscal Stability and Economic Growth. The four key service objectives include:

1. **Improving Access to NYC** through increased frequencies, faster speeds to GCT, and direct access to PSNY.
2. **Linking Connecticut cities with better feeder line connections.** Enhance connectivity between Connecticut cities by providing and enhancing through-service between them.
3. **Improving Trip Times** along the NHL and branch lines. Improve travel times not only to PSNY (e.g., travel time savings of 15-20 minutes to/from NYC) but also between cities in CT.
4. **Enhancing Customer Experience** by providing state-of-the-art rail equipment for longer distance express routes. Includes 2x2 seating, meeting space, broad band internet, charging facilities, and other amenities at every seat.

5.3.1. Initial Service Concepts

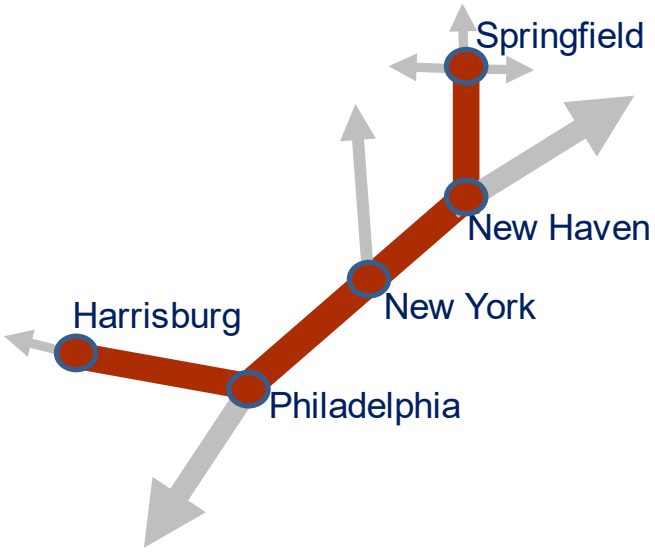
The project team evaluated multiple service concepts, including a comprehensive analysis of various service stopping patterns and the "2+2" concept for NHL trains. None of the service pattern variations were determined to be superior to the current operation in terms of travel time and travel experience. The 2+2 concept, while offering modest travel benefits, required very large (perhaps infeasible) capital investments at certain stations to accommodate a mix of local and express stopping patterns and convenient passenger transfer. Ultimately, the team advanced two concepts for improved service to NYC that would also improve intra-Connecticut rail connectivity and reduce trip times. The two service concepts included:

1. New York Express (NYX) service operating from the HFL as a through service via the NHL to PSNY and points west; and
2. Grand Central Express (GCX) service similarly connecting the HFL to GCT via the NHL.

These two alternative service concepts were developed and evaluated as feasible options to improve NYC access, better link intra-Connecticut cities, and improve travel times from the stations it would serve. The two concepts were envisioned to utilize the new "Connecticut Car" design.

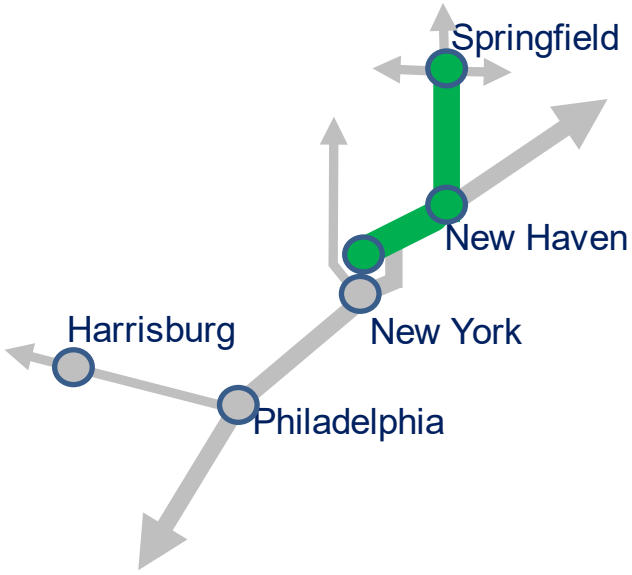
5.3.1.1. New York Express (NYX)

This concept would expand travel options along the NHL to/from PSNY by extending existing Keystone Corridor service to the HFL. The service would strategically fill gaps in existing Amtrak Regional Service on the NHL, Keystone Service on the Harrisburg Line, and HFL service between New Haven and Springfield. It would require partnering with Amtrak and/or the state of Pennsylvania for the operation and a joint procurement of equipment. Schedules would also need to be coordinated with CT*rail*, MNR, Long Island Rail Road (LIRR), NJT, and Southeastern Pennsylvania Transportation Authority (SEPTA) operations. This service would allow for new station pairs between PSNY and the NHL and HFL. This would also allow for one-seat rides between HFL stations and NHL stations, thereby improving commuter travel options between Hartford and places like Stamford and Greenwich. It would also allow for improved connectivity between Connecticut and Pennsylvania.



5.3.1.2. Grand Central Express (GCX)

This concept would improve travel times between the east end of the NHL and HFL to/from GCT. It would feature express service between New Haven and GCT and allow one-seat ride travel from HFL stations to/from GCT. This would also allow for one-seat rides between HFL stations and NHL stations, thereby improving commuter travel options between Hartford and places like Stamford and Greenwich. Schedules would need to be carefully coordinated with CT*rail*, Amtrak, and MNR operations. Assigning slots over the Park Avenue Viaduct and into/from GCT will particularly require active partnering with MNR.



The project team also analyzed joint service that would provide the benefits of both service concepts.

5.4. Analysis of Service Concepts

The project team performed a series of analyses to identify the opportunities and limitations posed by each of the two service concepts. The analyses included ridership and revenue projections, an estimate of the potential impact of a TOD growth scenario, an estimate of capital and operating costs, and a trade-off analysis.

5.4.1. Ridership and Revenue Projections

The potential future ridership under each concept was tested using the modeling process described in Section 4, Market Assessment. Table 7 presents the ridership results of this test.

Table 7 Service Concept Ridership Projections

Line Totals	Scenarios						
	Base Year No Build	2025 No Build	2025 No Build - Base No Build (% Change)	2025 NYX	2025 NYX - 2025 No Build (% Change)	2025 GCX	2025 GCX - 2025 No Build (% Change)
Hartford Line (HFL - HFL/NHL/PSNY)	1,620	1,710	6%	2,100	23%	1,870	9%
CT*rail* Operated	520	560	8%	610	9%	670	20%
Amtrak Operated, CT*rail* Fare	270	280	4%	320	14%	340	21%
Amtrak Intercity (HFL - NHL/PSNY)	830	870	5%	1,170	34%	870	0%
New Haven Line (NHL-NHL/PSNY)	143,230	150,980	5%	151,020	0%	152,010	1%
Metro-North Railroad (MNR)	142,560	150,260	5%	150,260	0%	151,300	1%
Amtrak Intercity (NHL - PSNY)	670	710	6%	750	6%	710	0%
Shore Line East (SLE-NHL/SLE/PSNY)	1,990	2,100	6%	2,100	0%	2,100	0%
MNR Operated	280	290	4%	290	0%	290	0%
Amtrak Operated	1,490	1,570	5%	1,570	0%	1,570	0%
Amtrak Intercity (SLE - NHL/PSNY)	220	240	9%	240	0%	240	0%
Amtrak Northeast Corridor (SLE/HFL/NHL-NEC)	4,010	4,250	6%	4,410	4%	4,250	0%

The HFL has a 23% increase in ridership relative to the No Build in the NYX scenario primarily coming from the Amtrak Intercity ridership with extended trains between PSNY and Hartford. The GCX has more modest increases in HFL ridership (9%), though there is a larger increase in MNR NHL ridership with the additional MNR trains servicing the line. The NYX scenario appears to primarily increase inter-state travel (Amtrak trips) with limited connectivity to the Connecticut portion of the NHL. The GCX scenario has a more significant increase in intra-state ridership with the additional MNR and CT*rail* service in Connecticut. The SLE does not have any service changes when comparing these scenarios with the No Build.

Order of magnitude estimates of revenue for each scenario were also developed. Using an average revenue generated per ride for each service and the projected future ridership described above, the project team estimated the additional revenue generated by each tested concept. Table 8 shows the estimated change in revenue for the 2025 modeled concepts relative to the No Build scenario. The NYX scenario generates most of its revenue on increase of NEC Regional trips with the extended Keystone services to Hartford creating an extended travel market. The GCX scenario generates more total trips, but less revenue as most are on the MNR NHL.

Table 8 Average Additional Weekday Revenue by Line

Average Weekday Forecasts	2025 No Build		2025 NYX				2025 GCX			
	Ridership	Revenue ($ 2018)	Ridership	Revenue ($ 2018)	Ridership Change	Revenue Change	Ridership	Revenue ($ 2018)	Ridership Change	Revenue Change
Hartford Line										
CT*rail* Operated + Amtrak Operated, CT*rail* Fare	840	$ 5,050	930	$ 5,590	90	$ 540	1,010	$ 6,070	170	$ 1,020
Amtrak Intercity	870	$ 38,400	1,170	$ 47,000	300	$ 8,600	870	$ 38,400	0	$ 0
New Haven Line										
Metro-North Railroad (MNR)	150,260	$1,318,790	150,260	$1,318,790	0	$ 0	151,300	$1,327,920	1,040	$ 9,130
Amtrak Intercity	710	$ 27,600	750	$ 28,200	40	$ 600	710	$ 27,600	0	$ 0
Shore Line East										
MNR Operated + Amtrak Operated	1,860	$ 8,000	1,860	$ 8,000	0	$ 0	1,860	$ 8,000	0	$ 0
Amtrak Intercity	240	$ 13,900	240	$ 13,900	0	$ 0	240	$ 13,900	0	$ 0
Amtrak Northeast Corridor	4,250	$424,300	4,410	$ 437,000	160	$ 12,700	4,250	$ 424,300	0	$ 0

5.4.2. Future Growth Scenario

In order to better understand how policies promoting transit-oriented development (TOD) along the HFL may impact future ridership, the project team developed a scenario in which denser development would produce additional jobs and population in these areas. The project team developed a methodology for estimating the potential increase in jobs and population in a TOD scenario by adapting a method utilized by the Regional Plan Association in their "Untapped Potential" report. Results of this scenario estimate are displayed in Table 9.

Table 9 TOD Scenario Demographic Projections

Municipality	New Developable Area (sf)	Added Population in 2025	Added Jobs in 2025
New Haven[1]	16,758,005	21,405	17,213
Wallingford	216,893	140	152
Meriden	1,443,143	2,898	3,151
Hartford	2,320,256	13,263	11,391
Newington	1,321,761	1,378	1,499
West Hartford[2]	2,190,625	8,610	9,362
TOTAL	**24,250,683**	**47,694**	**42,768**

(1) Summary includes all sites that are within 1/2 mile of Union Station and/or State Street Station

(2) Because the proposed West Hartford station is on the town's border with Hartford, some sites listed in this row are located within the City of Hartford

These figures were then added to the base demographic inputs of population and jobs used for modeling. The team modeled 2025 NYX service initiative with and without the added TOD demographic inputs. The outcome of the model runs is provided in Table 10 below.

Table 10 TOD Scenario Ridership Growth Projections

	2025 Base No Build	2025 Base NYX	2025 TOD NYX	2025 TOD NYX - 2025 Base NYX (Increment)	2025 TOD NYX - 2025 Base NYX (% Change)
Line Totals					
Hartford Line (HFL - HFL/NHL/PSNY)	**1,710**	**2,100**	**2,140**	**40**	**2%**
CT*rail* Operated	560	610	620	10	2%
Amtrak Operated, CT*rail* Fare	280	320	320	0	0%
Amtrak Intercity (HFL - NHL/PSNY)	870	1,170	1,200	30	3%
New Haven Line (NHL-NHL/PSNY)	**150,980**	**151,020**	**151,040**	**20**	**0%**
Metro-North Railroad (MNR)	150,260	150,260	150,260	0	0%
Amtrak Intercity (NHL - PSNY)	710	750	780	30	4%
Shore Line East (SLE-NHL/SLE/PSNY)	**2,100**	**2,100**	**2,110**	**10**	**0%**
MNR Operated	290	290	290	0	0%
Amtrak Operated	1,570	1,570	1,580	10	1%
Amtrak Intercity (SLE - NHL/PSNY)	**240**	**240**	**240**	**0**	**0%**

The initial findings of the high-level ridership forecast indicate an opportunity for growth in ridership as a result of TOD. Furthermore, the inter-regional NEC FUTURE model used to calculate these results relies on large Transportation Analysis Zones that are not well-suited for capturing the higher propensity of those living and working closer to stations to travel via rail (as opposed to car). Thus, the added ridership results shown above are likely a conservative estimate of the potential impact of TOD. Further analysis, led by local and regional stakeholders, would provide additional insight into opportunities for ridership gains as a result of TOD policies, and thus should be included in future planning efforts.

5.4.3. Capital and Operating Costs (Task 4.4)

The CTDOT Rail Capital Plan (2017-2021)[9] includes regular program funds for state-of-good-repair and enhancements to support CT*rail* passenger service. On average, the state of Connecticut expects to spend between $700 and $900 million a year on rail infrastructure and equipment. The NYX and GCX Service Concepts as developed do not require additional capacity and therefore do not require any capital expenditure beyond that already programmed in the capital plan. Additional improvements to speed and capacity are being considered as part of a longer-term service strategy for 2035. This longer-term vision is being developed in coordination with the Northeast Corridor Commission, MNR, and Amtrak.

The project team developed high-level operating and maintenance costs associated with the NYX and GCX scenario by using a cost per train mile of $70. This figure was developed based on an analysis of the costs associated with existing service on the NHL, SLE, and HFL. As it was recorded in 2016 and 2017, this data was then adjusted to 2019 dollars. The team found that the fully allocated operating costs (in 2019 dollars) of each service would be:

- GCX: 250 Weekday Round Trips Springfield - GCT has an annual cost estimated at $27 million
- NYX: 250 Weekday Round Trips Springfield - PSNY has an annual cost estimated at $25 million

The team also found that some economies of scale are possible, depending on crew turn linkages and actual (as opposed to allocated) additional costs, which have a high potential for cost reductions.

5.4.4. Trade-off Analysis (Task 4.5)

Initial analysis shows that these two service concepts each have strengths and limitations. In both concepts, the HFL saw the biggest percentage growth of ridership. Further analysis into both concepts as well as associated infrastructure improvements continues and will be incorporated into future strategic planning efforts. A brief summary of the key elements of each service concept is provided in Table 11.

Table 11 Key Elements of NYX and GCX Service Concepts

Penn Station Express (NYX)	Grand Central Express (GCX)

• 10 roundtrips per weekday
  • 10 to/from PSNY
  • 6 with Philadelphia Extension
  • Limited 1-seat rides on NHL
  • 10 on HFL with new AM and PM peak trips
  • 3 trainsets in service (6 cars)
  • Linked with Keystone
  • Linked with HFL shuttles
  • Amtrak operations and maintenance (Philadelphia)
  • 42 cars in service including Amtrak shuttles
	• 12 roundtrips per weekday
	  • 12 to/from GCT
	  • Peak and Off-peak trips
	  • Range of 1-seat rides on NHL
	  • 10 on HFL with new AM and PM peak trips
	  • 2 CT*rail* train frequencies replaced
	  • 3 trainsets in service (4 cars)
	  • Independent operation
	  • Match SLE and CT*rail* consists
	  • Assumed contract/MNR operations and maintenance
	  • 24 cars in service including Amtrak shuttles

[9] See Section 5.1 for more information

Implementing either of these service concepts would require significant cooperation with other agency partners. The GCX concept would require coordination with MNR on issues such as NHL and GCT slots, dispatching, equipment usage, and a potential modification to the NHL Service Agreement. The NYX concept would require coordination with Pennsylvania Department of Transportation (PennDOT) on issues related to equipment specifications, procurement, and maintenance as well as with Amtrak on access to the Hell Gate Line, PSNY slots, and equipment. Schedule coordination would extend to LIRR, NJT, and SEPTA operations. The extension of the HFL to Springfield in either concept would require coordination with Amtrak, Mass DOT and potentially the Pioneer Valley Transportation Authority (PVTA) in terms of costs related to station, yard, and equipment maintenance/access, including a potential modification to operation and access agreements.

A more detailed list of pros and cons for each concept is provided in Table 12 and in Table 13.

Table 12 Pros and Cons of GCX Service Concept

GRAND CENTRAL EXPRESS SERVICE (GCX)	
PRO - GCX	**CON - GCX**
Achieves bona-fide express service between New Haven and GCT and between HFL stations and GCT	Does not address resiliency goal of serving two separate Manhattan terminals
Provides useful one-seat ride options between HFL and NHL stations	Does not address desire for expanded access to PSNY and points west
Only requires 3 additional initial train sets	Amtrak may have concerns with potential for redundant (Springfield to NYC) service
DC dual-mode locomotives required for this service are compatible with MNR requirements – presents an opportunity to piggyback on planned order	Requires negotiations with MNR for slots into GCT and provision of additional operating staff
Fare structure is compatible with NHL, CT*rail*, and SLE service	

Table 13 Pros and Cons of NYX Service Concept

NEW YORK EXPRESS SERVICE TO PENN STATION (NYX)	
PRO - NYX	**CON - NYX**
Infills Amtrak Regional train slots on NHL to come closer to hourly service	Limited number of new frequencies requires transfers with MNR trains for NHL passengers when they take alternate trains to/from PSNY
Extensions of selected Keystone trains reduce new train berth needs at PSNY	Longer service runs (331 miles between Springfield and Harrisburg) will be subject to greater instances of delay and compromise NHL slots
Uses common next generation car design (requires PennDOT collaboration)	Additional equipment requirements are greater than for GCX - likely minimum of 5 trainsets, more likely 7 trainsets
	Requires rotation with at least one Amtrak Shuttle consist to achieve schedule (indicates all three consists should be the same)
	Service requires either new AC dual-mode locomotives or engine changes; AC dual-mode design could be unique on Amtrak system, introducing new service and maintenance requirements
	Continued use of engine changes, in-lieu of dual-mode locomotives, will add 10-13 minutes of travel time to HFL stations
	Complex institutional framework - multiple agreements needed with MNR, Amtrak, LIRR, PennDOT

6. Conclusion & Recommendations

Forecasts suggest that ridership on the Connecticut rail network will continue to increase as job and population growth continues throughout the region. The aging rail fleet and existing infrastructure constraints limit the ability for CTDOT to meet the needs of this expected growth and expand the capacity of the Connecticut rail network. The project team identified potential solutions highlighted by a new fleet procurement plan and new service concepts that can address these capacity constraints. The new "Connecticut Car" would offer state-of-the-art travel experiences along any rail line in Connecticut and beyond to New York. The New York Express Service to PSNY (NYX) and Grand Central Express (GCX) service concepts would improve access to NYC and reduce trip times along the network. These service concepts, along with fleet procurement strategies and infrastructure improvements, should undergo further analysis as part of future planning efforts.

CT*rail*Strategies

Appendix A Existing Conditions Report

CT*rail* Strategies

Contents

Table of Figures

Tables

Overview of the Connecticut Rail System

The purpose of the initial task of the New Haven Line Speed and Capacity Analysis study is to document the existing infrastructure and operating conditions of the New Haven Line, its three branch lines, as well as the CT*rail* services of Shore Line East and the Hartford Line, with the goal of determining the capabilities and limitations of the existing infrastructure. Part 1 of this report provides information regarding the existing condition of the New Haven Line within the State of Connecticut; however, it precludes data for the portion of the New Haven Line within the State of New York (with the exception of some information regarding access to Grand Central Terminal). This effort sets the framework for how to improve the New Haven Line and its service in the future. Part 2 of this report will expand upon information in the first section to further document the existing conditions of the three New Haven Line Branches and of the CT*rail* services (Shore Line East and Hartford Line).

Figure 1: Map of Connecticut Passenger Rail System

The New Haven Line (NHL) operates between New Haven, Connecticut and Grand Central Terminal (GCT) in New York City and is the most heavily traveled commuter rail line in the country. The system benefits from its proximity to, and its being an integral part of, the New York City metropolitan market area, which drives a significant portion of demand. The rail system consists of the New Haven Line Mainline and its three branches: the New Canaan Branch Line (NCL), the Danbury Branch Line (DBL), and the Waterbury Branch Line (WBL); these lines are operated by Metro-North Railroad (MNR), a part of New York's Metropolitan Transportation Authority (MTA) system. The

NHL is also a critical link in Amtrak's Northeast Corridor (NEC), allowing connections between Washington D.C., Philadelphia, New York, Stamford, New Haven and Boston. The Shore Line East and Hartford Line, which are identified as the CT*rail* system, also provide connecting service to the NHL but are not operated by MNR. Shore Line East is operated by Amtrak and the Hartford Line service is operated by both Amtrak and Transit America Services. The State of Connecticut contributes financially to the operation of all services except for the Amtrak NEC service. A summary of the routes in the Connecticut passenger rail system is shown below; the station counts for the Branch Lines and the CT*rail* Lines do not include stations already counted as part of the New Haven Line Mainline:

Table 1: Connecticut Passenger Rail System

New Haven Line	Length (miles)	Number of Stations	Start-End	Primary Equipment Operated	Number of Tracks
New Haven Line (CT)	45(73)[1]	21	Greenwich-New Haven	Electric	4
New Haven Line (NY)	16	8	Mount Vernon E.-Greenwich	Electric	4
Branch Lines					
New Canaan Branch Line	7.9	4	Stamford-New Canaan	Electric	1
Danbury Branch Line	24.2	7	South Norwalk-Danbury	Diesel	1
Waterbury Branch Line	27.1	6	Bridgeport-Waterbury	Diesel	1
CT*rail* Lines					
Shore Line East	49.8	7	New Haven-New London	Diesel	2
Hartford Line	62	7	New Haven-Springfield	Diesel	2

Part 1: New Haven Line Mainline

The following pages will specifically address the New Haven Line Mainline from the CT/NY border to New Haven Union Station. These efforts set the framework for how to improve the New Haven Line and its service in the future.

1.1 Overview of the New Haven Line

The New Haven Line (NHL) typically refers to the Mainline that extends east to west from New Haven Union Station to Grand Central Terminal in New York, a distance of approximately 73 miles. This line generally operates as a four-track system that is fully electrified, with overhead catenary existing throughout Connecticut and a third-rail system west of mile post (MP) 15 (Pelham, New York) to Grand Central Terminal. Catenary between MP 15 (just west of Pelham Station in Pelham, New York) and New Haven is a 12kilovolt 60 cycle Alternating Current (i.e., 12kv 60 cycle AC) design, while the 3rd rail system provides 600 volts of Direct Current (DC). Between MP 61 (just east of the Devon Wye in Milford, Connecticut) and just west of MP 65 (in the vicinity of Old Gate Lane in Milford, Connecticut) there is no "Track 3"; as such trains operating through this section are limited to three tracks, which restricts capacity. There are currently no clearance limitations on the NHL or its branches for single

[1] Note that the New Haven line technically originates 12 miles from GCT. The total distance from GCT to NH is 73 miles with 61 miles of that on the New Haven Line, 45 miles in CT and 16 in NY. Grand Central and 125th Street are not included in this count.

level passenger trains; however, if future plans include multi-level coaches there are several bridges on the NHL west of the Connecticut border with New York that are below the 15' 5" minimum clearance requirement for this type of car. Table 2 details these bridges.

Table 2: NHL Bridges with Vertical Clearance Less than 15' 5"

Mile Post	Town and State	Road Intersection	Clearance	Track Number(s)
16.54	New Rochelle, CT	Memorial Highway	15' 4 ¼"	1
20.74	Mamaroneck, NY	Hillside Avenue	15' 4 ¼"	2
20.89	Mamaroneck, NY	North Barry Avenue	15' 5 ½"	2
21.45	Harrison, NY	West Street	15' 3 ½"	1
21.89	Harrison, NY	Broadway	15' 5 ½"	2
23.18	Rye, NY	North Street	15' 3 ½"	1 & 3

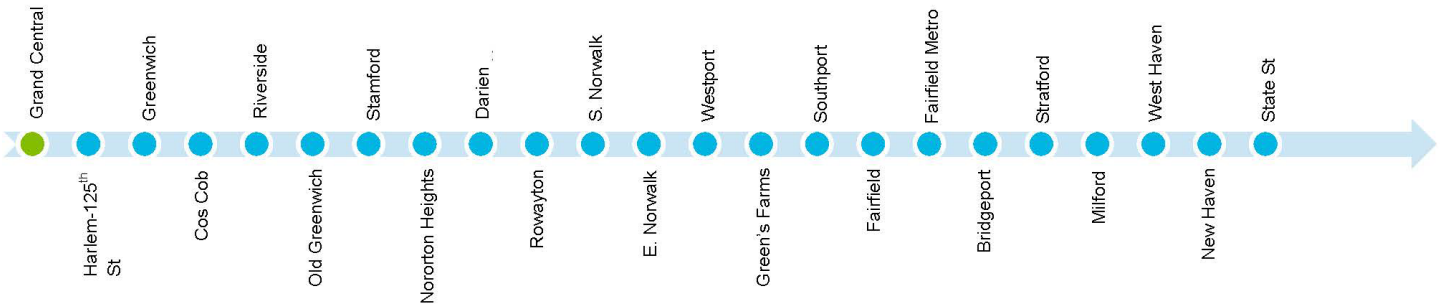


Figure 2: NHL Mainline Station Stops

NHL Mainline AM Peak Period Service

Figure 2 shows NHL mainline station stops. A total of 53 New Haven Line (NHL) AM peak period westbound trains from Connecticut traveling directly into Grand Central Terminal (GCT) arrive between 6:00 AM and 10:00 AM. An additional 12 commuter trains serve intermediate destinations such as Stamford and New Haven during the same period. Amtrak also runs 3 westbound intercity trains to Penn Station, New York in the AM peak period, making a total of 68 trains traveling in the westbound direction. During the same period, 32 revenue and non-revenue trains originate from GCT traveling eastbound to NHL destinations, an additional 15 commuter trains originate from intermediate points, and Amtrak operates 4 intercity trains destined to Boston for a total of 51 trains running in the eastbound direction. The combined total of 119 trains during the four-hour peak period is matched by only a few locations globally.

For the predominant travel market to GCT, the 53 trains identified above operate an average distance of 46 miles along the NHL, with an average length of 8.1 cars. The combined service delivers over 42,000 seats to GCT during the AM peak period. During the critical 8:00 AM to 9:00 AM peak hour, 20 NHL trains arrive at GCT (one every three minutes) and provide over 17,000 seats. Every NHL station receives at least two trains stopping at it during

this period, with 17 stations seeing at least double that figure. Because of its critical operations role, Stamford receives a total of 11 trains stopping during this 60-minute period.

The table below displays the number of AM peak period departures to GCT from key NHL Mainline stations, and serves to demonstrate the extraordinary level of service Stamford receives during the period. There are significantly fewer inbound AM trips from stations east of Stamford. A more detailed table is included on the following page.

Table 3: AM Peak Period Westbound Trips into GCT from NHL

Station Origin	Frequency (# of trips)	Average Headway (minutes between trains)
New Haven Union Station	13	0:18
Bridgeport	16	0:15
Stamford	39	0:06
Greenwich	21	0:11
Total into GCT (including New York trains)	**53**	**0:04**

The current operation of the New Haven Line (NHL) is limited by existing infrastructure along the Mainline tracks as well as at GCT, making expansion of the service extremely challenging. Despite the four-track configuration, the NHL peak period service is operated to fit within a three-track system due to the continuous reconstruction efforts necessary to bring the infrastructure to a state of good repair. Midday and evening service is run to conform to a two-track operation to allow the infrastructure work to efficiently proceed. Train length is also limited by the length and capacity of the available overnight layover facilities. Only a few tracks at the present yards are capable of accommodating the maximum train length of 12 cars.

Grand Central Terminal has a theoretical capacity to accept or discharge up to 50 trains per hour, or a total of 200 trains during the 4-hour AM peak period. New Haven Line (NHL) trains from Connecticut compete for the limited available space with trains from the two other Metro-North Railroad lines – the Harlem and Hudson Lines – as well as with Amtrak *Empire Service* trains during the summer of 2018 due to infrastructure renewal efforts underway at Penn Station New York. Because of the pronounced peaking of train movements to meet market demand, terminal operations call for using three tracks inbound in the morning and three tracks outbound in the afternoon. The capacity of the three peak period tracks is greater than the capacity of the terminal to store all of the equipment within it or the ability of the remaining single track in the reverse-peak direction to accommodate additional train movements to suburban stations or layover yards. At-grade crossing movements at "Control Point 5" (CP-5), where trains destined to the Hudson Line diverge from the Mainline serving the Harlem and New Haven Lines, also present a significant limitation. Many station platforms have limited length and cannot accommodate long trains. This requires careful planning of the station stops along the lines to balance ridership demands with the shorter-than-desired trains. These constraints affect operations along all three MNR branch lines.

Travel Characteristics of NHL Mainline Trains

Service along the New Haven Line (NHL) is formed by a complex set of train stopping patterns and schedules. They have been established to provide both travel opportunities to/from Grand Central Terminal (GCT) and to provide reasonable travel options to/from intermediate stations and destinations. Schedules have been developed around a "Zone Schedule" strategy which can offer travel time and seat availability benefits compared

to other scheduling strategies. The number of zones varies by time of day and includes up to nine discreet NHL zones in the AM peak period. Because of the large variability between individual train schedules, a series of metrics have been defined to help characterize the service for individual stations as well as along the entire NHL itself. The metrics have been calculated as a range to help assess the service provided at each station.

Typical travel times from New Haven Union Station to Grand Central Terminal (GCT) range from 2 hours to 1 hour and 46 minutes. The fastest scheduled travel times of New Haven Line trains to GCT vary by departing station and generally range from 1 hour 46 minutes at the eastern terminus (New Haven Union Station) down to 42 minutes at Greenwich station. Differences in travel times between express and local trips can be significant, and the difference between the fastest and longest trip can exceed 20 minutes. Table 4 depicts AM peak period travel times from key New Haven Line Mainline stations to GCT.

Table 4: AM Peak Period Travel Times into GCT from NHL (in hours : minutes)

Station Origin	Shortest Time	Longest Time	Median Travel Time
New Haven Union Station	1:46	2:06	1:52
Bridgeport	1:19	1:40	1:29
Stamford	0:48	1:13	0:52
Greenwich	0:42	1:02	0:49

Travel characteristics may also be expressed as the average speed a train makes between the origin station and arrival at GCT. It provides a uniform metric to consider when comparing characteristics between stations which otherwise may present a wide range of values. The average speed accounts for differences in maximum speeds the train is scheduled to make, the time associated with it stopping at intermediate stations and any "Recovery Time" built into the schedule, which is an essential component to achieving reliability. Table 5 depicts average travel speeds into GCT from key NHL stations during the AM peak period.

Table 5: AM Peak Period Average Travel Speeds (in MPH) into GCT from NHL

Station Origin	Fastest	Slowest	Median
New Haven Union Station	41	34	39
Bridgeport	42	33	37
Stamford	41	27	38
Greenwich	40	27	34

The number of intermediate stops a train makes is also of interest. Each stop changes the riding experience as passengers, who may be carrying luggage, get on and off the train. As the train decelerates, makes its station stop and then proceeds, the ride comfort characteristics change considerably, as does the car temperature condition with the admission of outside air from each door opening. Each stop is also accompanied by announcements advising passengers of the upcoming stop and then providing them with safety and travel information after each departure. A large number of intermediate stops and repetitive announcements can be a source of customer complaints. Table 6 depicts the number of intermediate AM peak period station stops into GCT from key NHL stations.

Table 6: Number of Intermediate AM Peak Period Station Stops into GCT from NHL

Station Origin	Fewest	Most	Median
New Haven Union Station	6	20	14
Bridgeport	2	16	10
Stamford	1	15	3
Greenwich	2	11	4

Consistent with the number of intermediate stops made by a train is consideration of the average distance the train is scheduled to run between station stops from its origin station to destination. The average distance is representative of the entire trip and not for every intermediate station. While many trains operate on an all-stop local pattern, often with relatively uniform distances between the stations, express trains can operate for long distances with no stops. The average distance accounts for both types of operation by calculating the total number of stops made and dividing it by the number of miles the train is scheduled to operate. Very short average distances (1-2 miles) border on distances found between stations in urban transit systems. Very long distances (10-20 miles) approach guidelines for intercity rail systems. Table 7 depicts average miles run between key station stops on the NHL.

Table 7: Average Miles Run Between Station Stops — AM Peak into GCT from NHL

Station Origin	Longest	Least	Median
New Haven Union Station	12	4	5
Bridgeport	28	3	6
Stamford	33	2	11
Greenwich	14	3	7

The characteristics and metrics noted above have been calculated for all New Haven line stations and may be found in Appendix G.

Annotated Track Map

An Annotated Track Map (ATM) was developed for the New Haven Line (NHL) and provides information for the Connecticut portion between Greenwich Station and New Haven State Street (MP 28 — MP 73.2). The ATM is a linear representation of the NHL and its infrastructure, with additional annotations addressing specific infrastructure and concerns. The map was developed to address the complexity of the systems' existing conditions, and how those conditions relate to the limitations and capabilities of the NHL. While the ATM is a graphic representation of the rail system, infrastructure locations displayed on the ATM are spatially accurate and scaled throughout the system. Using a graphic interface provides a tool to visualize multiple complex systems while also conveying their relationship to other infrastructure within the system. This becomes apparent when identifying 'hotspots' and trends for delays (slow orders), state of good repair issues, or where multiple concerns compound.

The following pages present a static version of the ATM; an Interactive version of the ATM is available in section 1.5 of the document. The interactive version of the ATM allows users to turn layers on and off and click on features for additional detail. The ATM will be updated annually to reflect changes in operating conditions.

The ATM addresses system infrastructure, limitations and concerns, and operational factors to build a high-level understanding of the rail system. The subsequent pages of this report will detail the implications of infrastructure limitations (by category) identified within the ATM. Specific aspects identified within the ATM include:

Infrastructure:

- Tracks and track location
- Branch Lines
- Stations and Platforms
- Bridges (open-deck; ballasted; movable)
- Control Points (CPs)

Limitations and Concerns:

- Mud Spots (i.e. drainage concerns)
- Slow Orders
- Poorly or Seriously Rated Bridges (NBI-67 Structural Rating)

Operational Factors:

- Maximum authorized speed (MAS) by track
- Curves (including speed through curves)
- Storage and Maintenance Facilities (excluding New Haven)

Figure 3: New Haven Line Track Map (Greenwich to Norwalk)

Legend

- Rail Station
- Mud Spots
- Slow Order
- Poorly Rated Rail Bridge
- Rail Bridge (ballasted)
- Future Rail Station
- Platform
- Siding
- Movable Bridge
- Rail Bridge (open deck)

Notes:

Note: Train speeds are based on MAS by mile post and do not account for acceleration and deceleration rates. It is likely that effective delay is higher.

Note: Slow orders are updated on a continuous basis and the ones presented above are only a snapshot. The data source is the Daily Train Operations Bulletin Order effective August 2019.

Note: NBI-67 Ratings are the National Bridge Inventory Structural ratings. Rating values 3 and 4 represent bridges that meet minimum tolerable limits, with a rating of 3 specifically indicating a high priority for corrective action - such as rehabilitation or replacement.

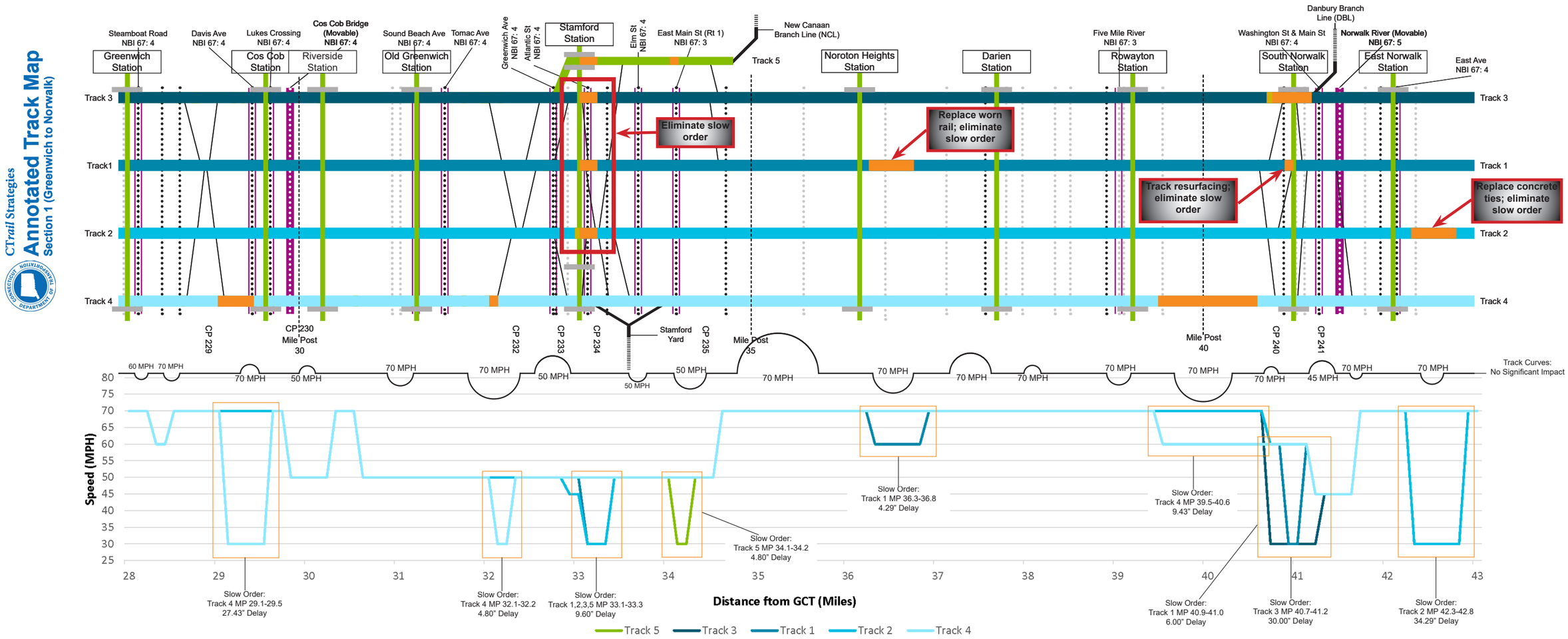


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Figure 4: New Haven Line Track Map (Westport to Bridgeport)

Legend

- Rail Station
- Future Rail Station
- Mud Spots
- Platform
- Slow Order
- Siding
- Poorly Rated Rail Bridge
- Movable Bridge
- Rail Bridge (ballasted)
- Rail Bridge (open deck)

Notes:

Note: Train speeds are based on MAS by mile post and do not account for acceleration and deceleration rates. It is likely that effective delay is higher.

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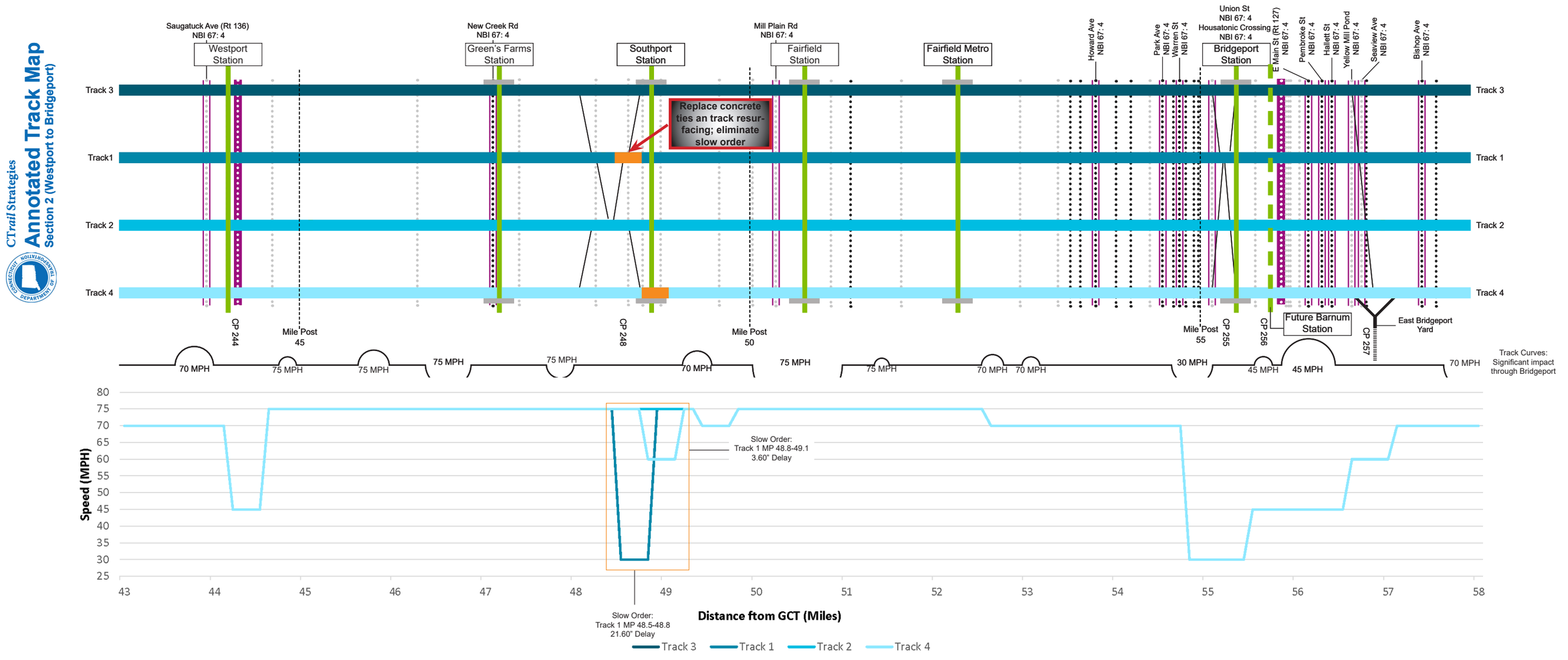

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Figure 5: New Haven Line Track Map (Stratford to New Haven)

Legend

- Rail Station
- Future Rail Station
- Mud Spots
- Platform
- Slow Order
- Siding
- Poorly Rated Rail Bridge
- Movable Bridge
- Rail Bridge (ballasted)
- Rail Bridge (open deck)

Notes:

Note: Train speeds are based on MAS by mile post and do not account for acceleration and deceleration rates. It is likely that effective delay is higher.

Note: Slow orders are updated on a continuous basis and the ones presented above are only a snapshot. The data source is the Daily Train Operations Bulletin Order effective August 2019.

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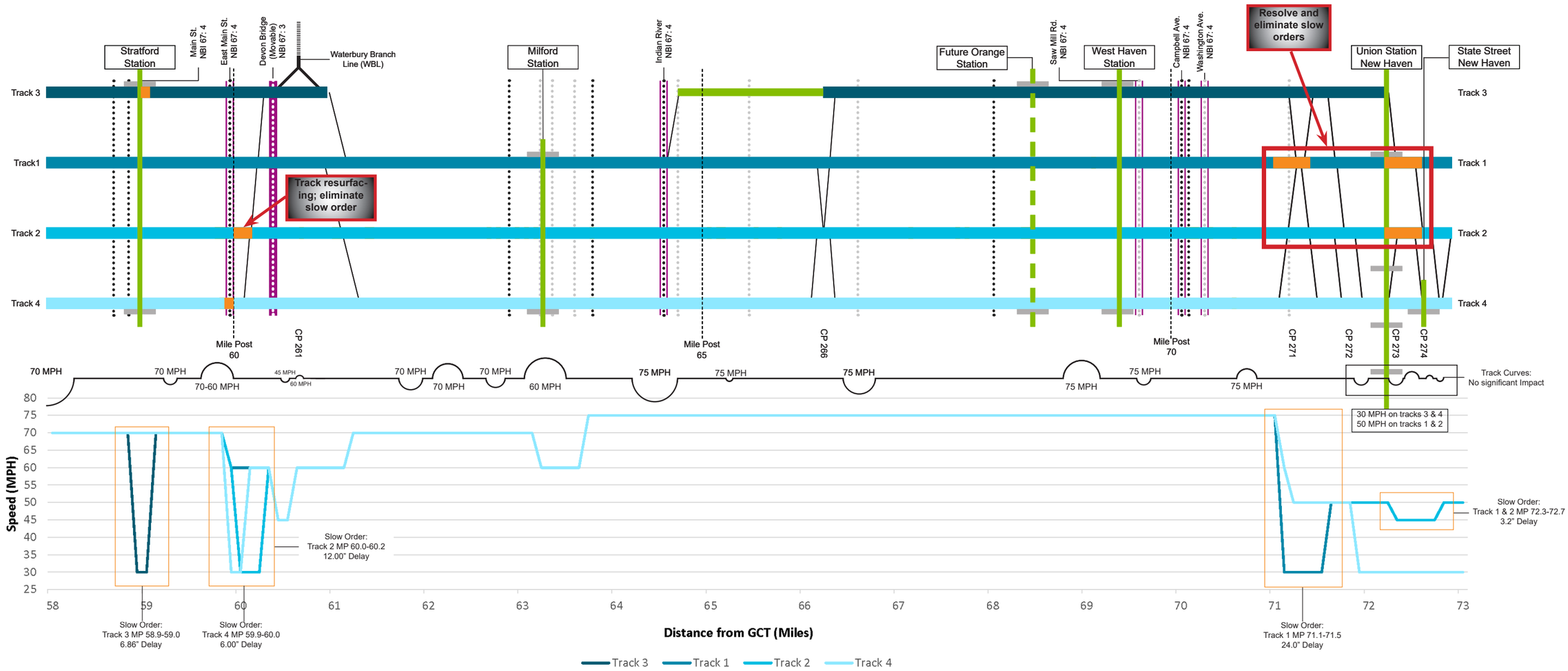
CT*rail* Strategies

Annotated Track Map

Section 3 (Stratford to New haven)



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1.2 Capabilities and Limitations of the New Haven Line

The Connecticut rail system is different in scope and scale from most other rail networks in the country and is only rivaled by the other New York City metropolitan area systems, as well as other commuter services in large urban areas. Its daily ridership exceeds that carried by any other single commuter rail line in the nation. The NHL's aging infrastructure, dated design standards and alignments and multiple crossings of large marine estuaries makes it very challenging to maintain. It requires particularly complex technologies for propulsion of the trains operating over it, and needs continuous, careful coordination with other rail services to keep operations fluid. These characteristics produce concerns that are critical to the mobility of this region. Overall findings demonstrate that while the Connecticut rail system, particularly the New Haven Line, delivers a high level of service, the system is broadly limited by a constrained terminal, line haul and equipment capacity, the state of its infrastructure and the status of long-term, ongoing construction and maintenance.

The purpose of the remaining tasks of this study is to identify both operational and infrastructure improvements that can be made with future investments.

Capabilities: The Connecticut rail system provides a generally high level of service, with the New Haven Line (NHL) currently operating 53 trains into Grand Central Terminal (GCT) during the weekday morning peak hours (6:00 AM – 10:00 AM), which accounts for approximately 23% of all MNR trains operating in the same period directly into GCT. Currently the NHL records ridership in excess of 130,000 on weekdays, making it the most heavily traveled commuter rail line in the United States. Previous investments in infrastructure, equipment and service improvements facilitate this ridership. Since 2000 the Connecticut Department of Transportation (CTDOT) has worked towards upgrading and modernizing key facilities, including catenary, signal systems, stations and the communications network. CTDOT has also purchased new electric coaches (M8s) for NHL Mainline and New Canaan Branch Line service and service was expanded to include increased service hours on the Danbury Branch Line. In June of 2018, CTDOT opened the CT*rail* Hartford Line, a new commuter rail service connecting New Haven, Hartford, and Springfield, Massachusetts to the NHL in New Haven. Work is also underway for the design and installation of a new signal system for the Waterbury Branch.

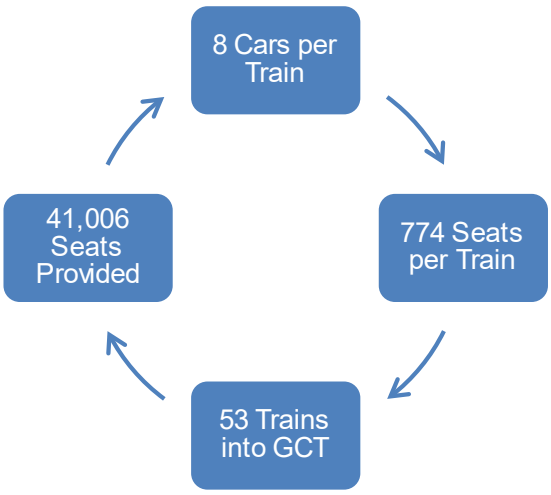


Figure 6: AM Peak Inbound Capacity

Limitations: The high density of train traffic currently operating makes it difficult to take on large scale capital improvements on the NHL Mainline without impacting service, unless work is carefully staged over long periods using night work or slow order segments. Additionally, development along much of the alignment of the New Haven Line and its three branches geographically constrains the railroad's right-of-way. Single track operations on the three NHL branches limit growth in service options. The expansion of facilities, the construction of additional track, or the construction of new stations is limited by the land available to site these facilities. The following is a summary of limitations relating to each of the elements of the system reviewed in this task:

Bridges: The existing condition of bridges has been an ongoing concern, as the rehabilitation and/or replacement of bridges is not only costly but also impacts operations throughout the construction window (with "slow orders" – a restricted speed limit – being imposed on trains operating through the work area). On the NHL Mainline there are 34 bridges rated in either poor or serious condition. The existing under-grade bridges generally allow

operations without restrictions, but it is likely that across a 25-year time frame many of these bridges will require significant rehabilitation or replacement, which will impact service during construction.

Figure 7: Walk Movable Bridge

Catenary and Traction Power: Both the catenary and traction power systems have recently been upgraded or are still in the process of being upgraded. Accordingly, concerns surrounding these facilities are relatively limited. The current system does not limit speed or service. While the traction power system is sufficient to handle current service, its ability to handle additional service cannot be fully assessed until a study of the power system is completed.

Figure 8: Catenary Structures on the New Haven Main Line

Track and Track Geometry: The track geometry and spacing limits operable speeds throughout the system to varying degrees; this variability leads to broad fluctuations in the maximum allowable speeds, which inhibit the efficient operation of the rail system. This limitation, in turn, is difficult to address given the constraints of the rail alignment. Straightening of the tracks would be cost prohibitive and is limited by right-of-way constraints. Permanent speed restrictions are exacerbated by slow orders that are caused by concerns about the railroad's state of good repair related to drainage, tie and track damage, and profile deviations. Of these causes, the impacts from poor drainage are of particular concern. Standing water can destabilize the rail bed and lead to premature wear of the concrete ties. There are currently 95 identified "mud spots" (poorly drained areas) along the New Haven Line and its three branches, requiring the replacement of more than 5,700 concrete ties.

Stations and Platforms: NHL Mainline stations are largely in good condition and receive periodic modernization and improvements. All stations – with the exception of Merritt 7 on the Danbury Branch Line and all of the Waterbury Branch Line stations – have high level platforms. The major limiting factor surrounding stations is geographic constraints that limit their ability to provide adequate parking for users. This is particularly true for Fairfield County stations on both the New Haven Line Mainline and New Canaan Branch Line. In most cases, the land to expand parking at these stations does not exist. Fairfield Metro (with 1,500 parking spaces) and West Haven (with 660 spaces) are the most recent new stations with significant parking, but this does not change the fact that many other stations have significant waiting lists for parking permits.

Figure 9: West Haven Station

Signals and Communications: The future signal system and current communications system do not pose significant concerns for the operation of the New Haven Line. A minor concern exists regarding the impacts that Positive Train Control (PTC) could have on maximum speeds once it is installed. With a PTC system, maximum speeds are limited electronically; if a vehicle under the control of a PTC system exceeds its authorized speed, the train is slowed to zero before it can resume service. The Waterbury Branch Line (WBL) is the only line in the Connecticut rail system that is not currently signalized and does not have active passing sidings; this lack of signalization currently severely limits the service provided on that line. Design of a new signal system for the WBL is underway and funding is available for its construction.

Rail Yard(s) Storage: The Connecticut rail fleet is stored at six different yards, with five being in Connecticut. The current yard storage in the Connecticut rail system is adequate for the existing fleet but is not well-positioned for fleet expansion. The 90+ additional M8 car delivery will exceed the available capacity of the existing yards once the "dead storage" of equipment is removed; and it will be important to progress completion of construction activities in New Haven. A consist-by-consist evaluation will be needed to fine-tune the actual useable surplus storage, and to verify alternate capacity where Maintenance of Way (MOW) activities share yard use. A future task of this study, Task 9 Rail Yard Requirements, will identify existing space by location and fully explore the range of potential for expansion. For further details see Appendix F.

Under-Grade Bridges (Movable): Movable bridges have a section of the superstructure which can be moved (opened) to create additional vertical clearance for marine traffic to pass through the navigation channel below it. This ability to open allows the rail line to be constructed over navigable waterways without excessive grade changes or prohibiting boat traffic. However, movable bridges present several unique concerns which affect operation of trains along the rail corridor:

- Train operations are interrupted when the bridge is opened.
- Speeds are restricted at the bridge due to track joint details between the fixed approach and the movable span.
- Movable bridges are complex and require significant maintenance. Without proper maintenance they have the potential to get stuck in the open position, preventing the passage of trains.

There are five movable bridges along the New Haven Line, with Peck Bridge at mile post (MP) 55.90 (in Bridgeport, Connecticut) being the only one to have recently been replaced. The other four movable bridges are each over

100 years old and require replacement. The Connecticut Department of Transportation (CTDOT) is currently undertaking the replacement of the WALK Bridge in Norwalk.

MNR sets the track speed for the movable bridges. Generally, the condition of the miter rails (the section of rail in the transition zone between a movable and a fixed piece of track) or mechanical components will dictate the allowable speed. Even if the bridge were in excellent condition, MNR would still limit the speed due to the miter rails. Generally, the maximum design speed for movable bridges is 60 MPH.

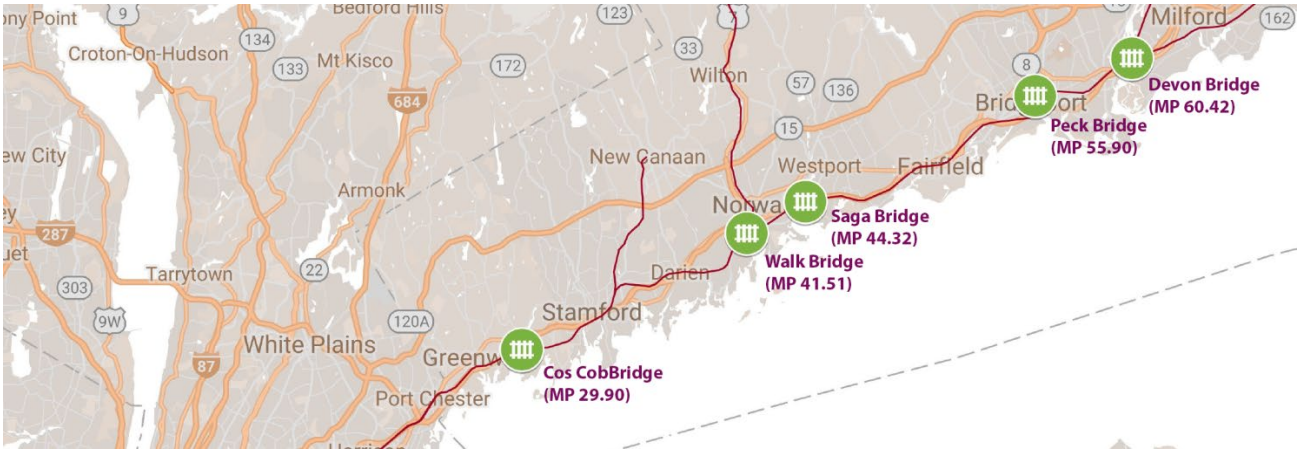


Figure 10: Location of the Five Movable Bridges Along the New Haven Line

Slow Orders: Every day a document called the Daily Train Operations Bulletin Order (DTOBO) is published; this document contains a list of slow orders that restricts speeds through these segments. A slow order is a temporary mandate that requires all trains, during all hours, operating over a given section of track, on a specific track, to adhere to a particular reduced speed. Reasons for mandated speed restrictions vary widely, but can include surface issues, deviation of the track profile, damaged or worn rail, and too many "bad" ties over a given section of track, among other things. They are typically assessed during ongoing track inspections and generally represent maintenance and state of good repair issues. These mandates remain in place until repairs can be made or conditions have improved.

On the New Haven Line, the daily slow orders presented in the DTOBOs restrict the line's ability to operate efficiently. For the purposes of this analysis the team received the DTOBO effective for April 20, 2018. While the analysis only includes a single bulletin, the average duration of the slow order is close to a year, making the information below a likely representation of what a "standard" set of slow orders looks like. The sheet provided accounted for slow orders across all Metro-North operated lines. The document reported 29 slow orders between the New Haven and Harlem Lines, with 28 of those on the New Haven Line. The average duration of slow orders at the time of analysis was approximately 348 days and the average slow order length just under one half mile. The impact of this is that authorized speeds over slow-ordered zones were reduced by an average of 41 percent, to a speed of approximately 37 MPH from an average authorized speed of 66 MPH.

For the next phase of the study, the team will review the areas identified with slower speeds against other information – including operational considerations, existing infrastructure including bridges, track geometry and right-of-way conditions – to determine if and what improvements may be gained.

Drainage: Proper drainage is critical for the effective operation of the rail line; poor drainage can lead to the destabilization of the rail bed, deterioration of ties and track, and damage to signals and switches.

In those areas where drainage is not adequate, water pools saturate the soil and create what are known as mud spots. While mud spots are often temporary and develop during extended wet periods, the impacts persist even after drying of the rail bed occurs.

These mud spots affect rail operation in two principal ways: first, they destabilize the rail bed, reducing allowable speeds; and second, they greatly reduce the life of the thousands of concrete ties, leading to increased maintenance costs. Complete tables regarding mud spot data are included in the appendix. The photo below shows the increased tie wear due to water. The water, in essence, creates a slurry with the surrounding soils and ballast and erodes the ties' surface as the soils and ballast vibrate with the passing of trains. Beyond eroding the tie surface, persistence of standing water can redistribute ballast leading to deformation of the rail profile in the form of sagging, protrusion, or lateral movement. This redistribution of ballast occurs when water, combined with the train wheels passing over the poorly drained area, pumps fine grain soils upward into the ballast. As a result of these fine-grained soils "fouling" upward into the ballast the strong interlocking state of the ballast is lost. Once the ballast loses its ability to be interlocked the track sags and experiences lateral movement as noted above.

Figure 11: Example of Fouled Ballast Resultant from Poor Track Drainage

Metro-North has surveyed mud spots on the New Haven, Hudson and Harlem Lines; this report only includes the New Haven Line and its three branch lines. The survey reports 95 locations between mile post (MP) 12 in New York and MP 73 in New Haven that caused significant deterioration of concrete ties. It is estimated that across these locations more than 5,700 ties will need to be replaced due to damage from mud spots. Through the spring of 2018, only 17 spots have been addressed.

1.3 Services and Equipment

Services: The Connecticut rail system employs an elaborate zone schedule in the delivery of its mainline and branch line services; this approach has created an efficient yet highly dense rail service due to heavy demand during peak hours. The services provided are reflective of the demands of the user groups, and therefore the type of service and the frequency of service to stations changes by direction, time of day and location along the line. Even with the sophisticated zone structure, however, the number of trains on the New Haven Line (NHL) is so great during peak hours that travel times are often adversely affected. Even though schedules are designed

to build in recovery time (to account for travel time delays), crowded stations – even for express trains – cause longer dwell times that impact the schedule. Essentially, the NHL can be characterized as operating at maximum capacity today during peak periods.

Along the New Haven Line, service is generally operated seven days a week and in excess of 20 hours a day. The AM inbound peak is from Train 1301 (departing Stamford at 4:42 AM) to Train 1841 (departing Danbury at 7:51 AM) inclusive (with Train 1841 arriving into Grand Central Terminal at 9:59 AM). The PM outbound peak is from Train 1542 (departing Grand Central Terminal at 4:02 PM) to Train 1382 (departing Grand Central Terminal at 7:40 PM) inclusive.[2] The three branch lines operate in coordination with the main line service to either facilitate connections or to provide limited through service to Grand Central Terminal (GCT). Of the three branch lines, the Waterbury Branch Line operates the most limited schedule, with no direct service to GCT. This is due to a lack of signalization, not having operational passing sidings, and limits to the train slots available within GCT.

Trip Frequency: Station stops do not receive an equal level of service, with service being allocated based on demand at each location. The greatest density of service along the New Haven Line occurs between Grand Central Terminal (GCT) and Stamford, where combined train densities (eastbound + westbound) are at or exceed 20 trains per hour during the peak commuting periods. For the peak hour and peak direction (8:00 AM-9:00 AM inbound and 5:00 PM-6:00 PM outbound) these volumes are even higher. However, east of Stamford, combined train volumes are significantly lower, generally at or around ten trains per hour. This is reflective of the reduced travel demand at these locations along the line. Average frequency for the AM peak hour (8:00 AM-9:00 AM) is depicted below; graphs and tables for other timeframes are available in the appendix.

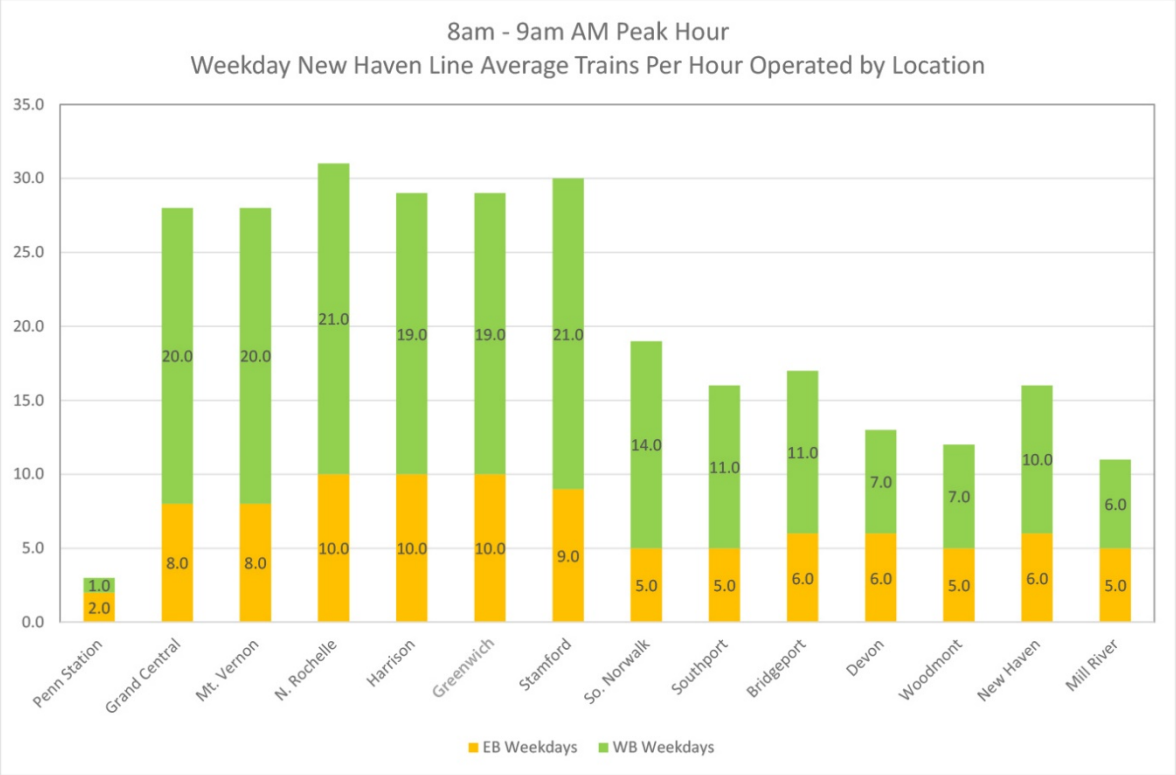


Figure 12: AM Peak Hour Average Trains per Hour by Station

[2] Note: "Inbound" refers to any train heading towards Grand Central Terminal (GCT) while "outbound" refers to any train heading away from GCT. This language also refers to any MNR Branch and the CT*rail* SLE and Hartford Line.

Of the New Haven Line stations, Stamford receives the greatest level of service, with an average of six-minute headways inbound during the four-hour period between 6:00 AM and 9:00 AM; equating to 39 trains departing during that period. Comparatively, stations both to the east and west have significantly longer headways and substantially fewer trains. Both New Haven Union Station and West Haven station record an average of 18-minute headways and just 13 trains departing over the same four-hour period. West of Stamford, Greenwich receives the highest level of service, averaging eleven-minute headways, with 21 trains departing during the same four-hour period. Headways and level of service for the four-hour outbound period between 4:00 PM and 8:00 PM generally mirror the four-hour inbound period, with the exception of marginally shorter headways and the addition of two trains servicing West Haven and New Haven Union Station. Service outside of these peak periods and peak directions is lower.

Trip Duration: Not accounting for slow orders or fluctuations in maximum authorized speeds, trip duration is controlled by the number of stops over a given segment and the time of day. However, despite variation in these variables throughout the day, the differences between the slowest and fastest trips are relatively minimal (except for Stamford, where the difference between the shortest and longest trip is around 30 minutes). During the morning peak period, service in general is more concentrated to the peak hour period, whereas service during the evening peak is extended over a longer period of time, reflecting a wider variance in return trips from Grand Central Terminal (GCT) during the evening. The table below depicts inbound trip duration from Connecticut New Haven Line stations.

Table 8: New Haven Line Trip Duration into GCT (in hours: minutes)

Time to GCT	New Haven, CT	West Haven, CT	Milford, CT	Stratford, CT	Bridgeport, CT	Fairfield Metro, CT	Fairfield, CT	Southport, CT	Green's Farms, CT	Westport, CT	East Norwalk, CT	South Norwalk, CT	Rowayton, CT	Darien, CT	Noroton Heights, CT	Stamford, CT	Old Greenwich, CT	Riverside, CT	Cos Cob, CT	Greenwich, CT
Best Time	1:47	1:42	1:33	1:27	1:20	1:15	1:11	1:16	1:12	1:07	1:04	1:01	1:03	0:59	0:56	0:49	0:55	0:52	0:49	0:44
Median Time	1:56	1:51	1:42	1:36	1:29	1:24	1:20	1:22	1:19	1:14	1:11	1:06	1:04	1:00	0:56	0:51	0:56	0:53	0:50	0:50
Longest Time	2:06	2:01	1:53	1:47	1:40	1:35	1:31	1:28	1:25	1:20	1:17	1:12	1:05	1:01	0:57	1:13	1:10	1:08	1:05	1:02

Equipment: The rail system utilizes two different trainset types: electric multiple-unit rail cars (EMUs) and locomotive-hauled coaches. The EMUs operate on the New Haven Line and the New Canaan Branch Line (the only electrified branch), while the locomotive-hauled coaches operate throughout the system, but exclusively on the Danbury and Waterbury Branch Lines, as well as on the CT*rail* Hartford Line and CT*rail* Shore Line East. On the NHL Mainline, coaches going into Grand Central Terminal (GCT) must be operated with dual-mode (diesel/electric) locomotives. A table depicting weekday equipment is provided. Please note that this is not a rolling stock roster.

Table 9: NHL Weekday Equipment Operated

Line	Number of Trainsets	Number of EMUs	Number of Locomotives	Number of Coaches
New Haven Line	41	326	0	0

1.4 Operating Costs and Revenue[3]

The New Haven Line: The New Haven Line (NHL) is operated and maintained by MNR – a public benefit corporation; the physical rail line and accompanying right-of-way in New York is owned by the State of New York; the Connecticut portion of the line is owned by the State of Connecticut. The Amended and Restated Service Agreement (ARSA) governs the rights and responsibilities of the Metropolitan Transportation Authority (MTA), MNR, and the Connecticut Department of Transportation (CTDOT) in funding and operating the NHL Mainline and branch line services. The three party's deficit-fund this Agreement between the States of Connecticut and New York based upon a 65 percent (Connecticut)/35 percent (New York) respective allocation that is ridership-based with respect to operating the mainline. Deficit funding reflects the notion that the rail line is not capable of sustaining itself though ticket sales alone. The revenues along the New Haven Line and its three branches from ticket sales are less than the costs to operate the rail line, meaning that it operates in deficit. The State of Connecticut and New York fund this gap to facilitate the continuation of service, and they do so at a level relative to the amount of service operated in each given jurisdiction. Connecticut contributes 65%, with New York contributing 35%; capital expenditures are funded in a similar manner. Because a majority of the New Haven Line and all three of its branches are within Connecticut, Connecticut funds a larger portion of the gap. The New Canaan, Danbury, and Waterbury Branch Line services are funded 100% by Connecticut.

Capital Funding and Other Expenditures: Capital funding for the rolling stock fleet is allocated in a similar manner to operational funding on the New Haven Line at a 65 percent (Connecticut)/35 percent (New York) split, as are all other movable assets. Non-movable assets such as stations and facilities are capital-funded according to the state in which they are located, while administrative assets are allocated to Connecticut according to the New Haven Line operating cost share of the MNR system. This includes the Harlem and Hudson Lines as well the New Haven Line and its three branches.

Grand Central Terminal (GCT): GCT costs are paid by Connecticut as a fixed fee, while other costs such as operational expenses and third rail power on the Harlem and Hudson Lines leading into GCT are borne by the New Haven Line (i.e., at the 65 percent Connecticut/35 percent New York split) and allocated according to car-mile usage.

MNR and CTDOT may separately set fares for their territory, but they must be approved by the other party and an allowance for a "fare differential" is made if the mainline fare structure is out of alignment. Revenues deducted from expenses result in the deficit; the NHL deficit-model is calculated using 21 allocators and is paid monthly using a two-month prior adjusted advance, and annually reconciled by means of a "Thirteenth Bill".

Operational Terms: The New Haven Line calendar year budget cycle begins with an August formulation that is then presented in October to CTDOT, and in December CTDOT and MNR/MTA approval process occurs. In the event of a dispute, MNR is permitted to enact the prior years' charges subject to certain allowable cost inflation;

[3] The information contained within this section is representative, derived from publicly available sources and subject to further validation.

this action is only in effect until a permanent resolution is enacted. Changes in the budget are chiefly driven by service changes, equipment acquisition/fleet growth, and labor and materials inflation.

Three-year NHL Retrospective: Between state fiscal years 2016-2017 expenses grew 5.8%, while revenues grew only 2%; the result of this is that the deficit and CTDOT subsidy grew 15%. The largest increase in cost was for operating and maintenance, equaling $13.8 million; this increase was largely due to an increase in fleet size and an expansion of services. Administrative assets grew by $11.2 million. The largest increase in non-operating cost was post-employment benefits ($10.8 million). Over a 20-year period, the NHL CTDOT subsidy payment has risen at an average rate of less than 7% per year. Annual operating costs for 2017 were $177.6 million.

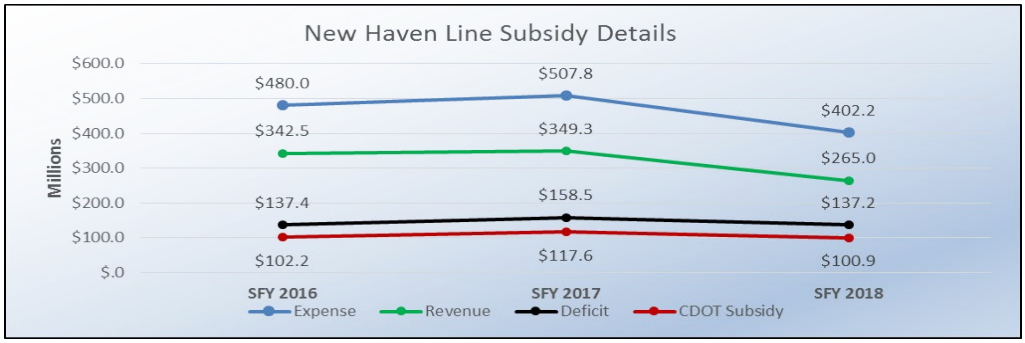


Figure 13: New Haven Subsidy Three Year Retrospective

Part 2: Branch Lines and CT*rail* Lines

The following pages will address the New Haven Line's three branches (New Canaan, Danbury, and Waterbury), as well as Shore Line East service between New Haven and New London, and Hartford Line service between New Haven and Springfield. These efforts will set the framework for how to improve the Connecticut rail system. The New York portion of the NHL will not be detailed further.

2.1 Overview of the Connecticut Branch Lines and CT*rail* Lines

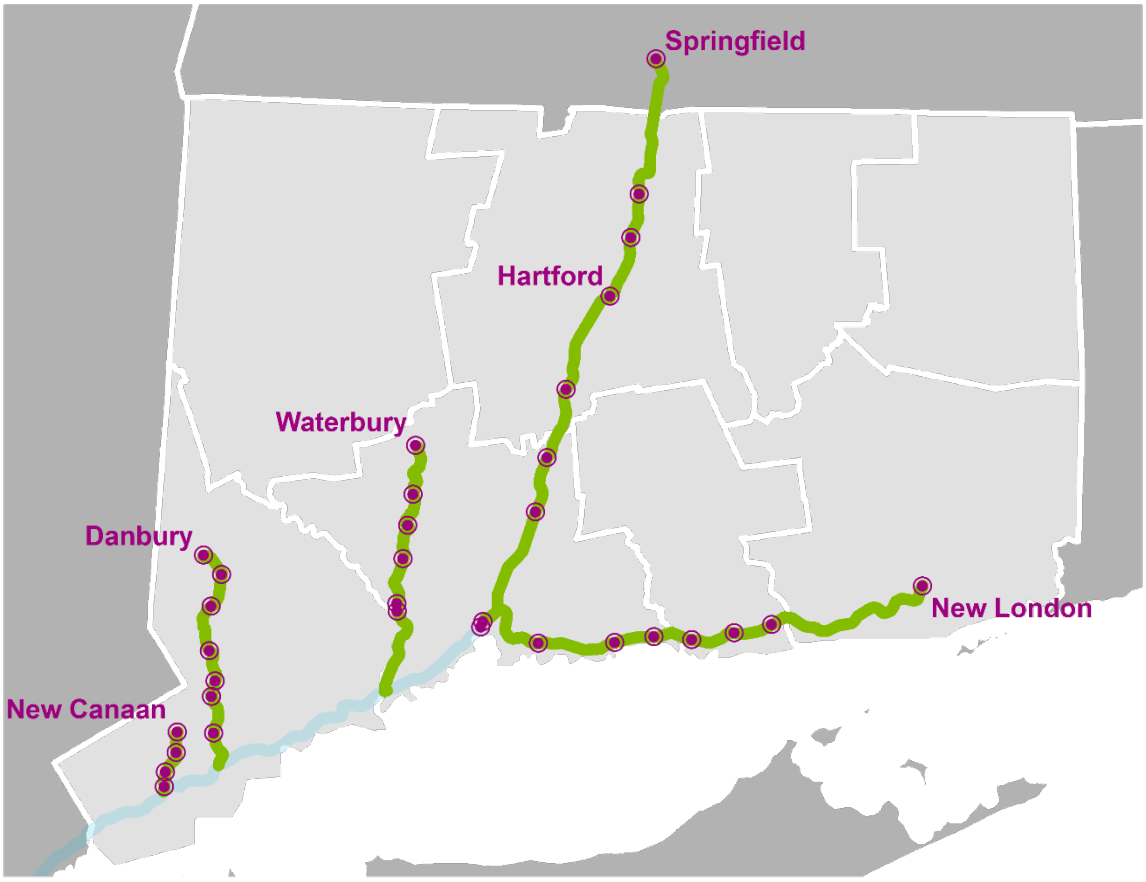


Figure 14: Map of Branch Lines and CT*rail* Lines

The New Haven Line (NHL) operates as the primary artery for the Connecticut rail system between New Haven, Connecticut and Grand Central Terminal (GCT) in New York City. It is the branch lines and the CT*rail* service that connect interior portions of the state to the NHL, and riders between New Haven and Springfield, and New Haven and New London. This additional service specifically consists of three MNR operated branch lines – the New Canaan Branch Line (NCL), the Danbury Branch Line (DBL), and the Waterbury Branch Line (WBL); and two additional CT*rail* commuter lines – Shore Line East (operated by Amtrak) and the Hartford Line (operated by Amtrak and Transit America Services). Additional interstate service is operated by Amtrak along the Northeast Corridor (NEC) and along what is now the Hartford Line. Neither of these interstate services are subsidized by Connecticut and will not be detailed in this report.

A summary of the routes in the Connecticut passenger rail system is shown below; the station counts for the Branch Lines and the CT*rail* Lines do not include stations already counted as part of the New Haven Line.

Table 10: Summary of Non-NHL Passenger Service in Connecticut

	Length (miles)	Number of Stations	Start-End	Primary Equipment Operated	Number of Tracks
Branch Lines					
New Canaan Branch Line	7.9	4	Stamford-New Canaan	Electric	1
Danbury Branch Line	24.2	7	South Norwalk-Danbury	Diesel	1
Waterbury Branch Line	27.1	6	Bridgeport-Waterbury	Diesel	1
CT*rail* Lines					
Shore Line East	49.8	7	New Haven-New London	Diesel	2
Hartford Line	62	7	New Haven-Springfield	Diesel	2

Annotated Track Map

An Annotated Track Map (ATM) was developed for each of the three branch lines (NCL, DBL, and WBL) and the two CT*rail* Lines (SLE and Hartford Line). The ATM is a linear representation of the NHL and its infrastructure, with additional annotations addressing specific infrastructure and concerns. The map was developed to address the complexity of the systems' existing conditions, and how those conditions relate to the limitations and capabilities of the Branch and CT*rail* lines. While the ATM is a graphic representation of the rail system, infrastructure locations displayed on the ATM are spatially accurate and scaled throughout the system. Using a graphic interface provides a tool to visualize multiple complex systems while also conveying their relationship to other infrastructure within the system. This becomes apparent when identifying 'hotspots' and trends for delays (slow orders3), state of good repair issues, or where multiple concerns compound.

The following pages will present each ATM by Line. The ATM will be updated annually to reflect changes in operating conditions.

The ATM addresses system infrastructure, limitations and concerns, and operational factors to build a high level of understanding of the rail system. The subsequent pages of this report will detail the implications of infrastructure limitations (by category) identified within the ATM. Specific aspects identified within the ATM include:

Infrastructure:

- Tracks and track location
- Stations and Platforms
- Bridges (open-deck; ballasted; movable)
- Control Points (CPs)

Limitations and Concerns:

- Mud Spots (i.e. drainage concerns)
- Slow Orders
- Poorly or Seriously Rated Bridges (NBI-67 Structural Rating)

Operational Factors:

- Maximum authorized speed (MAS) by track
- Curves (including speed through curves)
- Storage and Maintenance Facilities (excluding New Haven)

Figure 15: New Canaan Branch Line Track Map

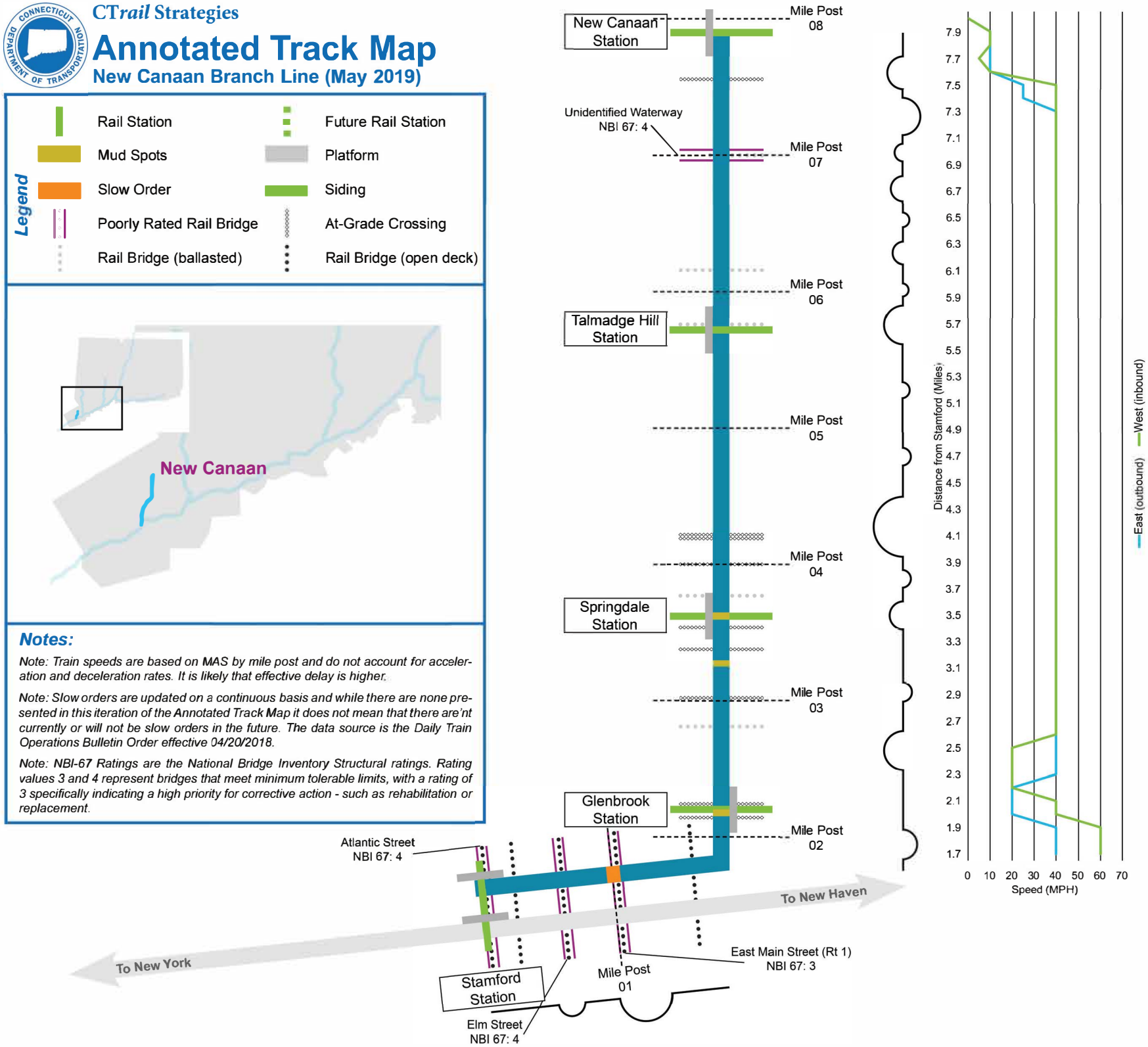


Figure 16: Danbury Branch Line Track Map

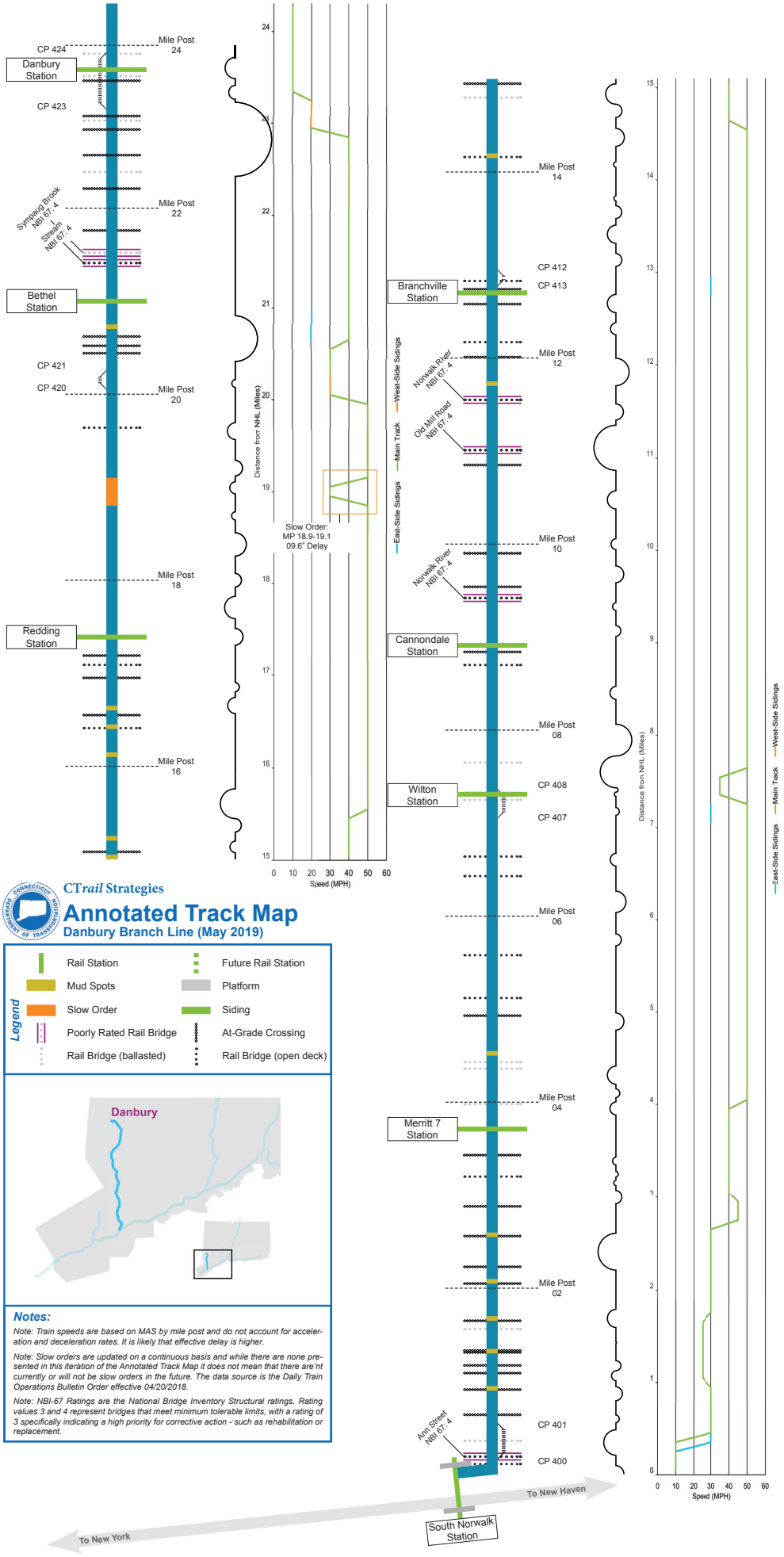


Figure 17: Waterbury Branch Line Track Map

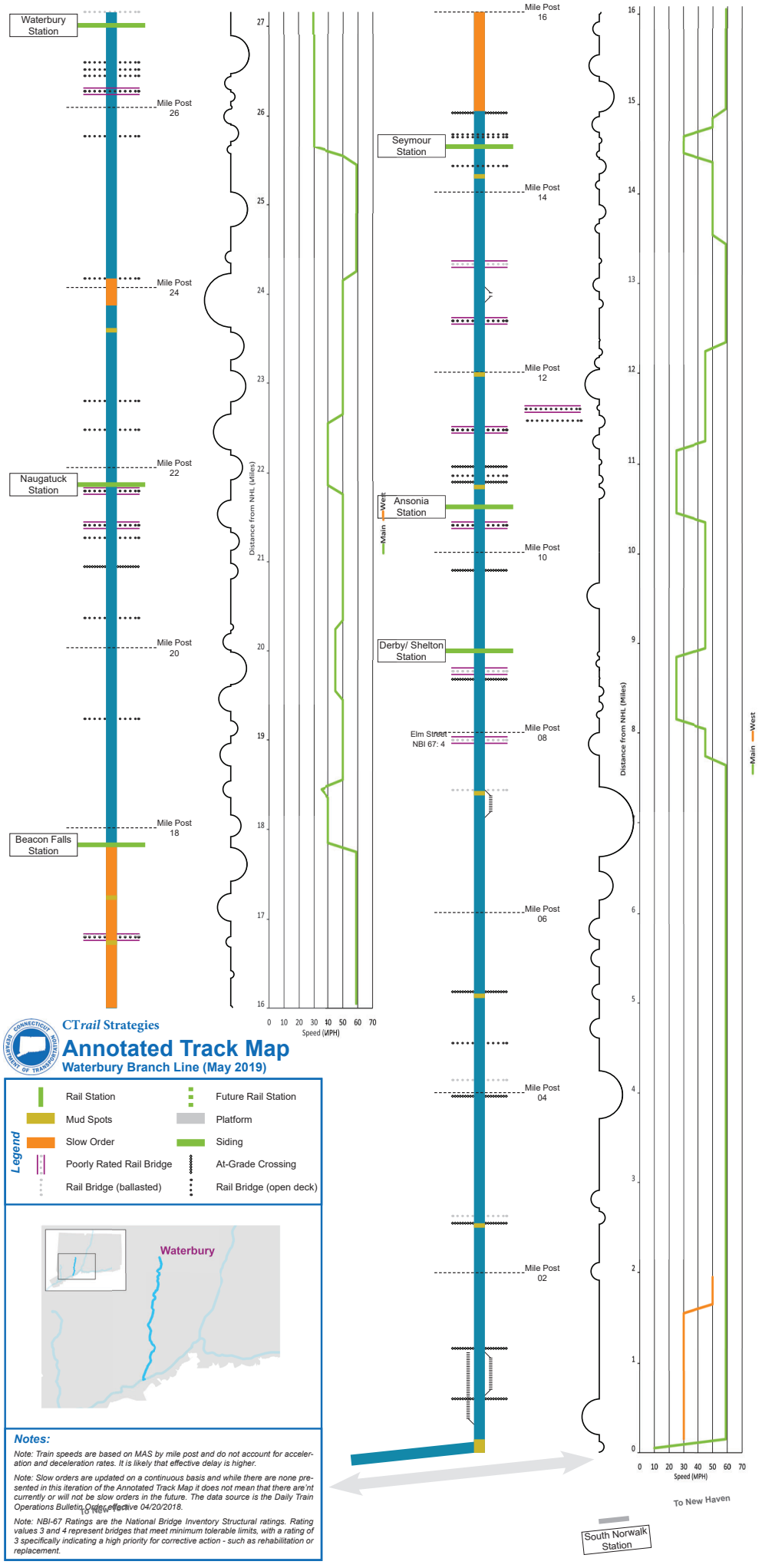


Figure 18: Hartford Line Track Map MP 2 - MP 26

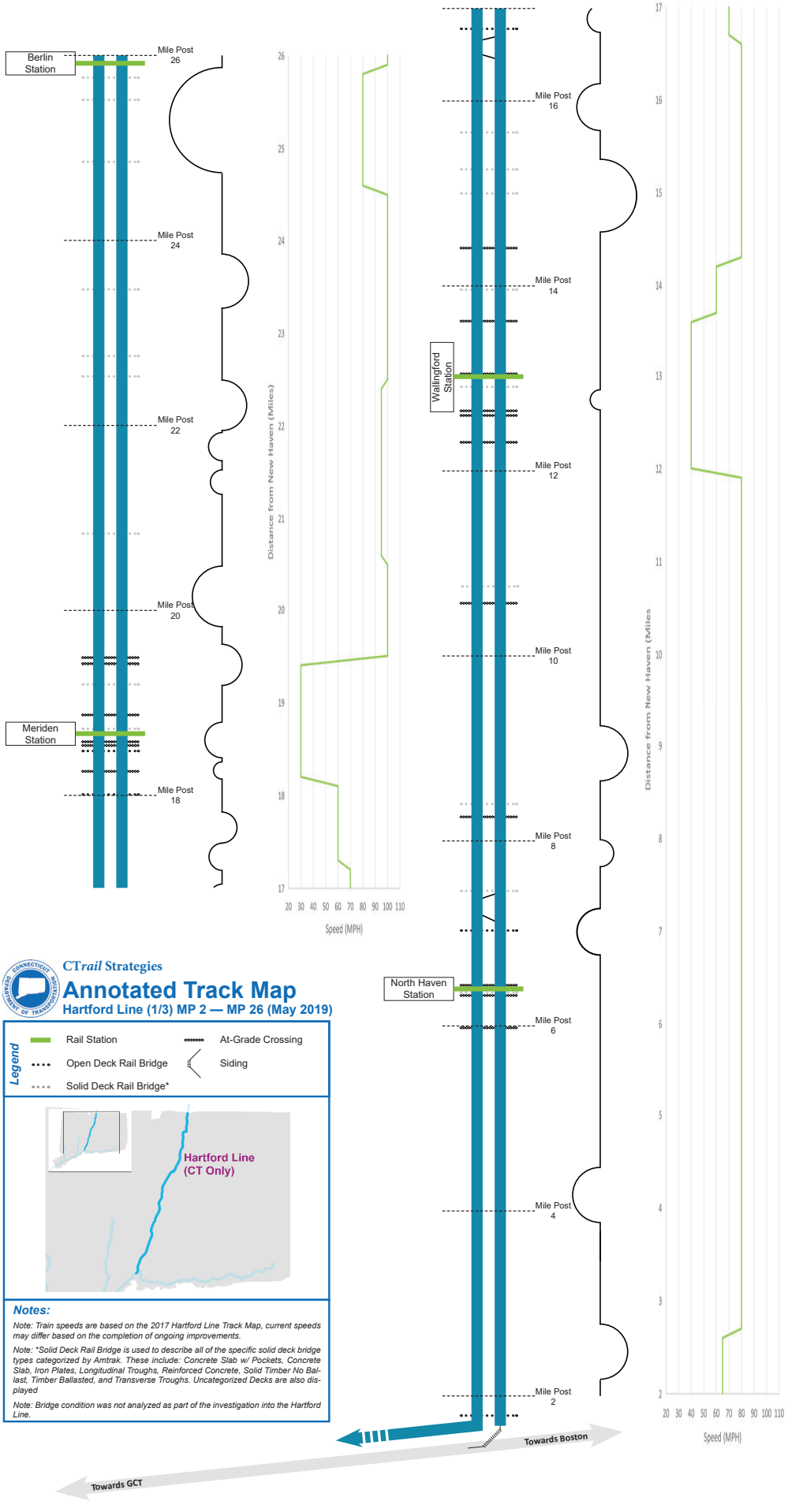


Figure 19: Hartford Line Track Map MP 26 - MP 50

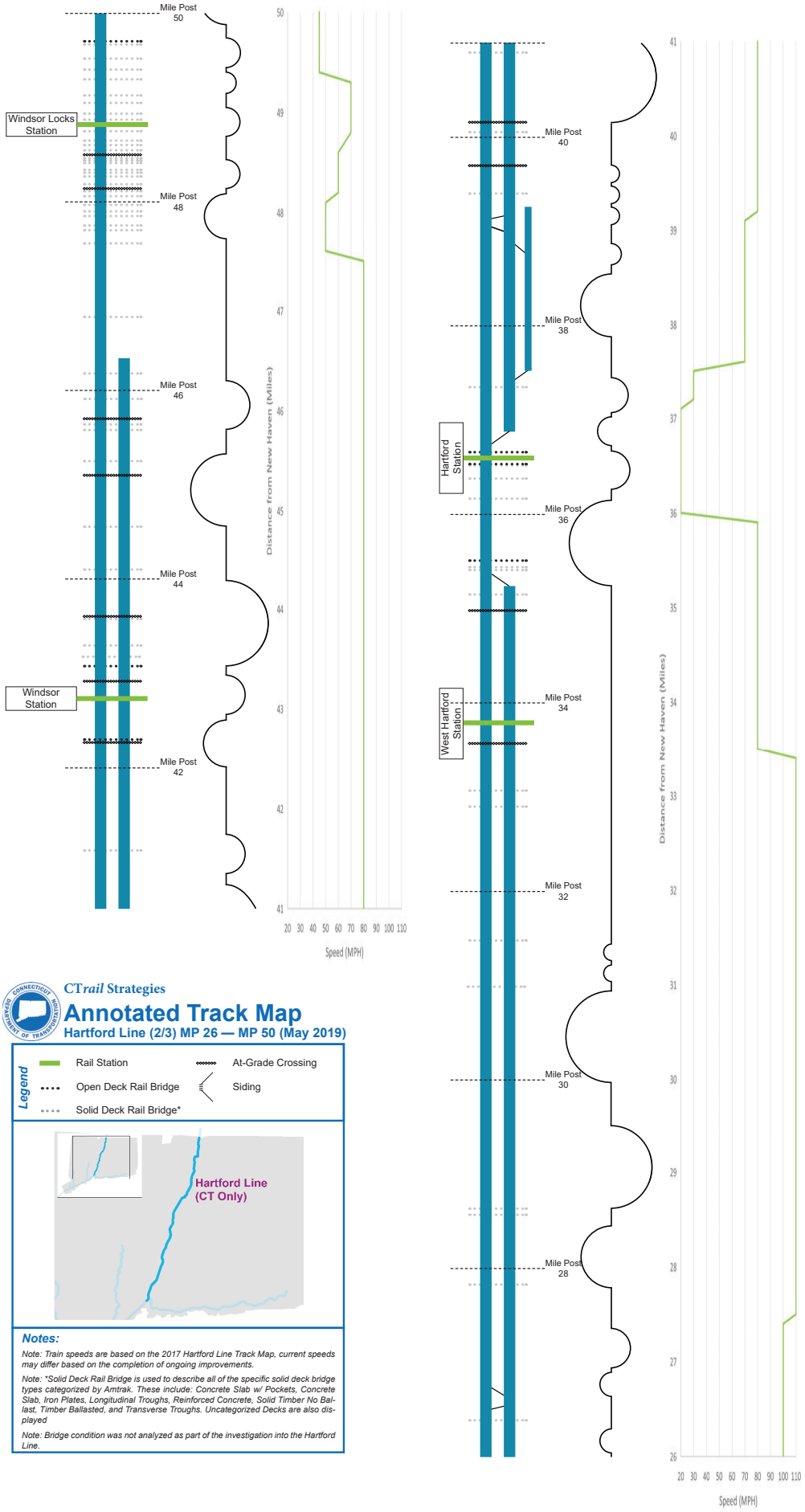


Figure 20: Hartford Line Track Map MP 50 - MP 56

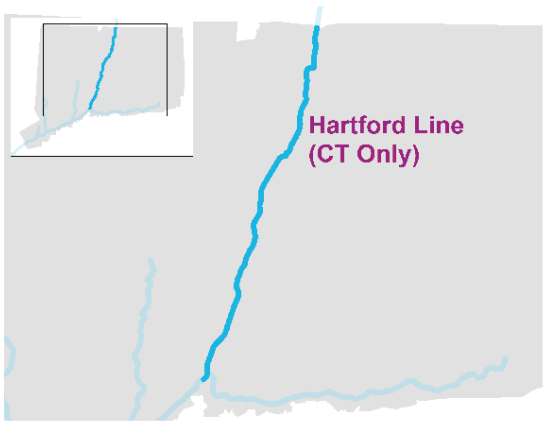
CT*rail* Strategies

Annotated Track Map

Hartford Line (3/3) MP 50 — MP 56 (May 2019)

Legend

- Rail Station
- Open Deck Rail Bridge
- Solid Deck Rail Bridge*
- At-Grade Crossing
- Siding



Notes:

Note: Train speeds are based on the 2017 Hartford Line Track Map, current speeds may differ based on the completion of ongoing improvements.

*Note: *Solid Deck Rail Bridge is used to describe all of the specific solid deck bridge types categorized by Amtrak. These include: Concrete Slab w/ Pockets, Concrete Slab, Iron Plates, Longitudinal Troughs, Reinforced Concrete, Solid Timber No Ballast, Timber Ballasted, and Transverse Troughs. Uncategorized Decks are also displayed*

Note: Bridge condition was not analyzed as part of the investigation into the Hartford Line.

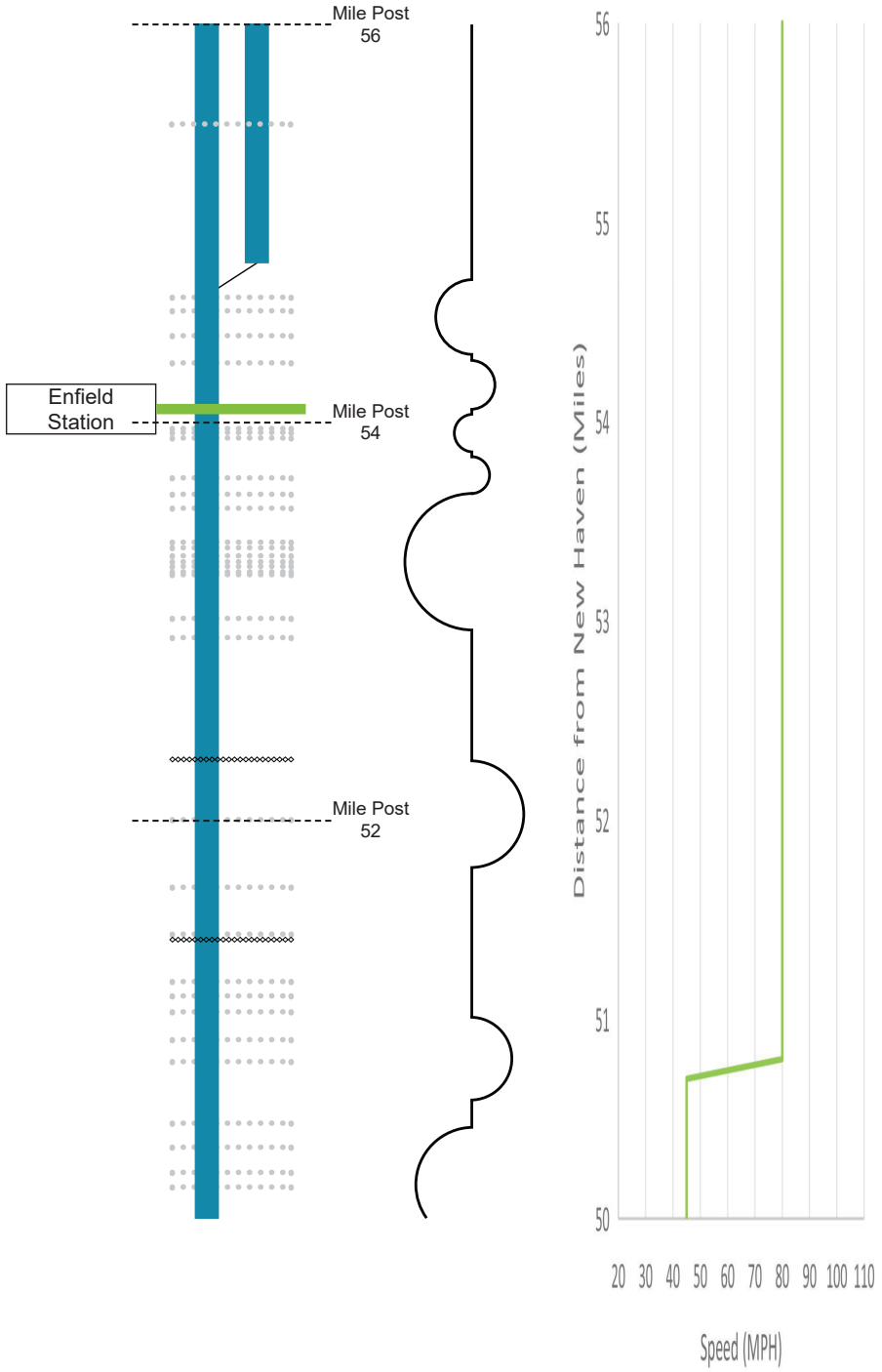


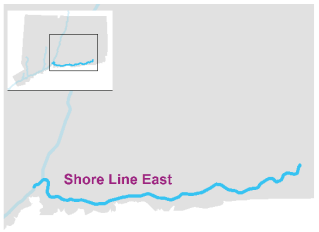
Figure 21: Shore Line East MP 73 - MP 98

CT*rail* Strategies

Annotated Track Map

Shore Line East (1/2) MP 73 — MP 98
December 2020

- Rail Station
- Open Deck Rail Bridge
- Solid Deck Rail Bridge*
- Siding
- At-Grade Crossing



Notes:

Note: Train speeds reflect Amtrak operational speeds for Train Type "C" speed equipment, which Shoreline East operates.

**Solid Deck Rail Bridge is used to describe all of the specific solid deck bridge types categorized by Amtrak. These include: Concrete Slab w/ Pockets, Concrete Slab, Iron Plates, Longitudinal Troughs, Reinforced Concrete, Solid Timber No Ballast, Timber Ballasted, and Transverse Troughs. Uncategorized Decks are also displayed with this symbology.*

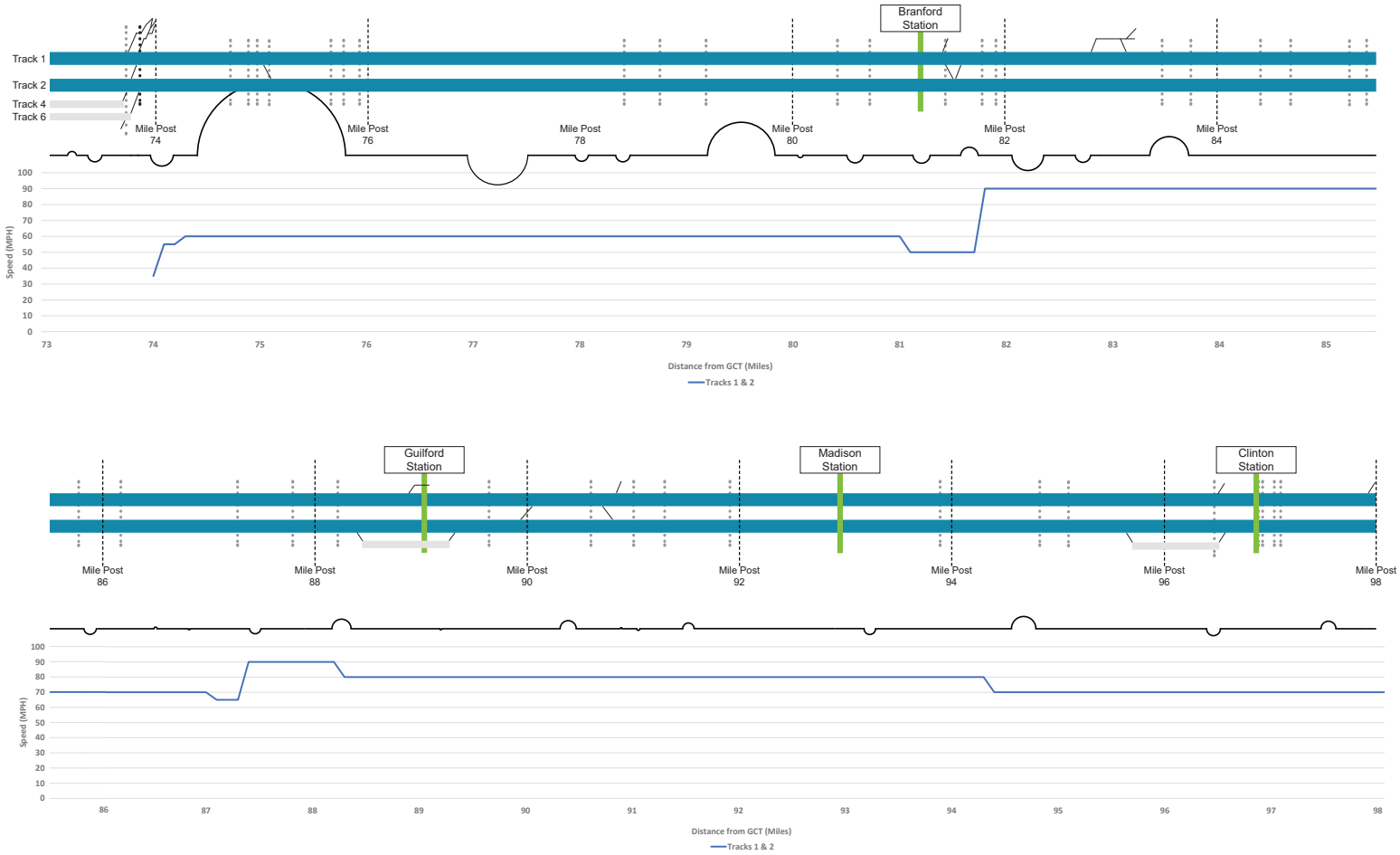


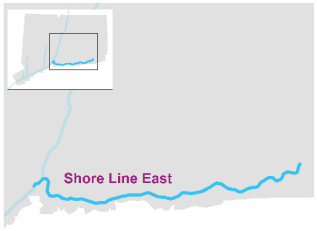
Figure 22: Shore Line East Track Map MP 98 - MP 123

CTrail Strategies

Annotated Track Map

Shore Line East (2/2) MP 98 — MP 123
December 2020

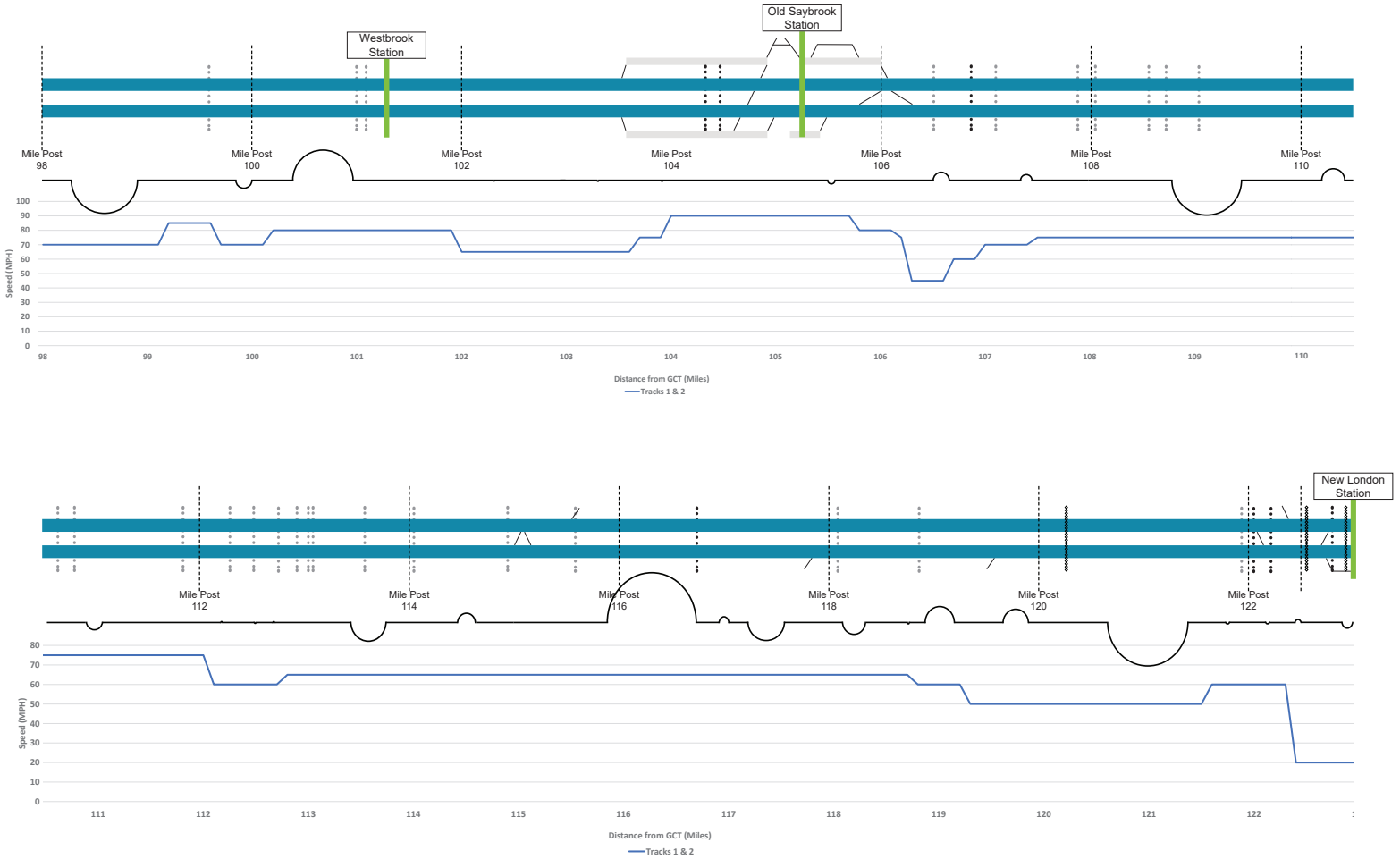
- Rail Station
- Open Deck Rail Bridge
- Solid Deck Rail Bridge*
- Siding
- At-Grade Crossing



Notes:

Note: Train speeds reflect Amtrak operational speeds for Train Type "C" speed equipment, which Shoreline East operates.

**Solid Deck Rail Bridge is used to describe all of the specific solid deck bridge types categorized by Amtrak. These include: Concrete Slab w/ Pockets, Concrete Slab, Iron Plates, Longitudinal Troughs, Reinforced Concrete, Solid Timber No Ballast, Timber Ballasted, and Transverse Troughs. Uncategorized Decks are also displayed with this symbology.*



2.2 Capabilities and Limitations of the Branch Lines and the CT*rail* System

Capabilities

With the addition of the new Hartford Line, which bisects the state, a larger portion of Connecticut residents now have access to a commuter rail line. The three branch lines – the New Canaan Branch Line (NCL), Danbury Branch Line (DBL) and Waterbury Branch Line (WBL) – provide service from Connecticut's interior to the New Haven Line and the markets it serves. Similarly, Shore Line East and the Hartford Line provide service to the New Haven Line, with Shore Line East serving coastal Connecticut and the Hartford Line serving the central valley along the I-91 corridor. These five rail lines broaden the service area of the Connecticut rail system and increase the effectiveness for Connecticut residents, its greatest capability is the reach that the system conveys.

Limitations

With the exception of the Hartford Line, many components along the Branch Lines and Shore Line East such as bridges, the equipment operated, and signals are in need of refurbishment or updating. To varying extents these factors, limit operating speeds and service density. Both the DBL and WBL generally rely on a limited and aging diesel-hauled fleet, however the DBL does operate dual-mode locomotives for limited through service into GCT[4]. All three of the branch lines are limited by the fact that they operate over a single track. Single track systems, even those that are signalized and have passing sidings, are ultimately limited in the frequency of service that they can deliver. The branch lines are generally not operating at capacity, and long-term growth is constrained by track limitations and equipment availability. The NCL is the only electrified branch line and is therefore able to operate M8 electric multiple unit (EMU) cars, which more readily allows for through service into GCT. The two CT*rail* lines, the Hartford Line and Shore Line East, operate diesel hauled fleets similar to that of the DBL and WBL and operate over Amtrak controlled territory which could limit future service expansions.

Connecticut Branch Lines (NCL, DBL & WBL)

Table 11: AM Peak Period Branch Line Trains

Branch Line	Through Trains to GCT	Connecting Trains
New Canaan Branch Line	5	All through Trains
Danbury Branch Line	4	1
Waterbury Branch Line	0	2

Table 12: Weekday Branch Line Ridership

Branch Line	Weekday Ridership
New Canaan Branch Line	2,450
Danbury Branch Line	1,245
Waterbury Branch Line	564

[4] A dual-mode locomotive is a locomotive that can operate under power of an electric motor and a conventional diesel engine. A dual-mode locomotive is required for service into GCT following a crash in the Park Avenue Tunnel in 1902 steam engines and later diesel locomotives were barred from operated in the tunnel. The ban remains in place for air quality and visibility concerns.

Travel Characteristics of the Branch Lines

Service along the New Haven Line (NHL) is formed by a complex set of train stopping patterns and schedules. They have been established to provide both travel opportunities to/from Grand Central Terminal (GCT) and to provide reasonable travel options to/from intermediate stations and destinations. Schedules have been constructed around a "Zone Schedule" strategy which can offer travel time and seat availability benefits compared to other scheduling strategies. The three MNR-operated branches follow this travel pattern and use zone scheduling integrated with NHL Mainline scheduling. Both the NCL and DBL provide one-seat rides into GCT, and the WBL runs limited through service to Stamford.

New Canaan Branch Line (NCL)

The NCL is the furthest west and shortest of the three branch lines, with a length of less than 10 miles. The NCL is the only branch line that is electrified and therefore operates M8 trainsets from the branch line directly into GCT. All five of the AM peak period inbound trips are through trains to GCT; connecting trains are only operated during off-peak times.

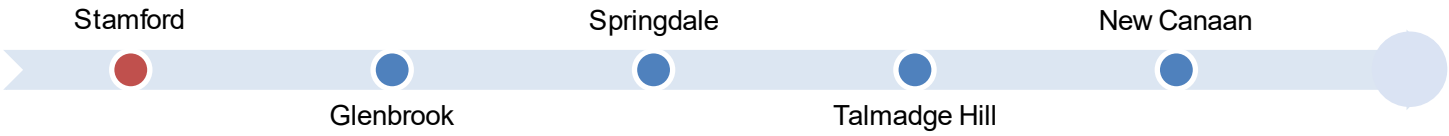


Figure 23: NCL Station Stops and Connecting Station

Capabilities:

The NCL is the furthest west and shortest of the three branch lines, with a length of less than 10 miles. The NCL is the only branch line that is electrified and therefore operates M8 EMU trainsets from the branch line directly into GCT. All five of the AM peak period inbound trips are through trains to GCT; connecting trains are only operated during off-peak times. The electrified nature of this line facilitates seamless one-seat ride with NHL Mainline service into and from GCT.

Limitations:

Being such a short line, with four stops and 11 at-grade crossings across less than 10 miles, train speeds are limited along the NCL. The maximum allowable speed on the NCL is 60mph, however this speed is allowed for just 30% of the line, while the remainder of the line is limited to 40mph. Similar to the other two MNR branch lines, the NCL operates as a single track system, and also operates with no passing sidings. Into and out of Stamford, the NCL operates on track five of the NHL. With that being said, NCL trains merge with the main line east of Stamford, where capacity is already constrained during peak hours.

Bridges and At-Grade Crossings:

There are two overhead bridges (OH) and 10 Under-Grade bridges (UG) along the NCL. The two OH bridges occur where I-95 crosses over Track 5 of the NHL prior to the NCL turning north off from the NHL[5]. None of the UG bridges on the single-track alignment are considered to be in poor condition (NBI-67 4 or 3). However, several bridges between the Stamford Station and the single-track alignment of the NCL are in poor condition, these bridges are accounted for in the NHL Existing Conditions report.

Unlike the NHL, the NCL has 11 at-grade crossings, an at-grade crossing is a location where the rail line crosses a road at grade with the roadway, meaning that there is no separation between rail and vehicle traffic. All at-grade

[5] The NCL operates on about 1.7 miles of Track 5 on the NHL

crossings are protected with gates except for one private crossing (4 of the 11 at-grade crossings are privately held).

Catenary and Traction Power:

Because the NCL runs through trains from the NHL Mainline, the line operates the same 125 Kilovolt (KV) catenary as the NHL Mainline. This means that NCL passengers are able to take a one-seat trip from the branch line all the way to GCT.

Track and Track Geometry:

Covering just under eight miles, the New Canaan Line (NCL) begins at the Stamford station stop, operating on Track 5 of the NHL for a little under two miles, the single-track alignment of the NCL begins at about MP 74.7 on the New Haven Line (NHL) and curves north halfway between Stamford and Noroton Heights. It is the shortest of all the MNR branch lines and the only one that is electrified, its single track is maintained FRA Class 3 standards, meaning that the line has a theoretical maximum allowable speed of 60mph. However, the NCL has an average speed of 40mph, and a maximum allowable speed (MAS) of 60mph, which occurs for 0.04 miles just before the NCL splits from the NHL. After the split, trains slow down considerably as they approach the high density of stations and at-grade crossings along the line.

Stations and Platforms:

There are five station stops on the NCL starting with Stamford Station and ending at New Canaan Station, all stations have high level platforms with a minimum length of 300 feet at Talmadge Hill Station, and maximum length of 450 feet at New Canaan Station. Parking utilization along the NCL is between 82 to 88 percent of capacity.[6] An ongoing Western Connecticut Council of Governments (WestCOG) parking study will be able to provide further details on parking trends in and around the branch line. New Canaan stands out as a branch station with low train frequency but a significant market share of ridership, parking, and parking revenue. This may be due to the station's location at the end of the branch.

Table 13: NCL Station and Platform Summary

Station	Capacity	# Permit Spaces	# Daily Spaces	# Accessible Spaces	Annual Permit Fee	Monthly Parking Fee	Daily Parking Fee
Glenbrook	156	63	90	3	N/A	$50-$98	$4
Springdale	211	149	56	6	N/A	$50-$98	$4
Talmadge Hill	368	270	96	2	$465	N/A	$5
New Canaan	570	418	146	6	$612	N/A	$5

Signals and Communications:

Much of the existing equipment on the NHL and its branch lines dated to the mid 1950's reached the end of their useful life, requiring replacement of the wayside signal enclosures (houses and cases), signal relays and controls, control panels, cables, switch machines and signals. The outdated wayside signal system for the New Canaan Branch Line has since been replaced. Positive Train Control (PTC) was a mandated improvement by the FRA, however the system missed the deadline and applied for a two-year extension to 2020 which Congress approved.

[6] A 2019 WestCOG Parking Study can provide additional detail on parking capacity and limitations along the NHL

Rail Yard[s] Storage:

The NCL is the only branch line that is electrified and therefore operates M8 trainsets from New Canaan Station directly into GCT. The NCL has storage at New Canaan station, where three tracks at the station fan out from the single-track main line entering the station. These tracks can store a total of 24 cars. Because the NCL operates between Stamford and New Canaan, complex deadhead movements are not required.

Slow Orders:

There are currently no slow orders in place on the NCL. However, this does not preclude the possibility of future slow orders.

Drainage:

While drainage is a concern for any rail line, the 2018 Mud Spot Analysis report only indicated one location along the NCL where drainage issues were causing water to accumulate, creating a mud spot.

Danbury Branch Line (DBL)[7]

The DBL is approximately 24 miles in length and extends from South Norwalk to Danbury. It provides shuttle style service as well as operating four direct through trains to GCT, using a dual-mode locomotive[8] during the AM peak period. The branch line is currently not electrified and has only recently been signalized. The highest ridership on the branch is during the AM peak period and particularly on its four through trains.

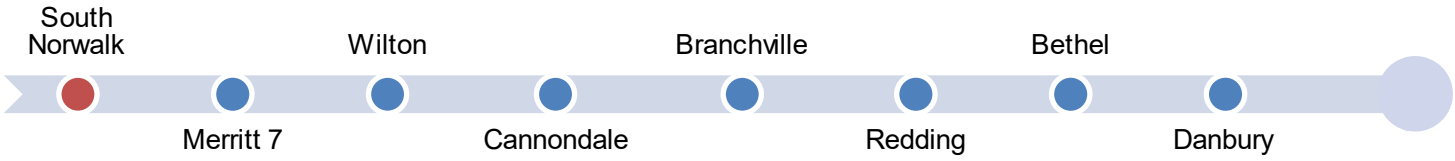


Figure 24: DBL Station Stops and Connecting Station

Capabilities:

The Danbury Branch Line (DBL) benefits from the operation of dual-mode locomotives which allow for some one seat rides into and from GCT during peak periods. These through trains into GCT during the AM peak period have the highest ridership, although many of the trips are generated by riders boarding from NHL Mainline stations.

Improvements to the signalization and Centralized Train Control (CTC) have allowed CTDOT to add service to the Danbury Branch Line. Six weekday trips were added, three are inbound to Grand Central Terminal (GCT) and three are outbound, bringing the total number of trips a day up to 26. The increased service expanded total service hours and added two through trains, one outbound in the AM and one outbound in the PM to/from GCT.

Limitations:

As with all the MNR branch lines, the DBL is limited by its single-track configuration and need for passing sidings to facilitate higher trains frequencies. The DBL currently has five passing sidings, including one into and out of Danbury Station. A 2018 report submitted to the Connecticut State Legislature outlined that the implementation of a Merritt 7 Shuttle Service would require the construction of an additional passing siding in the vicinity of the Merritt 7 Station. It is likely that other forms of service expansion or modification would require similar infrastructure improvements. The report further outlined that expansion of service would likely require the

[7] A Danbury Branch Line Evaluation Summary Report was submitted to the state legislature in 2018 and provides greater detail about proposed improvements.
[8] Dual-Mode Locomotive refers to a locomotive that can operate using either diesel power or electric third rail.

purchase of additional equipment, as the existing rolling stock is not sufficient to serve a further augmented schedule.

Bridges and At-Grade Crossings:

There are 19 Over-Head (OH) and 24 Under-grade (UG) bridges on the DBL, of the UG bridges six of them are considered to be in poor condition (NBI 3 or 4). The condition of these bridges does not currently appear to be affecting railroad operations, however only 10 bridges have been rehabilitated since their construction (many bridges date to the first half of the twentieth century and several to the 1890's).[9]

There are 34 at-grade crossings along the DBL. Several of the at-grade crossings are either for commercial property access or other private uses. At-grade crossings were upgraded in conjunction with the new signal system to ensure reliable operation of the signals and to improve safety. New gates were installed at the following at-grade crossings: Jennings Road, Norwalk; Cross Street, Norwalk; Portland Road, Ridgefield; Depot Road, Ridgefield; and Long Ridge Road, Redding.

Catenary and Traction Power:

This branch line is not electrified and currently operates a combination of diesel hauled and dual mode consists. This branch was electrified from 1925 to 1961 when the service was switched to diesel. Recent reports have investigated re-electrifying the line, however these efforts were found to be cost prohibitive when compared with the system's ridership. Current plans are to improve infrastructure and expand the existing push-pull fleet.

The southern portion of the rail line, where it connects to the NHL is currently under construction. Although electrification of the entire line is cost-prohibitive, the Danbury Branch Dockyard Project consists of electrifying approximately one mile of the DBL between Washington Street and the railroad crossing at Jennings Place, among other rail improvements. The project is occurring in conjunction with the reconstruction of the Walk Bridge.

Track and Track Geometry:

This branch consists of 24 miles of single track between Danbury and South Norwalk. This line runs at an average speed of 35 mph and ranges from a low of 10 mph to a maximum speed of 50 mph. The branch line runs at its lowest speed, 10mph, at the DBL/NHL split and near its arrival at the Danbury Station. It reaches its highest speed of 50 mph from MP 4.0 to 7.3, 7.6 to 14.5, and 15.6 to 20.0. The branch line operates at lower speeds through tunnels and at the multiple at-grade crossings.

Stations and Platforms:

All stations on the DBL have high level platforms except for Merritt 7; however, plans are in place to replace Merritt 7 with a 510-foot-long high-level platform. Beyond Merritt 7, many of the stations have received upgrades or renovations since the early 2000's. On the DBL, parking utilization is at 81% and the total parking capacity for this branch is 989 spaces. Many of the stations offer free parking and have available spots.

[9] Complete inventory of bridges and bridge conditions are included in the appendices of this document.

Table 14: DBL Station and Platform Summary

Station	Capacity	# Permit Spaces	# Daily Spaces	# Accessible Spaces	Annual Permit Fee	Monthly Parking Fee	Daily Parking Fee
Merritt 7	88	86	0	2	$150	N/A	$5.00/day
Wilton	251	0	240	11	$150	N/A	N/A
Cannondale	140	138	0	2	$0	N/A	N/A
Branchville	168	166	0	2	$250	N/A	$5.00/day
West Redding	82	65	13	4	$250	N/A	$6.00/day
Bethel	197	165	26	6	$250	N/A	$0.25/hr
Danbury	147	129	12	5	$250	N/A	$1.50/hr

Signals and Communications:

Much of the existing equipment on the NHL and its branch lines dated to the mid 1950's reached the end of their useful life, requiring replacement of the wayside signal enclosures (houses and cases), signal relays and controls, control panels, cables, switch machines and signals. The DBL has recently been signalized and Positive Train Control (PTC) for the line was completed in August 2019. Metro-North anticipates having Positive Train Control operational across its entire territory by the third quarter of 2020.

Rail Yard[s] Storage:

The DBL has on branch storage, a small rail yard in Danbury adjacent to the station which currently serves as storage for DBL equipment. There are 38 spaces to hold the 31 coaches and five locomotives, resulting in a surplus of 2 spaces. This indicates that space to absorb additional equipment is limited. The feasibility of expanding the yard capacity at Danbury is being investigated as part of the broader CT*rail* Strategies project.

Slow Orders:

A previous Daily Train Operations Bulletin Order (DTOBO) from April 20th, 2018 showed a single slow order along the Danbury Branch Line from mile post 18.9 to 19.1, covering 0.2 miles. Trains were required to reduce their speed by 40% along that section of track, slowing down to 30 MPH from a maximum allowable speed (MAS) of 50 MPH. The slow order has since been rehabbed as it does not show up on the November 28th, 2018 DTOBO.

Drainage:

Thirteen mud spots were identified by the 2018 Mud Spot Analysis Report on the DBL. The distribution of the mud spots along the line is not equal and there are several areas of higher density, the first between MP 1 and MP 2 and the second between MP 15 and MP 17. Additionally, in 2011 a section of track between Bethel and Redding lost its underpinning following a heavy rain event and subsequent flooding. Earth and rock were washed away removing the rail bed and leaving a 150-foot section of track suspended 20 feet in the air.

Figure 25: 2011 DBL Washout

Waterbury Branch Line (WBL)

The WBL is the furthest east of the three NHL branch lines and connects to the New Haven Line Mainline at the Devon Wye in Stratford. The primary transfer point for the 27.1-mile line is at Bridgeport; however, there is limited service to Stratford and Stamford. There are no through trains into GCT. The branch line is currently not signalized and has no active passing sidings, making the full extent of the branch line "dark territory". Dark territory is commonly defined as a rail line that does not have a signal system. Metro-North has further interpreted this type of operation to restrict service on the Branch (Manual Block). One train can follow another but only after they report clear of the block. Operationally, there are two deadhead trains sent up to Waterbury from Stamford Yard each morning. The first train leaves Waterbury and must clear the block at the wye at the Housatonic River just south of Derby Station before the second train can enter the Branch. Therefore, regardless of equipment limitations, the density of service on the branch is limited and will remain in this condition until a new signal system is installed. It is important to note that a new signal system and additional passing sidings have been designed for the WBL, and construction funds allocated for the entire project; this is expected to be implemented by the end of 2020 and will positively impact the branch line and improve service options, though it is not a panacea for single track operations.

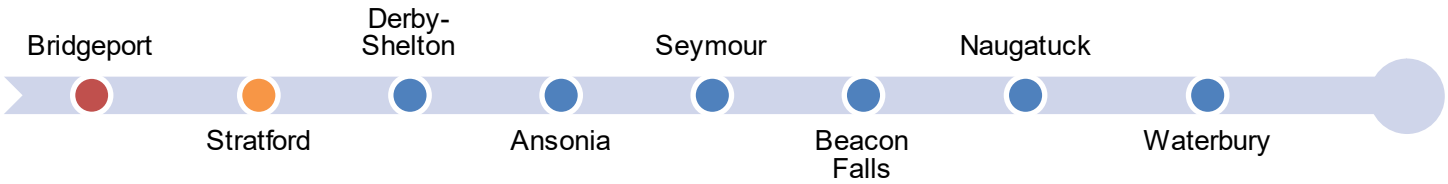


Figure 26: WBL Station Stops and Connecting Station

Capabilities:

Passenger service on the Waterbury Branch Line began in the mid-1800s and has been in continuous operation since then. While ridership did decline between 2011 and 2016, daily ridership for 2017 went up 17% from the previous year with around 1,014 daily riders. The ridership decline recorded can be attributed to infrequent and unreliable service. However, the branch line does benefit from the market of the Naugatuck Valley with the line providing service between Bridgeport and Waterbury. Considering the region's net export of commuters, lower

property costs compared to Fairfield County, and good proximity to jobs centers both inland and along the shoreline, the WBL could see significant growth with improved service.

Limitations:

This branch consists of an unsignalized, non-electrified single track with no passing sidings making it impossible for northbound and southbound trains to pass one another along the branch this makes it currently impossible to operate more than one train on the branch concurrently. It is this operational constraint that ultimately limits service on the branch line. The equipment, particularly the diesel-hauled locomotives used, are a limiting factor in reducing service disruptions due to their age and reliability. While signalizing and installing sidings on the line would allow for additional trains to operate on the branch line, the fleet size, condition of the equipment and ability to service and store additional equipment, would remain limiting factors in being able to improve reliability and expand service. Currently the branch line experiences service interruptions 3-5 times per month, and in these cases bussing is required to cover service gaps.

Bridges and At-Grade Crossings:

The WBL has numerous crossings with features including culverts, streams/rivers, roadways, power lines, and pedestrian paths. The branch has seven public at-grade crossings, five of which are found in the town of Milford.

Catenary and Traction Power:

The WBL is not electrified and currently operates a diesel fleet. Unlike the DBL, this branch line was not historically electrified. Electrification of part or all the Waterbury Branch is being considered but is unlikely to provide a substantial benefit given the required investment in new infrastructure and rolling stock since the same level of service can be accomplished by running existing diesel and/or dual-mode trains.

Track and Track Geometry:

This branch consists of 27 miles of existing track between Waterbury and Bridgeport. Track geometry limits the speed of the line at some points. This line runs at an average speed of 40 mph, ranging from 10 mph to 59 mph. The branch line runs at its lowest speed, 10 mph, at the WBL/NHL split, and it reaches its highest speed of 59 mph at the 0.16-7.6, 12.3-13.5, 14.88-17.8, and the 24.2-25.4 mile marks. The branch line runs at lower speeds of 30 mph over bridges, curves, and at the at-grade crossings.

Stations and Platforms:

All stations on the WBL have low-level platforms except for Waterbury. Additionally, none of the stations with low level platforms are handicap accessible, meaning that they have no infrastructure to aid individuals with mobility restrictions (wheelchair, cane, etc.). On the WBL, parking utilization is 27%, the lowest of all the branch lines, and the total capacity for this branch is 450 spaces. All the parking on the WBL is free and there is not a high demand for parking spaces at the stations on this branch line, this is attributed to overall lower ridership.

Table 15: WBL Station and Platform Summary

Station	Capacity	# Permit Spaces	# Daily Spaces	# Accessible Spaces	Annual Permit Fee	Monthly Parking Fee	Daily Parking Fee
Derby	75	0	70	5	N/A	N/A	N/A
Ansonia	50	0	48	2	N/A	N/A	N/A
Seymour	22	0	21	1	N/A	N/A	N/A
Beacon Falls	28	0	25	3	N/A	N/A	N/A
Naugatuck	125	0	125	0	N/A	N/A	N/A
Waterbury	150	0	150	0	N/A	N/A	N/A

Signals and Communications:

The WBL is not signalized and does not have active passing sidings or Positive Train Control (PTC), a system that can prevent collisions and derailments. Signalization and the addition of PTC are scheduled to be completed in conjunction and are programed for completion in 2020 (aligning with a Federal Railroad Administration (FRA) deadline).

Rail Yard(s) Storage:

The WBL is not electrified and operates 2008 Brookville BL20GH, GE Genesis P32AC-DM locomotives, and Shoreliner passenger coaches. There are two 3-car locomotive-coach trains stored in Stamford for Waterbury which take up eight spaces on the track. An underutilized right of way width across from the depot in Waterbury could be a potential layover site for these two train sets. Using this layover facility in Waterbury would eliminate the need to store Waterbury trains in Stamford, leaving more storage for other cars.

Slow Orders:

The WBL currently has no slow orders. There was one slow order from MP 23.8 to MP 24.1. This slow order was put into effect on December 29, 2016 and was in place for 654 days before being resolved on October 14, 2018.

Drainage:

Drainage conditions generally do not pose a concern on the WBL. There are relatively few mud spots across the nearly 30-mile alignment.

CT*rail* Lines (SLE & Hartford Line)

The Connecticut DOT operates two rail lines through their CT*rail* service. These include the Shore Line East (SLE) and, more recently, the Hartford Line. Shore Line East is an East-West service that connects shoreline communities between New Haven and New London. In 2018 the Hartford Line began operating service between New Haven and Springfield, Massachusetts. Neither service operates a one-seat ride into or from GCT. These two services supplement the Connecticut rail system and the region's transit network. Unlike the MNR-operated branch lines, these two CT*rail* lines share their track with Amtrak intercity services. While track east of New Haven is electrified, the SLE operates diesel hauled equipment. The Hartford Line is not electrified.

Table 16: AM Peak Period Branch Line Trains

Rail Line	Through Trains to GCT	Connecting Trains
Shore Line East	0	1
Hartford Line	0	1

Table 17: Weekday CT*rail* Line Ridership

Rail Line	Weekday Ridership
Shore Line East	2,450
Hartford Line	1,692

Travel Characteristics of the CT*rail* Lines

Service along the New Haven Line (NHL) is formed by a complex set of train stopping patterns and schedules. They have been established to provide both travel opportunities to/from Grand Central Terminal (GCT) and to provide reasonable travel options to/from intermediate stations and destinations. Schedules have been constructed around a "Zone Schedule" strategy which can offer travel time and seat availability benefits compared to other scheduling strategies. The three Metro-North operated branches follow this travel pattern and use zone scheduling integrated with NHL Mainline scheduling. Both the NCL and DBL provide one-seat rides into GCT, and the WBL runs limited service through to Stamford.

Shore Line East (SLE)

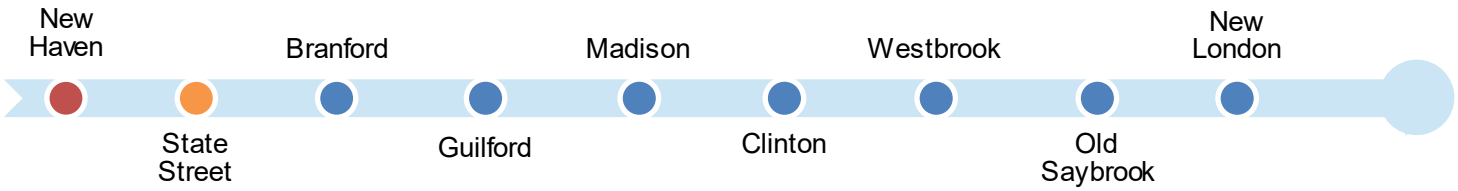


Figure 27: SLE Station Stops and Connecting Station

Capabilities:

CTDOT established the Shore Line East (SLE) commuter rail service in 1990 to serve commuters of eastern Connecticut, providing rail service from New London to New Haven where riders can transfer to MNR for service to Bridgeport, Stamford and New York City, among other local stops. In 2000 the SLE saw just fewer than 300,000 riders annually. By 2012, the service carried more than half a million riders and was experiencing ridership growth at 6.75% annually. The service stands as an important means of transportation for commuters and other user groups to bridge between New Haven and Eastern shoreline communities. SLE schedules are coordinated with NHL service to ease transfers in New Haven and SLE offers limited through service to Bridgeport and Stamford during the AM peak period.

Limitations:

Shore Line East service is limited east of the Connecticut River, with the only stop after Old Saybrook being New London. A major component causing limited service past Old Saybrook is the Connecticut River Bridge, a movable bridge that stays open most of the time to allow boats to pass through, thereby allowing only a limited number of trains to cross over per day. Plans are currently being developed by Amtrak to replace the bridge. Despite the limitations posed by this bridge, SLE service to Rhode Island is also being considered. In their 2015 Annual Report

and Recommendations, the Connecticut Public Transportation Commission called for the extension of SLE service eastward to Westerly, Rhode Island "as soon as practical".

Bridges and At-Grade Crossings:

Most existing grade crossings were converted to bridges or underpasses in the 1990s, leaving behind two at-grade crossings in downtown New London, just west of the station. In 2013, Amtrak replaced the Niantic River Bridge, one of the oldest movable bridges in the country. Currently, Amtrak plans to replace the Connecticut River Bridge. An Environmental Assessment and Preliminary Design has been completed, awaiting Federal Railroad Administration approval. The new design and Configuration of a replacement bridge would aim to improve reliability and offer higher speeds for Amtrak and Shore Line East trains. Amtrak will progress Final Design over the next two years, however, there are no identified funding sources for construction. [10]

Catenary and Traction Power:

Amtrak operates a 60 Hz traction power system along the Northeast Corridor, which includes track between New Haven and New London where SLE runs. This system was built in the 1990s, and supplies Amtrak locomotives with power from an overhead catenary system; however, SLE currently operates entirely with diesel locomotives. As agreed upon by Amtrak and Connecticut DOT, improvements to NEC power supply system are being considered to support the eventual introduction of electric train service on Shore Line East. Additionally, installation of catenary and related improvements on Track 6 at New London Station is being considered, in order to accommodate the electrification of Shore Line East service and in order to reduce conflicts between Amtrak and commuter service at the station. [11]

Track and Track Geometry:

SLE consists of 50 miles of track owned by Amtrak, over this extent the system operates on two tracks with locations of additional passing sidings. The track is generally maintained to a high standard due to Amtrak's operation of intercity service along the Northeast Corridor which has a MAS of up to 125mph. As a result, SLE operating speeds are not limited by track conditions or geometry.

Stations and Platforms:

There are nine stations along SLE, including New Haven State Street, and New Haven Union Station. All stations along SLE have high-level platforms and are ADA accessible. Old Saybrook was the initial terminus for the line when it began service in 1990, however in 1996 the service was extended to New London.

Table 18: SLE Station and Platform Summary

Station	Capacity	# Permit Spaces	# Daily Spaces	# Accessible Spaces	Annual Permit Fee	Monthly Parking Fee	Daily Parking Fee
Branford	471	0	451	20	N/A	N/A	N/A
Guilford	170	0	164	6	N/A	N/A	N/A
Madison	205	0	199	6	N/A	N/A	N/A
Clinton	110	0	104	6	N/A	N/A	N/A
Westbrook	184	0	178	6	N/A	N/A	N/A
Old Saybrook	203	0	197	6	N/A	N/A	N/A
New London [12]	N/A	N/A	N/A	N/A	N/A	N/A	N/A

[10] https://nec.amtrak.com/project/fourth-project/
[11] https://www.fra.dot.gov/necfuture/pdfs/2015_04alternatives_report.pdf
[12] The New London station does not have any reserved parking. There is limited on-street parking in front of the station. The majority of parking used at this station is the Water Street Garage. The garage covers five levels and has significant parking capacity.

Signals and Communications:
SLE uses Amtrak's signal system, which includes a PTC system, STC system, as well as updated trackside and wayside signals.

Rail Yard[s] Storage:
Yet to be assessed.

Slow Orders:
Not assessed due to data availability.

Drainage:
Beginning in April 2018, Amtrak began a major track work program between New Haven and Old Saybrook. Amtrak's train maintenance program began addressing ongoing drainage issues along the railroad right of way and upgrading track to improve the ride quality for customers. The track work has affected both SLE and Amtrak customers, limiting service and requiring substitute bus service to operate in place of some Shore Line East trains.

Hartford Line

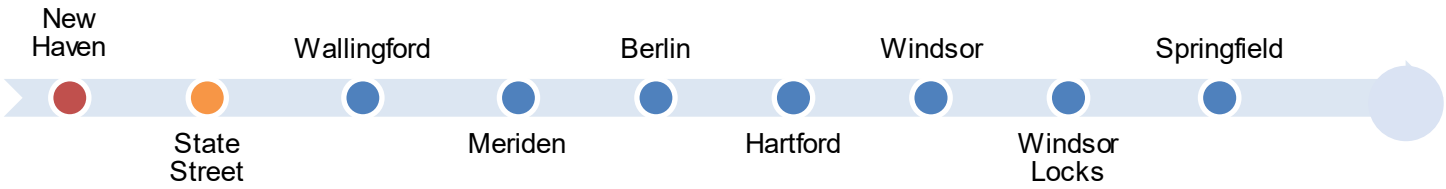


Figure 28: Hartford Line Station Stops and Connecting Station

Capabilities:
The CT*rail* Hartford Line passenger rail service launched on June 16, 2018 and operates at speeds up to 110 mph, with travel times between Springfield and New Haven as little as 81 minutes. Also, there is direct or connecting service to New York City and multiple frequencies to Boston or Vermont (via Springfield). New train stations are also planned at North Haven, Newington, West Hartford and Enfield. In the year since its launch, ridership has surpassed the projected 583,500 riders by 50,500, at over 634,000 riders in the first year. The line has also taken thousands of cars off the I-91 corridor, reducing both congestion and pollution on the corridor from cars.

Limitations:
Prior to the beginning of Hartford Line operations, the rail line went through significant improvements to increase speed, safety and capacity. However, the service that is provided is constrained by single track sections that make higher frequency train operations more complicated.

Bridges and At-Grade Crossings:
On top of the installation of double track, new signal and power cables, work on the new Hartford Line included at-grade crossing improvements, as well as rehabilitation of bridges and culverts. The line has numerous at-grade crossings which do not limit operating speeds or train movements.

Catenary and Traction Power:
The Hartford Line is currently not electrified; however, the long-term plan for High Speed Rail (HSR) service and infrastructure improvements in the New Haven-Hartford-Springfield (NHHS) rail corridor contemplates potential electrification of the line so that electric multiple-units (EMUs) could be used in lieu of diesel locomotives.

Track and Track Geometry:

Track along the Hartford Line is owned by Amtrak. In the mid-1980s, Amtrak removed some 25 miles of track to reduce the cost of maintaining the New Haven-Springfield line, converting the then double-tracked line to a single track with passing sidings. Since then, around 27 miles of additional double track was added to existing single-track sections in order to accommodate the increase in service that the new Hartford Line would bring. Additionally, two miles of new passing sidings as well as five new interlockings were added to the line.

Stations and Platforms:

The Hartford Line currently has nine station stops including New Haven Union Station and New Haven State Street, as well as Union Station in Springfield, MA. Plans for four additional regional stations are currently underway. These stations include North Haven, Newington, West Hartford, and Enfield. All are expected to be completed between 2020 and 2021, except for Newington which is still in early planning. High-level platforms, elevators, pedestrian overpasses, parking, and other amenities were added at the new Wallingford, Meriden and Berlin stations. All stations on the Hartford Line have high-level platforms and are ADA accessible.

Table 19: Hartford Line Station and Platform Summary

Station	Capacity	# Permit Spaces	# Daily Spaces	# Accessible Spaces	Annual Permit Fee	Monthly Parking Fee	Daily Parking Fee
Springfield	377	N/A	N/A	N/A	N/A	$65.00	$5.00[13]
Windsor Locks	30	N/A	N/A	N/A	N/A	$0.00	$0.00
Windsor	22	N/A	N/A	N/A	N/A	$0.00	$0.00
Hartford	200	N/A	N/A	N/A	N/A	$90.00	$15.00
Berlin	235	N/A	N/A	N/A	N/A	$20.00	$2.00
Meriden	290	N/A	N/A	N/A	N/A	$40.00	$7.00
Wallingford	221	N/A	N/A	N/A	N/A	$20.00	$2.00

Signals and Communications:

Positive Train Control (PTC) for the Hartford Line is provided by Amtrak. The increase in service expected along this corridor due to the implementation of the Hartford commuter line required the installation of new underground signal and communication cables. This was the first portion of construction for the New Haven-Hartford-Springfield (NHHS) Rail Program. This work was required to upgrade signals and communications for the NHHS rail corridor and prepare for subsequent track and infrastructure improvements to re-establish Track 2.

Rail Yard[s] Storage:

Yet to be assessed.

Slow Orders:

Not assessed due to data availability.

[13] Springfield Union Station uses the Union Station Garage which does not offer daily rates, the garage offers hourly and monthly rate and a separate monthly commuter rate.

Drainage:

To prevent track flooding and subsequent mud spots, a large investment was made in drainage when laying down the double track for the Hartford Line. 27 drainage culverts were installed along the 27 miles of track to ensure proper drainage for years to come.

2.3 Services and Equipment

Connecticut Branch Lines (NCL, DBL &WBL)

Table 20: Weekday Equipment Operated by Branch

Line	Number of Trainsets	Number of EMUs	Number of Locomotives	Number of Coaches
New Canaan Line	5	29	0	0
Danbury Branch Line	5	0	5	31
Waterbury Branch Line	2	0	2	6

New Canaan Branch Line (NCL)

Services:

The New Canaan Branch Line operates in coordination with mainline operations to provide service to GCT from Stamford. The NCL is the shortest of the three branches and the closest to GCT, generally operating Sunday-Friday (no service on Saturday), and has regular service hours of 5:27 AM to 11:25 PM for inbound trains and 12:20 AM to 10:58 PM for outbound trains. Seven trips originating in New Canaan go to GCT without the need to transfer in Stamford, and conversely, 9 trips direct from GCT terminate in New Canaan. In addition, 19 trips originate in New Canaan and terminate in Stamford where passengers can board connecting trains towards GCT or New Haven. Seventeen trips originate in Stamford and terminate in New Canaan. New Canaan trains lay over in Stamford and deadhead to New Canaan for the morning rush hours. While many of the trains run express from Stamford to GCT, the 5:31 AM train makes all stops to Stamford and all stops after Stamford until Rye, which increases travel time to GCT.

Trip Frequency:

Headway for the trains are 50-60 minutes throughout the day. During morning peak hours, there are increased passenger volumes for the 5:31 and the 6:23 inbound trains, for 9 AM arrivals into NYC. During evening peak hours, the 5:10 PM train has highest passenger volumes which is reflective of the service gap (between 5:10 PM and 7:28 PM train).

Trip Duration:

The trip duration between New Canaan and Stamford is 18 minutes for the outbound trip and 17 minutes for the inbound one. The trip duration between New Canaan and GCT is 66-81 minutes for an inbound train and 65-96 minutes for an outbound train.

Equipment:

The NCL is the only electrified CT*rail* branch line. The rail system utilizes Kawasaki M8 railcars and is electrified with overhead catenary. This branch has 5 trainsets consisting of 29 electric multiple-unit rail cars (EMUs) operating on a single track and at an average of 40 mph for inbound and outbound trips.

Danbury Branch Line (DBL)

Services:

The Danbury branch is a 24-mile non-electrified line that services six stations between Danbury and South Norwalk and operates in coordination with the mainline operations to provide service to GCT. Danbury provides a shuttle style service with 14 trains a day each way on weekdays. Passengers transfer to NHL trains at South Norwalk, with the exceptions of four through trains that make round trips directly into GCT. Five trains lay over in Danbury overnight to initiate the service for the next day – this is the only branch line terminus that has layover trackage. The highest ridership on the branch is during the AM peak period, particularly on its four through trains to GCT. All trains stop at all seven stations on the branch. All peak trains and some off-peak run to Stamford on weekdays. The branch generally operates Sunday-Friday (no service on Saturday) and has regular hours of 12:35 AM to 10:47 PM for outbound trains, and 5:29 AM to 10:32 PM for inbound trains.

Trip Frequency:

Headways for the outbound trains are 60 minutes during peak hours and 90-120 minutes for off peak hours. Headways for inbound trains are 30-60 minutes during peak hours and 90-115 minutes for off peak hours.

Trip Duration:

The trip duration between Danbury and South Norwalk is 54 minutes for the outbound route and 55 minutes for the inbound route. The travel time from South Norwalk to GCT ranges from 61 minutes to 72 minutes – the limited through service from Danbury to Grand Central takes a total of about 2 hours for commuters.

Equipment:

The branch line is currently not electrified and uses diesel locomotives in push-pull operation and has only recently been signalized. All the rolling stock cars are Shoreliner series cars. At this branch, there are 5 trainsets consisting of 31 coaches operated weekly at 30 mph on a single track.

Waterbury Branch Line (WBL)

Services:

The Waterbury Branch Line (WBL) is a 27-mile non-electrified line with six station stops. The transfer point from the Waterbury Shuttle to a New Haven Main Line train occurs at Bridgeport Station. Two diesel/electric powered trains are used for the shuttle and they deadhead every morning from Stamford yard to Waterbury and travel back and forth between Waterbury and Bridgeport throughout the day. There is one weekday morning peak train that operates from Waterbury to Stamford, but there are no through trains to GCT. The WBL generally operates Sunday-Friday (no service on Saturday) and has regular service hours 5:40 AM to 9:58 PM for inbound trains, and 8:06 AM to 11:18 PM for outbound trains. There are nine daily trips from Bridgeport to Waterbury and ten trips from Waterbury to Bridgeport, including the two deadhead trains from Stamford that provide the equipment for the service but carry no passengers. At the end of the service day, the two train sets are deadheaded back to Stamford where they lay over as there are no storage tracks in Waterbury.

Trip frequency:

Headways for outbound trains are 120 minutes, and 55-180 minutes inbound trains. During morning peak hours, there are increased passenger volumes for the 5:40 and the 6:35 inbound trains.

Trip Duration:

The trip duration between Waterbury and Bridgeport is 56 minutes for outbound trips and 55 minutes for inbound trips.

Equipment:

The WBL uses 2008 Brookville BL20GH and GE Genesis P32AC-DM locomotives and Shoreliner passenger coaches to shuttle passengers between Waterbury and Bridgeport. This branch has 2 trainsets consisting of 6 coaches and operates on a single track at an average of 40 mph. The branch line is currently not signalized and has no active passing sidings.

CT*rail* Lines (SLE & Hartford Line)

Table 21: Weekday Equipment Operated by CT*rail* Line

Line	Number of Trainsets	Number of EMUs	Number of Locomotives	Number of Coaches
Shore Line East	6	0	6	24
Hartford Line CT*rail*	N/A	N/A	N/A	N/A
Hartford Line Amtrak Shuttles	N/A	N/A	N/A	N/A
Hartford Line Amtrak Thru Trains	N/A	N/A	N/A	N/A

Shore Line East (SLE)

Services:

Shore Line East (SLE) is a 50-mile electrified line with 9 station stops. Although the line is electrified under Amtrak's 60 Hz traction power system, SLE currently operates entirely with diesel locomotives. Of the 22 inbound trains, 12 originate in Hartford and 10 originate in New London. Of the 10 that originate in New London, three are Amtrak trains, meaning that only SLE Multi-Ride Tickets are accepted. Similarly, of the 26 outbound trains, 14 terminate in Old Saybrook, and 12 terminate in New London. Of those 12, five are Amtrak trains.

Trip Frequency:

Headways for westbound trains during the morning peak period are between 30 and 100 minutes. Headways for outbound trains in the evening peal period are approximately a half hour. [14]

Trip Duration:

Trip duration between New Haven and New London is 70 minutes for inbound trips and 70-80 minutes for outbound trips. Trip duration between New Haven and Old Saybrook is 45 minutes for inbound trips and 45 minutes for outbound trips. The limited through service to Bridgeport and Stamford during the AM peak period is 23 minutes for Bridgeport and 55 minutes to Stamford. SLE provides two of these trips each morning with one providing an AM return trip and the second providing a PM peak return trip.

Equipment:

All SLE trains are diesel push-pull trains. SLE uses 1992 Mafersa coaches. Because of their lack of automatic doors, the SLE cars are prohibited from running into Grand Central Terminal. CT*rail* is considering a fleet acquisition to acquire M8 cars to replace existing EMU west of New Haven and existing diesel-powered trains on Shore Line East.

[14] It's important to note that for the Pre-Covid schedule analyzed all three of the PM Peak trips were partially replaced by bussing.

Hartford Line

Services:

The Hartford Line is a 62-mile non-electrified line with nine station stops, with eight of the nine stations in Connecticut, and the last in Springfield, MA. There are 17 weekday outbound trains. Of those 17 trains, five terminate in Hartford while the rest terminate in Springfield. There are 16 weekday inbound trains. Of those 16, five originate in Hartford while the rest originate in Springfield. The CT*rail* service on the Hartford line is supplemented by Amtrak service. Unlike Shore Line East there is full ticket reciprocity between CT*rail* and Amtrak trips over the line.

Trip Frequency:

Headways vary for both inbound and outbound trips due to some trains originating/terminating in Hartford and some in Springfield. Headways for outbound trains terminating in Hartford range between 40 minutes and 1 hour 20 minutes and with a 3-hour gap in service from 11:35pm to 3:36pm. Headways for inbound trains are between 35 minutes and 1. Passengers traveling to or departing from Hartford experience increased service due to the Springfield originating/terminating trips.

Trip Duration:

Similar to trip frequency, trip duration varies based on the originating/terminating station (i.e. Hartford or Springfield). Trips between New Haven and Hartford take 52 minutes, trips between New Haven and Springfield take between 1 hour 23 minutes and 1 hour 32 minutes. Equivalent southbound trips (Hartford/Springfield to New Haven) are similar in duration.

Equipment:

The Hartford line uses a fleet of upgraded diesel locomotives. For the initial launch of the Hartford Line, CTDOT leased 16 single level coaches from the Massachusetts Bay Transportation Authority. The sixteen coaches were spilt into four, four-car sets. The trains are push-pull, using CTDOT owned GP40 and P40 locomotives. The long-term plan for High Speed Rail (HSR) service and infrastructure improvements in the NHHS rail corridor contemplates potential electrification of the line so that electric EMUs would be used in lieu of diesel locomotives.

Glossary of terms

Term	Definition
At-Grade Crossing	Intersection of a railway and a road on the same level.
Ballasted	Track ballast consists of small rocks that form the trackbed upon which railroad ties are laid.
Catenary	An overhead line or wire used to transmit electrical energy to trains.
Centralized traffic control (CTC)	A system of railroad operation where the movement of trains over routes on a designated section of track is directed by signals controlled from a designated section of track or tracks without requiring the use of train orders and without the superiority of trains.
Consist	A group of rail vehicles which make up a train.
Control Point	An **interlocking** location.
Daily train operations bulletin order (DTOBO)	A daily report of train operations issued by train operators that detail any issues along the rail line such as slow orders.
Dual-mode locomotive	A dual-mode locomotive is powered either from an electricity supply, or by using the onboard diesel engine.
Electric Multiple Unit (EMU)	A multiple-unit train consisting of self-propelled carriages using electricity as the motive power.
Headway	The time between departing trains.
High-level platform	A train platform that is built up to eliminate the gap between the passenger and the train floor, thus reducing risk to passenger safety and increasing accessibility for handicapped passengers.
Inbound	For the purposes of this study, inbound refers to any train traveling in the direction of Grand Central Terminal.
Interlocking	Used to control traffic at a junction of two or more railroads, an interlocking includes signals and signal appliances that provide a clear signal to a train if a route is deemed safe, then lock in position until the train passes.
Maximum allowable speed (MAS)	The maximum speed at which a passenger train is allowed to operate on a particular section of track.
Moveable Bridge	A bridge over water that is able to move for the passage of vessels and boats in the waterway
Mud Spot	Also known as "mud pumping", a mud spot is a portion of track with poor drainage which can lead to the deterioration of concrete ties and the railbed.
NBI-67 Rating	A rating by the National Bridge Inventory that offers a structural evaluation of bridges.

Northeast Corridor (NEC)	An electrified railroad line in the Northeast megalopolis of the United States owned primarily by Amtrak running from Boston to Washington, D.C.
One-seat Ride	A train ride in which a passenger is able to get to their destination without having to transfer to another train.
Open-deck	A non-ballasted rail bridge.
Outbound	For the purposes of this study, outbound refers to any train traveling away from Grand Central Terminal.
Over-head Bridge (OH)	Any bridge that crosses overhead in relationship to the rail line.
Passing Siding	This is a section of track parallel to a through line and connected to it at both ends by switches. Passing sidings allow trains travelling in opposite directions to pass.
Positive train control (PTC)	PTC is a federally mandated safety control system that automatically reduces train speeds when needed, reducing train collisions and preventing human error.
Push-Pull Fleet	Push–pull is a configuration for locomotive-hauled trains, allowing them to be driven from either end of the train, whether having a locomotive at each end or not.
Slow Order	A slow order is a temporary mandate that requires all trains, during all hours, operating over a given section of track to adhere to a particular reduced speed.
Traction Power	A traction network or traction power network is an electricity grid for the supply of electrified rail networks.
Under-grade Bridge (UG)	Any bridge that crosses in relationship to the rail line.
Wayside signal system	Any signal - electrical, mechanical or otherwise - in a fixed location outside a train along the track.
Federal Railroad Administration (FRA)	An agency in the United States Department of Transportation. The purpose of the FRA is to promulgate and enforce rail safety regulations and consolidate government support of rail transportation activities.

CTrailStrategies

Appendix B RTC Analysis

APPENDIX B - RTC Analysis

New Haven Line Capacity and Speed Analysis

RTC Baseline Model Validation - Update

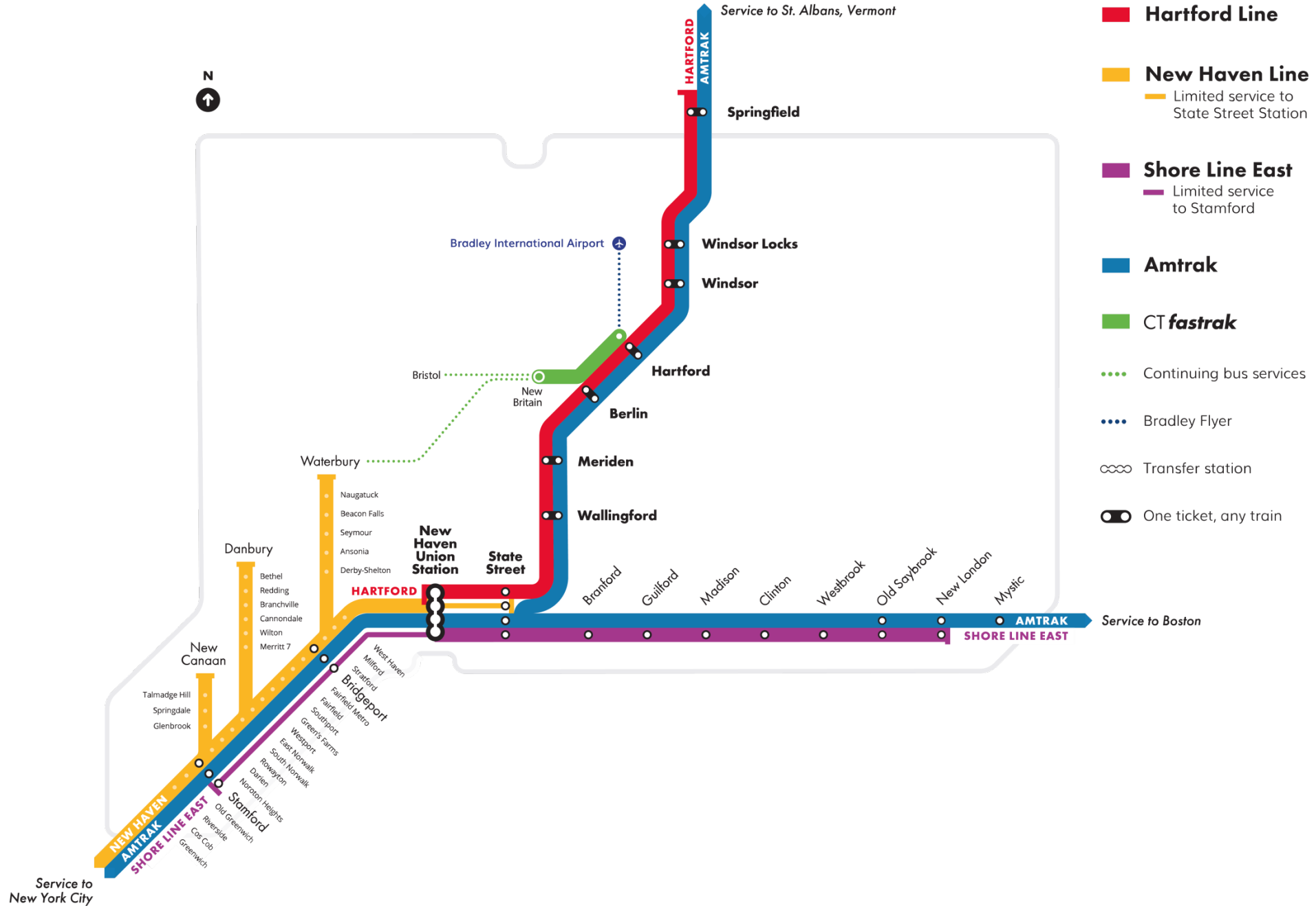
July 11, 2019

Rail Traffic Controller (RTC)

- Rail Simulation package developed by Berkeley Simulation Software.
- Primary Function: Accurate modeling and simulating rail networks.
- Unique Feature: Dispatches trains at the network level and uses meet-pass N-train logic that facilitates dispatch operations and capacity analysis.

Purpose for CTDOT use

- In-house validation capability of existing and future service plans.
- Provide network analysis capability on a regional perspective (all passenger routes in CT).
- Provide refined travel time source data for ridership / revenue forecasts, BCA analysis.
- Provide timely capacity and travel time assessments of potential capital improvement programs.
- Help identify future capacity and travel time improvements (location and function).
- Help define and prioritize future capital improvement funding programs.

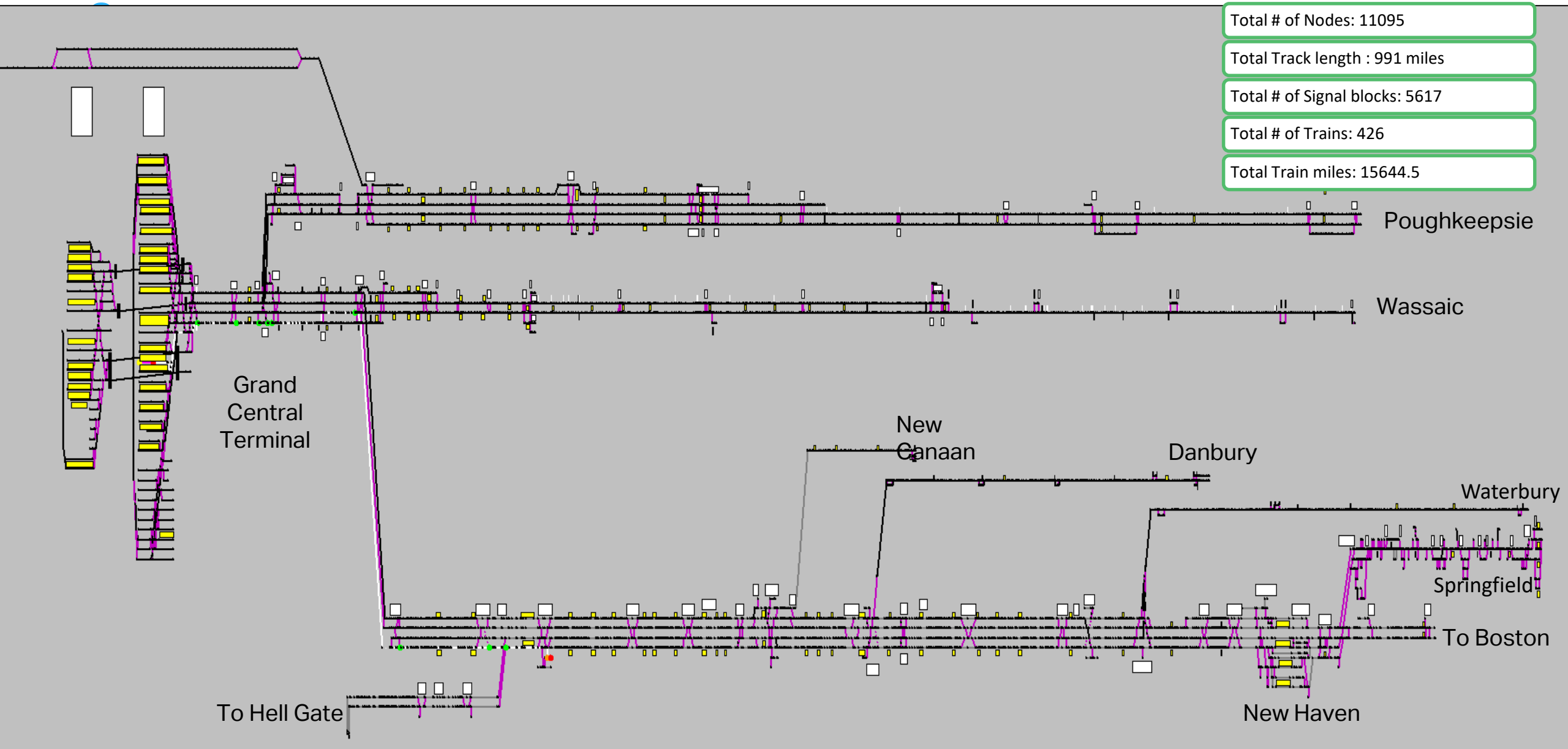

Service to St. Albans, Vermont
HARTFORD
AMTRAK
Springfield
N
Bradley International Airport
Windsor Locks
Windsor
Bristol
New Britain
Hartford
Berlin
Waterbury
Meriden
Wallingford
Naugatuck
Beacon Falls
Seymour
Ansonia
Derby-Shelton
Danbury
Bethel
Redding
Branchville
Cannondale
Wilton
Merritt 7
New Haven Union Station
State Street
HARTFORD
Branford
Guilford
Madison
Clinton
Westbrook
Old Saybrook
New London
Mystic
AMTRAK
SHORE LINE EAST
Service to Boston
New Canaan
Talmadge Hill
Springdale
Glenbrook
West Haven
Milford
Stratford
Bridgeport
Fairfield Metro
Fairfield
Southport
Green's Farms
Westport
East Norwalk
South Norwalk
Rowayton
Darien
Noroton Heights
Stamford
Old Greenwich
Riverside
Cos Cob
Greenwich
NEW HAVEN
AMTRAK
SHORE LINE EAST
Service to New York City
Hartford Line
New Haven Line
Limited service to State Street Station
Shore Line East
Limited service to Stamford
Amtrak
CT fastrak
Continuing bus services
Bradley Flyer
Transfer station
One ticket, any train

New Haven Line Speed and Capacity Study Baseline Model

Steps taken to develop the Baseline Model:

- Step 1: Adjusting to initial project scope
- Step 2: Updated Schedule
- Step 3: Reviewed Train Control
- Step 4: Validated Track Network
- Step 5: Validated Dispatch Protocols

Step 1: MNR East of Hudson Baseline Model – Adjusted to Initial Project



Step 2: Initial Schedule Update

- Timetable: Metro-North Railroad Operation Schedule – Timetable No 3, Effective April 2, 2017
- Trains Scheduled for:
  - New Haven Line
  - Danbury Branch
  - Waterbury Branch
  - New Canaan Branch
  - Shore Line East
    - Stamford thru trains only
  - Amtrak
    - Northeast Regional
    - Acela Express
- Frequency:
  - Monday through Thursday and extra Friday trains, except holidays.
  - Weekend and Special Schedules not included.

Hudson Line Harlem Line Trains Not Included

CT*rail* Trains Not Included (Added later)

Amtrak Shuttles Not Included (Added later)

Step 3: Train Control Review

- Signal control lines were not provided
- Signaling commands / blocks verified in network
- New 4-block, 5-Aspect system with the 270 code is in service for NHL

Step 4: Track Network Validation

- Track Speeds updated as per Metro-North Railroad Employee Timetable – Timetable No 3, Effective May 15, 2016.
- Verified:
  - Track alignment
  - Distances between platforms
  - Active maintenance speed restriction permits

Baseline Maintenance Speed Restriction Permits

#	Subdivision	Entry MP	Exit MP	Distance (miles)	Track #	Direction	Start Time DD:HH:MM	End Time DD:HH:MM	Reduced Speed (mph)	Maximum Authorized Speed (mph)
1	Hudson Line	3	3.3	0.3	1	Both	Th:23:00	Sa:09:30	30	60
2	Hudson Line	3	3.3	0.3	2	Both	Th:23:00	Sa:09:30	30	60
3	Harlem Line	5.6	6.2	0.6	2	Both	Th:23:00	Sa:09:30	30	60
4	Harlem Line	5.6	6.2	0.6	3	Both	Th:23:00	Sa:09:30	30	60
5	Harlem Line	5.6	6.2	0.6	4	Both	Th:23:00	Sa:09:30	30	60
6	New Haven Line	12.3	12.6	0.3	4	Both	Th:23:00	Sa:09:30	30	45 (MP 12.3 - MP 12.5) 60 (MP 12.5 - MP 12.6)
7	New Haven Line	12.5	12.6	0.1	1	Both	Th:23:00	Sa:09:30	30	60
8	New Haven Line	14.9	15.3	0.4	3	Both	Th:23:00	Sa:09:30	30	60
9	New Haven Line	19.6	19.7	0.1	3	Both	Th:23:00	Sa:09:30	30	80
11	New Haven Line	20	21.1	1.1	4	Both	Th:23:00	Sa:09:30	30	80
12	New Haven Line	25.5	25.7	0.2	4	Both	Th:23:00	Sa:09:30	30	70
13	New Haven Line	26.5	29.1	2.6	1	Both	Th:23:00	Sa:09:30	60	70 (MP 26.5 - MP 28.2) 60 (MP 28.2 - MP 28.4) 70 (MP 28.4 - MP 29.1)
14	New Haven Line	27.5	27.7	0.2	4	Both	Th:23:00	Sa:09:30	30	70
15	New Haven Line	29.2	29.4	0.2	3	Both	Th:23:00	Sa:09:30	30	70
16	New Haven Line	30.2	30.3	0.1	3	Both	Th:23:00	Sa:09:30	30	70
17	New Haven Line	32.7	32.8	0.1	4	Both	Th:23:00	Sa:09:30	30	50
18	New Haven Line	32.7	33.7	1	3	Both	Th:23:00	Sa:09:30	30	50
19	New Haven Line	33.2	33.7	0.5	1	Both	Th:23:00	Sa:09:30	30	50
20	New Haven Line	33.2	33.7	0.5	5	Both	Th:23:00	Sa:09:30	30	50
21	New Haven Line	34.9	35.6	0.7	2	Both	Th:23:00	Sa:09:30	60	70
22	New Haven Line	38.8	40.6	1.8	4	Both	Th:23:00	Sa:09:30	60	70
23	New Haven Line	41.6	41.8	0.2	4	Both	Th:23:00	Sa:09:30	60	70
24	New Haven Line	42.3	42.8	0.5	2	Both	Th:23:00	Sa:09:30	30	70
25	New Haven Line	44.3	44.4	0.1	4	Both	Th:23:00	Sa:09:30	20	45
26	New Haven Line	71.1	71.5	0.4	1	Both	Th:23:00	Sa:09:30	30	50
27	New Haven Line	72.3	72.7	0.4	1	Both	Th:23:00	Sa:09:30	45	50
28	New Haven Line	72.3	72.7	0.4	2	Both	Th:23:00	Sa:09:30	45	50
29	Danbury Branch	7.559	7.759	0.2	1	Both	Th:23:00	Sa:09:30	30	35 (MP 7.559 - MP 7.6) 50 (MP 7.6 - MP 7.759)
30	Waterbury Branch	14.9	17.8	2.9	1	Both	Th:23:00	Sa:09:30	50	59
31	Waterbury Branch	23.8	24.1	0.3	1	Both	Th:23:00	Sa:09:30	45	50

Step 5: Dispatch – Initial Scenario

- Model dispatched for 24 hours
- No lateness (perturbations) induced
- Assumed speed restrictions shown in table
- Assumed all tracks in service
- 100% on-time performance for the Baseline test
- Lateness statistics collected at terminals
- On-time performance (OTP) threshold: 3 minutes

Dispatch statistics RTC 74K (64-bit) 11 April 2019 10:01:13

General

Case : BCase06 comb Metro-North East-of-Hudson April 2016

Dispatched trains = 428 (0 failed) Number of conflicts= 4,509 (4,317) Execution: 4:47 (HH:MM:SS)

Simulation times (DD:HH:MM)

	Begin	End	Duration	Train count
Warm-up * :	Th:23:00	Fr:00:00	1:00	4
Statistical * :	Fr:00:00	Sa:00:00	1:00:00	417
Cool-down * :	Sa:00:00	Sa:01:00	1:00	7
Overall :	Th:23:00	Sa:01:00	1:02:00	428

* Trains starting within warm-up period and/or ending after simulation are excluded from statistics.

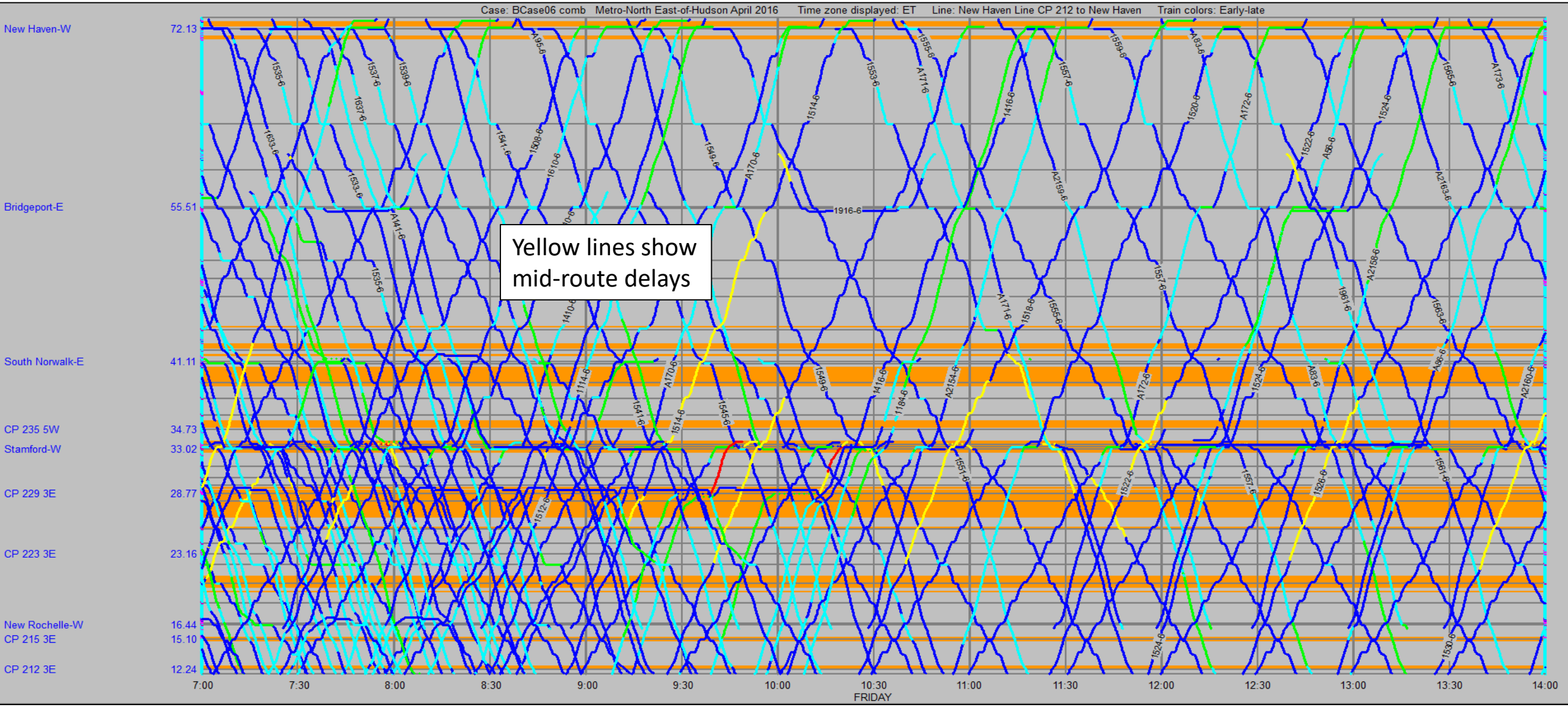
Statistics by train group

Train Group	Run-time Train Count	Average* Speed With Dwell	Delay Percentage	Total Train-miles	Delay minutes Per 100 Train-miles	Energy KWH	OTP
Acela Tilt On	20	49.248	1.10	1144.2	1.323	28060.3	100.0%
Psg/Acela Tilt O	23	42.085	1.01	1319.1	1.423	28937.8	100.0%
Herit/Psg Elect	249	34.112	1.40	11204.9	2.422	340003.7	100.0%
Herit/Psg Diesel	50	31.336	1.38	1976.3	2.608	0.0	100.0%
All train groups	342	35.068	1.35	15644.5	2.281	397001.8	100.0%

* Dwell times do not include time spent at initial and final terminals. Entry delay included in delay times.

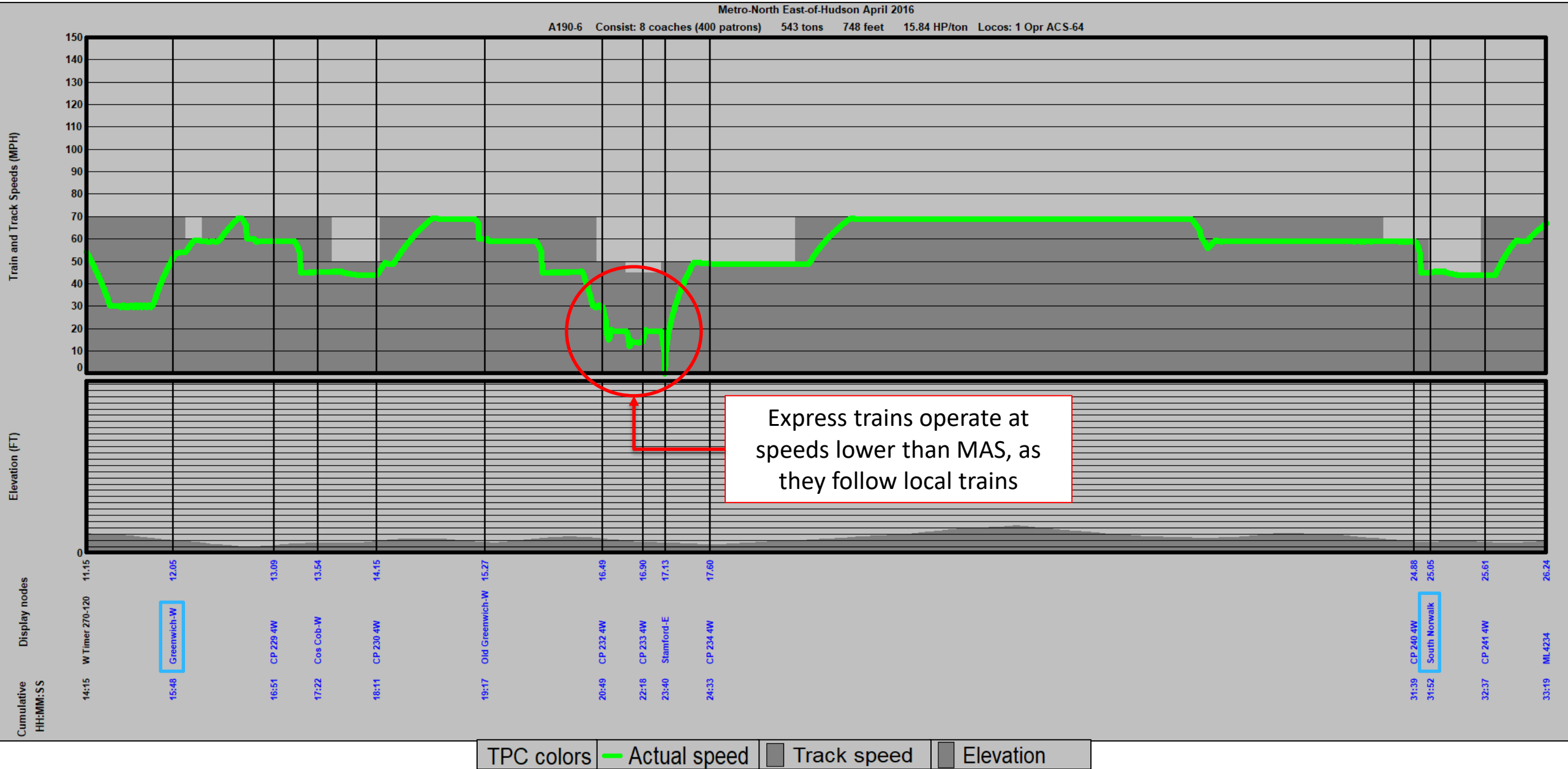
Horizon histogram | Analyze failure | Print | Close

Time – Distance Plot



Early by 3+ minutes | Early by 10+ minutes | On time | Late by 3+ minutes | Late by 10+ minutes

Train Performance Chart (A-190)



Delay Analysis Observations – Initial Scenario

- Overall initial system validation performed on-time
  - New signal system enhancement
  - Absence of Harlem and Hudson Line trains
  - Absence of 24/7 outages
  - Absence of perturbed operations
- CP 229 delays on Track 2 (can apply to other tracks as well)
  - Non-revenue “Zipper trains” dwell at CP 229 (track 2) for up to 20 minutes
- Mainline Track 4 Eastbound Peak Period delays
  - Express trains follow Local trains at lower speeds on Track 4 – New Rochelle to Stamford
  - Trains with first stop at Greenwich crossing over at CP-223
- Crossover delays / congestion at Stamford

Baseline Model Schedule Updated

- Timetable: Metro-North Railroad Operation Schedule – Timetable No 3, Effective April 2, 2017
- Trains Scheduled for:
  - New Haven Line
  - Danbury Branch
  - Waterbury Branch
  - New Canaan Branch
  - Shore Line East
    - Stamford thru trains only
  - Amtrak
    - Northeast Regional
    - Acela Express
- Frequency:
  - Monday through Thursday and extra Friday trains, except holidays.
  - Weekend and Special Schedules not included.

Hudson Line Harlem Line Trains Not Included

CT*rail* Trains Included (June 2018)

Amtrak Shuttles Included (June 2018)

Shore Line East Trains Included (April 2017)

Baseline Travel Time Statistics (30-30-30)

Trains dispatched express between New Haven and Grand Central Terminal; making stops at Stamford

Track	Simulated Travel Time (HH:MM:SS)	
	New Haven to Stamford	Stamford to Grand Central
3	0:44:57	0:47:30
1	0:43:13	0:42:06

Track	Simulated Travel Time (HH:MM:SS)	
	Grand Central to Stamford	Stamford to New Haven
2	0:41:59	0:41:52
4	0:47:31	0:42:29

24/7 Outages Scenario

To represent a more realistic scenario, 24/7 track outages were introduced at the following locations:

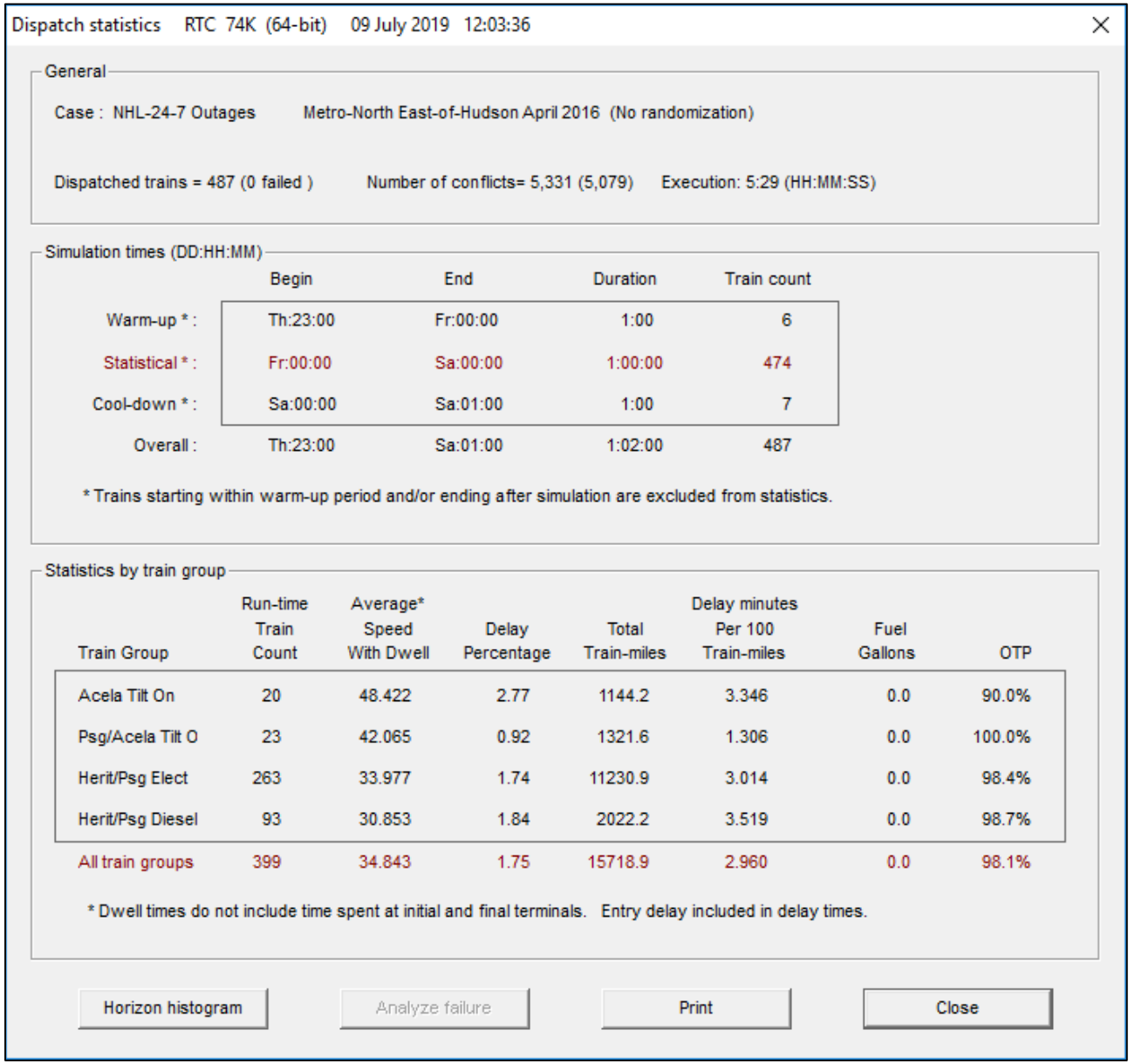
- CP 232 to CP 229: Track 3
- CP 241 to CP 248: Track 2 and Track 4
- CP 266 to CP 261: Track 1

This analysis has some critical assumptions applied to it as follows:

- Initial Baseline Model conditions are maintained
- Initial slow orders are maintained + the 24/7 outages
- Inclusion of updated signal system (270 code) does not reflect Baseline infrastructure conditions
- Does not include deterministic perturbations
- Absence of Harlem and Hudson Line trains

Dispatch - 24/7 Outages Scenario

- Model dispatched for 24 hours
- 98.1% on-time performance
- 7 late trains
- Maximum lateness of 12 minutes 48 seconds
- Lateness statistics collected at terminals
- On-time performance (OTP) threshold: 3 minutes



Dispatch statistics RTC 74K (64-bit) 09 July 2019 12:03:36

General

Case : NHL-24-7 Outages Metro-North East-of-Hudson April 2016 (No randomization)

Dispatched trains = 487 (0 failed) Number of conflicts= 5,331 (5,079) Execution: 5:29 (HH:MM:SS)

Simulation times (DD:HH:MM)

	Begin	End	Duration	Train count
Warm-up * :	Th:23:00	Fr:00:00	1:00	6
Statistical * :	Fr:00:00	Sa:00:00	1:00:00	474
Cool-down * :	Sa:00:00	Sa:01:00	1:00	7
Overall :	Th:23:00	Sa:01:00	1:02:00	487

* Trains starting within warm-up period and/or ending after simulation are excluded from statistics.

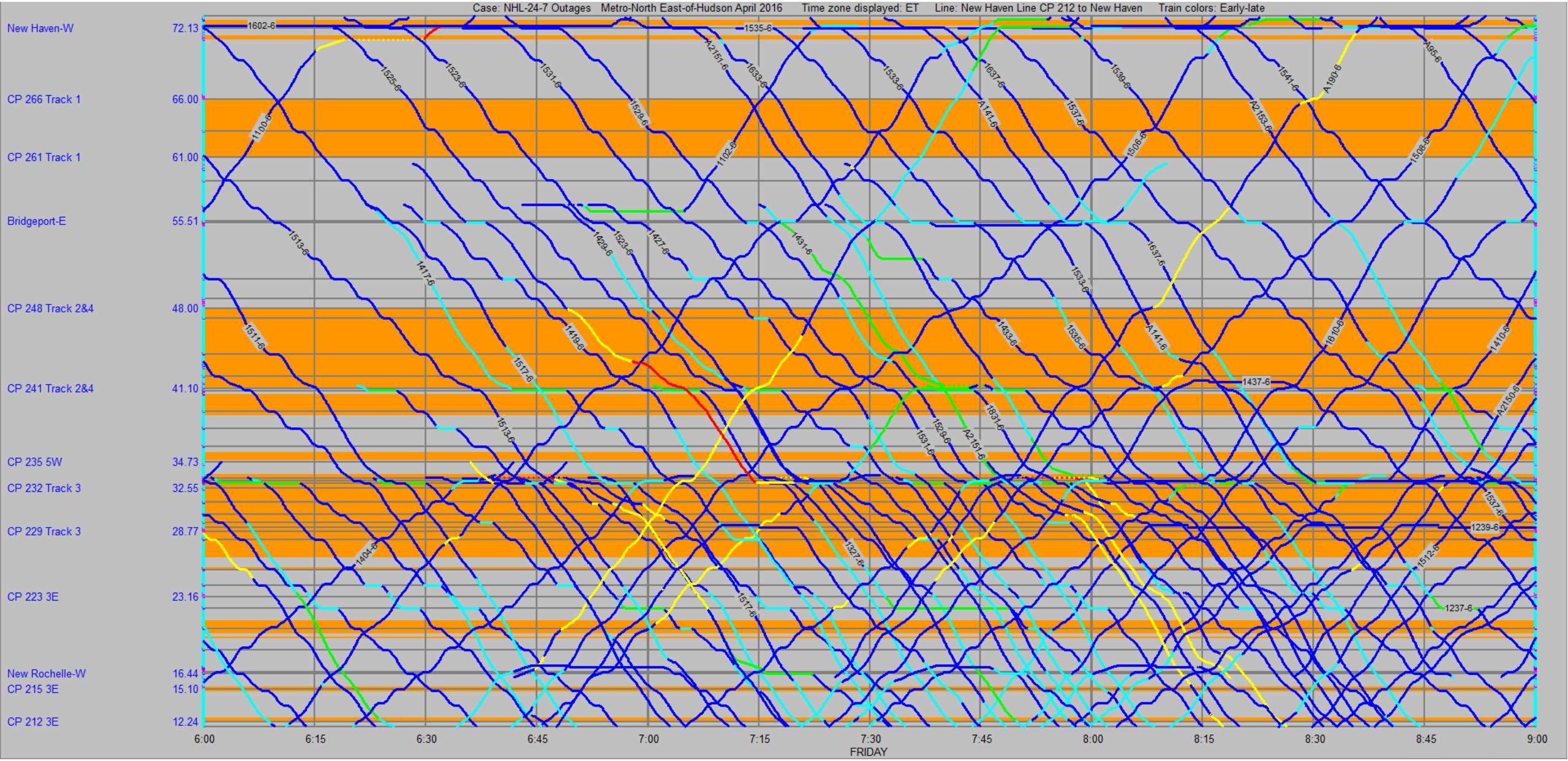
Statistics by train group

Train Group	Run-time Train Count	Average* Speed With Dwell	Delay Percentage	Total Train-miles	Delay minutes Per 100 Train-miles	Fuel Gallons	OTP
Acela Tilt On	20	48.422	2.77	1144.2	3.346	0.0	90.0%
Psg/Acela Tilt O	23	42.065	0.92	1321.6	1.306	0.0	100.0%
Herit/Psg Elect	263	33.977	1.74	11230.9	3.014	0.0	98.4%
Herit/Psg Diesel	93	30.853	1.84	2022.2	3.519	0.0	98.7%
All train groups	399	34.843	1.75	15718.9	2.960	0.0	98.1%

* Dwell times do not include time spent at initial and final terminals. Entry delay included in delay times.

Horizon histogram | Analyze failure | Print | Close

Time- Distance Plot: Morning Peak



Early by 3+ minutes

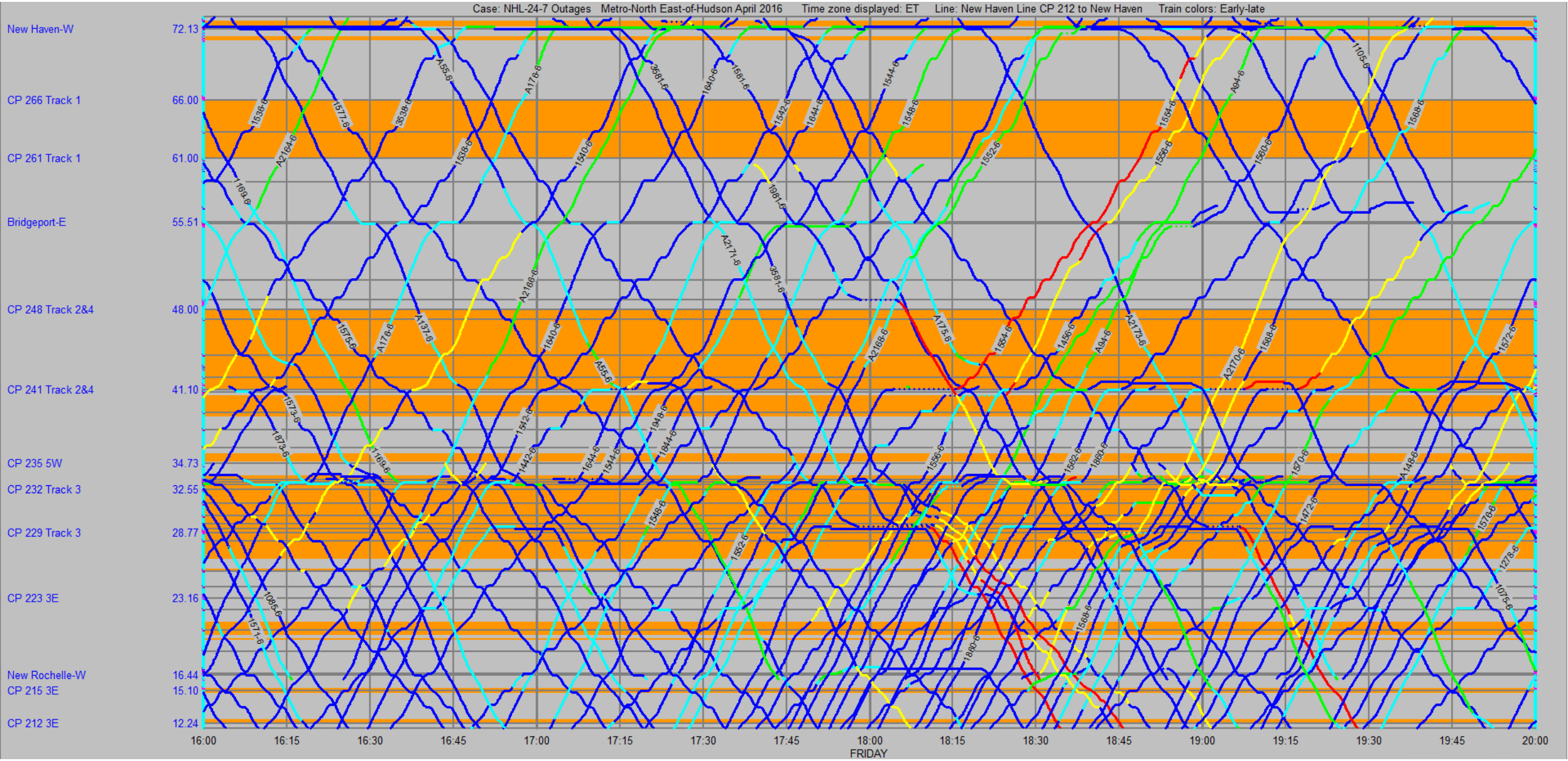
Early by 10+ minutes

On time

Late by 3+ minutes

Late by 10+ minutes

Time- Distance Plot: Evening Peak



Early by 3+ minutes

Early by 10+ minutes

On time

Late by 3+ minutes

Late by 10+ minutes

Delay Analysis Observations – 24/7 Outages Scenario

- Overall system validation performed 98.1% on-time
  - New signal system enhancement
  - Absence of Harlem and Hudson Line trains
  - Absence of deterministic perturbed operations
  - Reduction in service recovery time
- CP 229 delays on Track 1 and Track 2
  - Track 3 out of service between CP 232 and CP 229
  - Non-revenue “Zipper trains” dwell at CP 229
  - Cascading delays for trains on Track 1 and 2 in both directions
- Mainline Track 4 Eastbound Peak Period delays
  - Express trains follow Local trains at lower speeds on Track 4 between New Rochelle and Stamford
  - Trains with first stop at Greenwich crossing over at CP-223
- Crossover delays / congestion at Stamford
- Congestion between CP 241 and CP 248
  - Track 2 and Track 4 out of service
  - Express trains follow Local trains on tracks 3 and track 1

Comparison	Baseline Scenario	24/7 Outages Scenario
On-time Performance	100%	98.1%
Late trains	0	3 trains (3 to 5 mins late) 3 trains (5 to 7 mins late) 1 train (12.8 mins late)
Wait on Schedule	6.70% of Total Travel Time	6.09% of Total Travel Time
Delay %	1.37% of Total Travel Time	1.72% of Total Travel Time

Next Steps

- Model and simulate the following perturbations/randomizations:
  - Randomization: Initial Terminal Delay
  - Deterministic Perturbation: Mechanical Failure
  - Randomization: Dwell Time Delay
- Evaluate inclusion of Hudson and Harlem Line Trains
- Model and simulate approved service enhancements
  - Developed as part of Phase II of the CT Rail Strategies Study
  - Enhancing service to NYC – NHL and connecting lines
  - Linking cities within CT better
  - Aligned with equipment procurement
- Model and simulate approved 30-30-30 concepts
  - Hartford – New Haven
  - Hartford – Stamford
  - Hartford - NYC

Thank You.

CT*rail*Strategies

Appendix C Market Assessment

APPENDIX C - Market Assessment

CT*rail*Strategies

Memorandum

Topic:	Task 3.1 Model Selection and High Level Validation - Model Review
From:	AECOM
To:	CTDOT
Date:	October 10, 2019

The Market Assessment Task (Task 3) of the Phase 2 New Haven Line Speed and Capacity Analysis examines existing rail service, current ridership demand, and identifies and assesses the future travel demands and patterns. As part the Market Assessment, Task 3.1 reviews and selects models and conducts a high-level validation. The goal is to clarify the ways in which forecasting tools will be used, to consider non-traditional approaches to better capture the unique nature of the Connecticut travel market, to understand the trip making within the region and how demand for rail will change with expanded CT *rail* network, and to develop a post processor or other model overlay to better capture emerging markets, new services, and other factors not captured through available forecasting tools or models. The results of the model review and sensitivity tests on the selected models were presented at workshops held on July 24 and October 15, 2018. Subsequent discussions were held at the December 12, 2018 workshop and February 5, 2019 webinar.

This memorandum describes the following:

- A review of the existing models as potential methods of analysis for the CT rail market.
- Sensitivity Tests to test the existing models' effectiveness
- Selection of models for use in analysis
- Development of a post processor to summarize forecasts
- A high-level validation of the existing models

Review of Existing Models

This section documents each of the modeling approaches considered for the CT *rail* ridership forecasting effort. No *existing* forecasting tool or dataset is capable of completely capturing *all* the rail markets in Connecticut on the New Haven Line, Branch Lines, Shore Line East, and Hartford Line.

The models considered for this effort include the MTA's Regional Travel Forecasting Model (RTFM), the NEC FUTURE Interregional Ridership Model, and the Connecticut Statewide Model.

MTA's Regional Travel Forecasting Model (RTFM)

The RTFM is a modeling tool developed by the MTA to forecast traditional peak direction work trips. The model encompasses the New York City metropolitan area including Fairfield and New Haven counties in Connecticut. The model includes the entirety of the New Haven Line and Branch Lines (since they are operated by Metro North

(MNR) but does not extend to the rest of the state including areas reached by the Shore Line East and Hartford Line.

The RTFM performs well at modeling average weekday commute trips and performs assignment of ridership along transit lines at the AM peak period of 6 AM to 10 AM. Station boardings, line loads, and station to station trips can be tracked at the peak period level and factored up using survey derived peak to daily factors to estimate average weekday forecasts.

The RTFM can be modified to incorporate alternative demographic scenarios by feeding updated socioeconomic data through MTA's related Best Practices Model (BPM) which develops average weekday journeys which are then converted to trips to be used in the RTFM. For smaller demographic changes, trip tables can be factored using a Fratar model which is a model based on growth and population used to balance origins and destinations in the trip table. The RTFM zone structure, used as the geographic unit of analysis, can also be split if necessary to more finely analyze travel patterns in the travel market.

In addition, MNR has performed off-model analysis to better forecast reverse commuter and induced travel where new services are planned to be introduced. In particular, the new Bronx Stations associated with Penn Station Access (PSA) are forecasted by MNR to generate induced demand which are trips that are forecasted to be made with the introduction of new services in these areas that otherwise wouldn't exist. For scenarios in which PSA and the new Bronx stations that are planned as part of it are analyzed, the induced demand work done by MNR will be acknowledged if not included in the study. This methodology was presented by MNR staff (Tom Marchwinski) at the workshop on July 24, 2018.

Connecticut Statewide Model (CTSWM)

The Connecticut Statewide Model is a model developed for CTDOT in order to forecast statewide multimodal travel. At the time of this study the CTSWM was still in the process of being prepared for forecasting and was not available to be considered. At the travel demand webinar held on February 5, 2019, CTDOT gave an update on the status of the CTSWM stating that it was still in the process of being calibrated and other modeling efforts should be used for this analysis.

NEC FUTURE Interregional Ridership Model

The NEC FUTURE model is an interregional travel model used to forecast longer distance trips with a primary focus on intercity travel. The model area for the NEC FUTURE model includes the entire Northeast Corridor and includes Amtrak, Acela, and CT *rail* services along the Shore Line East and Hartford Line. The NEC FUTURE model forecasts trips at the annual station pair level and is factored to average weekday travel.

As the original model is designed for intercity travel, some adjustments would be necessary to use the NEC FUTURE model for analysis in this study. Updates could include adjusting the model to allow travel within 50 miles to accommodate trips happening within the travel market and updating the schedules to match existing services in the region for CT *rail*. In addition, trips made entirely on the New Haven Line could be prohibited so as not to capture the same commuter market as the RTFM.

Effectiveness of Existing Models (Sensitivity Tests)

In order to test the effectiveness of the RTFM and the NEC FUTURE model in capturing changes in the market area, a series of sensitivity tests were run on each model to test the impact of different service parameters on

ridership using 2010 trip tables.[1] Table 1 shows the sensitivity tests run through the models that were presented at the July and October 2018 workshops. Tests included decreasing headways to increase one-seat rides on various services, reducing and increasing in-vehicle travel time (IVTT), increasing fares, and through running New Jersey Transit trains through Penn Station to Stamford. For the RTFM, all sensitivity tests except test number 6 (which increased fares) were tested. For the NEC FUTURE model, only tests 3 through 6 were tested. Figure 1 and Figure 2 show the daily New Haven Line boardings in each sensitivity test. Figure 3 shows the daily boardings on the Shore Line East, Hartford Line, and New Haven Line. Test 3 (reduced trip time to GCT/PSNY) has the biggest impact while test 8 (NJT through running to Stamford) has the least impact.

Table 1: Model Sensitivity Tests

Test #	Market Test	Model Input/Variables
July 2018 Workshop		
1	Increased one-seat ride service to PSNY/GCT (NHL, Branch lines, SLE)	Increase GCT Service on inbound trains to GCT by decreasing headways by factor of 2 (e.g., from one to two trains an hour)
2	Increased one-seat ride service from Branch lines to GCT and/or PSNY	Increase GCT service from New Canaan/ Danbury by decreasing headways by factor of 2, Add Similar Service from Waterbury as Danbury with direct service
3	Reduced trip time to GCT/PSNY (express/limited stop service, improved speeds)	Factor IVTT in schedule for decreased runtime by factor of 2 (e.g., a 60-minute trip becomes a 30-minute trip)
4	Increased service frequency (peak)	Increase service by decreasing headways by factor of 2 for all inbound service
5	Increased bi-directional service	Increase reverse peak service by decreasing headways of all outbound trains by factor of 2
6	Fare policy change	Increase fares by 10%
October 2018 Workshop		
7	Increased IVTT	Factor IVTT in schedule for increased runtime by factor of 1.15
8	NJT through running to Stamford	Extend NJT service on NEC Line from PSNY to Stamford every half hour in both directions

[1] New York Metropolitan Transportation Council (NYMTC) 2010 Socioeconomic/demographic data

Figure 1: RTFM Sensitivity Tests - Daily New Haven Line Boardings from July 2018 Workshop*

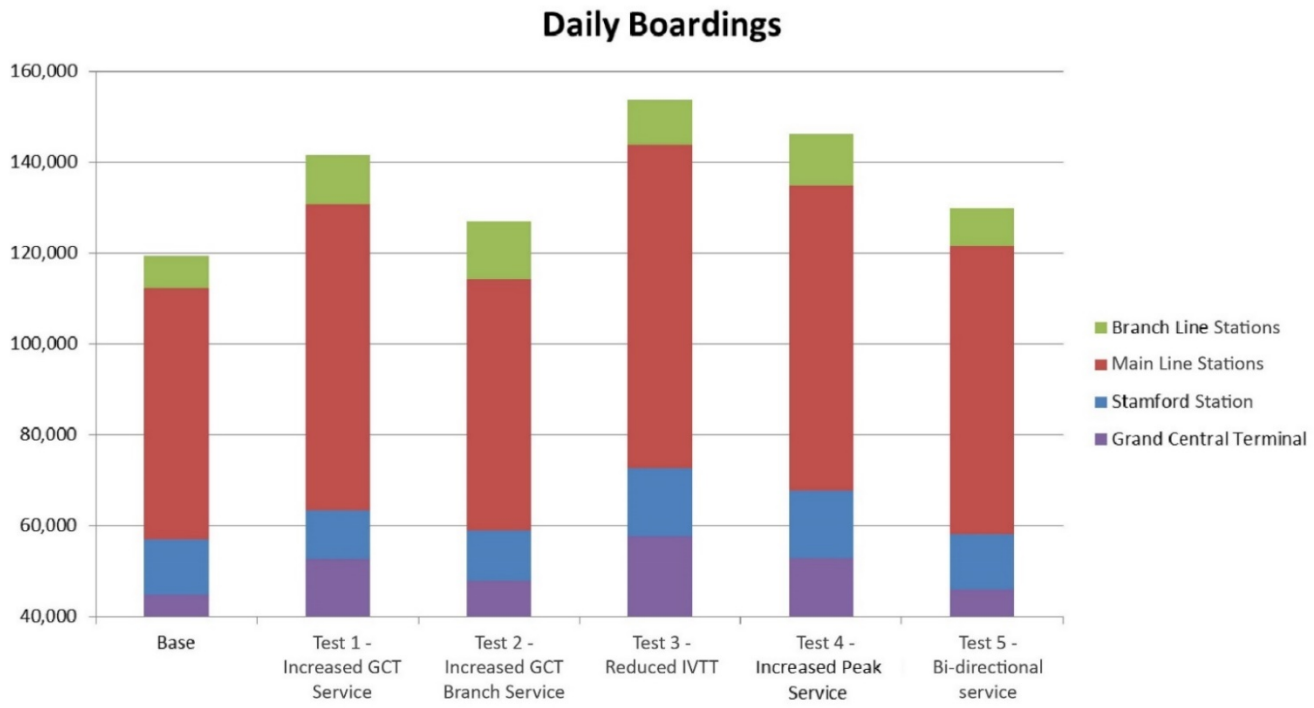
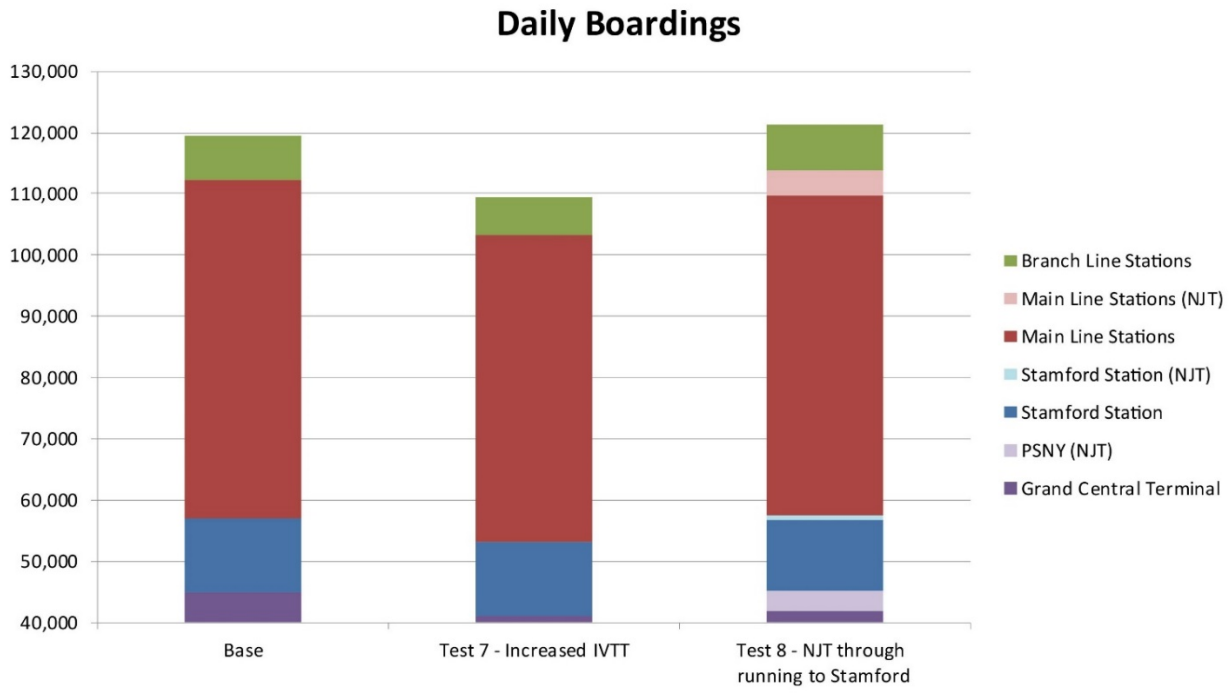
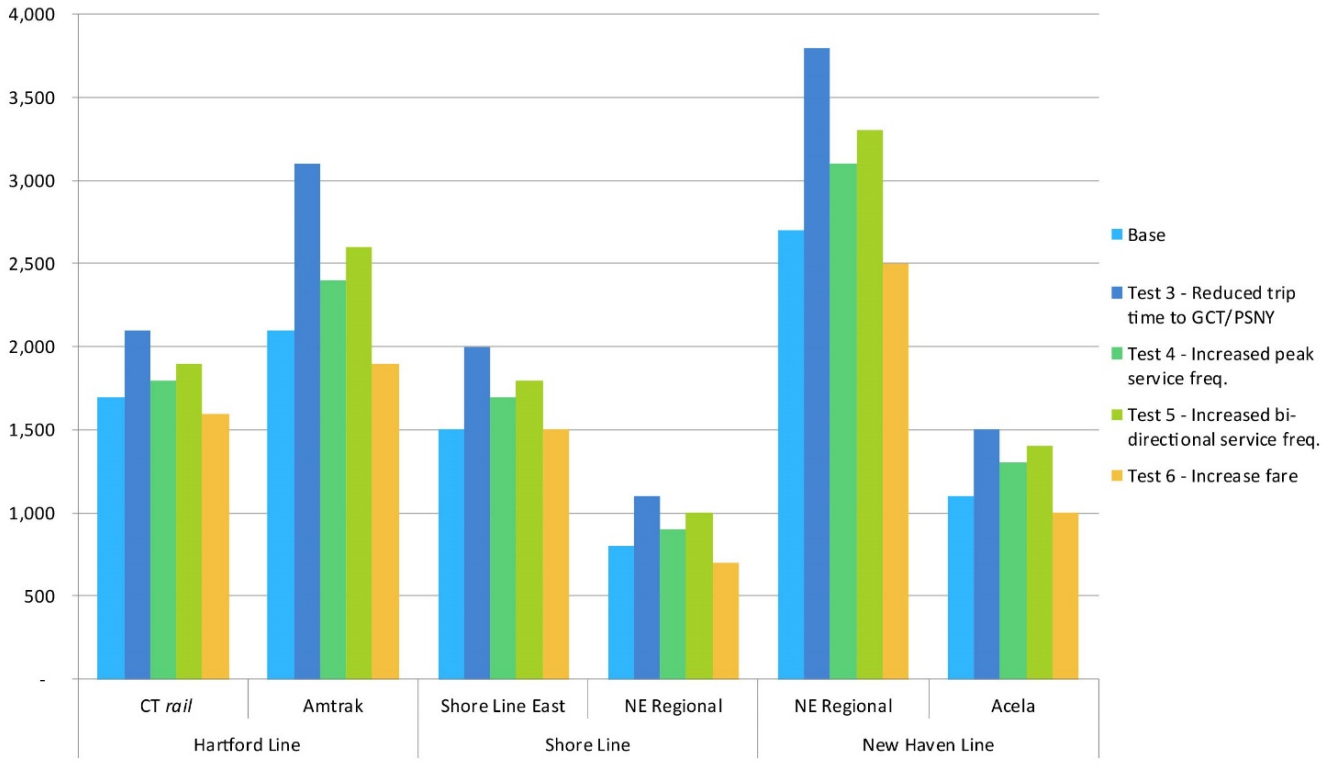


Figure 2: RTFM Sensitivity Tests - Daily New Haven Line Boardings from October 2018 Workshop*



* Note that Y-axis starts at 40,000 boarding, with all boardings below at Grand Central Terminal

Figure 3: NEC FUTURE Sensitivity Tests - Average Daily Boardings from July 2018 Workshop



After reviewing the sensitivity tests of the RTFM and the NEC FUTURE model in the July and October workshops, it was concluded that they were reasonably sensitive to changes in service.

Model Selection

After reviewing the effectiveness of the RTFM and the NEC FUTURE model, it was concluded that they were reasonably sensitive to changes in service. Thus the RTFM was selected to capture the commuter market for trips between New York City and New Haven on the New Haven and Branch Lines while the NEC FUTURE model is to be used to forecast both intercity and commuter trips along the Shore Line East and Hartford Line.

Model Application and Post Processor

In order to ensure that models captured their desired markets (RTFM for New Haven Line, NEC FUTURE for Hartford Line, Shore Line East, and Amtrak Intercity) some modifications were made to the NEC FUTURE model. First, the model was adjusted to allow for trips under 50 miles to be modeled in order to capture the commuter trips on the Shore Line East and Hartford Lines. Additionally, the model was adjusted to limit trips on the New Haven Line to those transferring from other rail lines in order to not replicate trips modeled by the RTFM. With these model updates, the RTFM and the NEC FUTURE model were to be used.

In order to generate results from each model and combine them, a common reporting from each model was developed. The RTFM generates results at an AM peak period level and the NEC FUTURE at an annual level. Each model's results used factors based on observed data to scale to the average weekday daily level. Each model

reports station to station ridership in order to track total travel between station pairs. Table 2 shows an example of how results were aggregated with the RTFM generating station to station ridership for the New Haven Line, and the NEC FUTURE model generating ridership for Hartford Line, Shore Line East, and Amtrak Northeast Corridor services. These station to station tables could then be combined or separated to track individual service level, CT *rail*, and total daily ridership between station pairs.

Table 2: Sample Station to Station Ridership Table

Station to Station Ridership	Farezone	NHL_74	NHL_74	NHL_72	NHL_71	NHL_71	NHL_71	NHL_71	NHL_1	NHL_1
Farezone	Station	DARIEN	NOROTON HEIGHTS	STAMFORD	OLD GREENWICH	RIVERSIDE	COS COB	GREENWICH	GRAND CENTRAL TERMINAL	PENN STATION
NHL_101	WATERBURY	0	0	180	0	0	0	0	170	0
NHL_101	NAUGATUCK	0	0	50	0	0	0	0	40	0
NHL_101	BEACON FALLS	0	0	80	0	0	0	0	80	0
NHL_101	SEYMOUR	0	0	20	0	0	0	0	20	0
NHL_101	ANSONIA	0	0	50	0	0	0	0	40	0
NHL_101	DERBY/SHELTON	0	0	20	0	0	0	0	20	0
NHL_92	DANBURY	0	10	50	0	0	0	10	300	0
NHL_92	BETHEL	0	0	10	0	0	0	0	80	0
NHL_92	REDDING	0	0	0	0	0	0	0	0	0
NHL_92	BRANCHVILLE	0	0	0	0	0	0	0	360	0
NHL_91	CANNONDALE	0	0	10	0	0	0	0	410	0
NHL_91	WILTON	0	0	10	0	0	0	0	260	0
NHL_91	MERRITT 7	0	10	20	0	0	0	0	300	0
NHL_73	NEW CANAAN	0	0	20	0	0	0	10	880	0
NHL_73	TALMADGE HILL	0	0	0	0	0	0	0	150	0
NHL_73	SPRINGDALE	0	0	10	0	0	0	10	430	0
NHL_73	GLENBROOK	0	0	10	0	10	0	10	270	0
NHL_82	STATE STREET	0	0	270	0	0	0	0	250	0
NHL_82	NEW HAVEN	0	0	220	0	0	0	10	700	0
NHL_82	WEST HAVEN	0	0	30	0	0	0	0	140	0
NHL_81	MILFORD	10	0	130	10	0	0	10	400	0
NHL_81	STRATFORD	10	10	160	0	0	0	10	380	0
NHL_77	BRIDGEPORT	10	10	750	0	0	10	10	1,330	0
NHL_76	FAIRFIELD METRO	10	10	130	0	0	0	10	100	0

High Level Validation

In order to validate the models for trips in the travel market, the ridership on each line and each service was compared with recent observed ridership.

For the comparison, ridership is included as:

- Hartford Line ridership if it has at least one trip end at a Hartford Line station and the other end at a Hartford Line station, a New Haven Line station, Penn Station, or Grand Central Terminal.
- Shore Line East ridership if it includes ridership that has at least one trip end at a Shore Line East station and the other end at a Shore Line East station, a New Haven Line station, Penn Station, or Grand Central Terminal.
- New Haven Line ridership if it includes ridership that has at least one trip end at a New Haven Line station and the other end at a New Haven Line station, Penn Station, or Grand Central Terminal.
- Amtrak Northeast Corridor if it has one trip end at a Shore Line East, Hartford Line, or Connecticut New Haven Line station and the other at a non-Connecticut, New Haven Line, or Grand Central/Penn Station Amtrak Northeast Corridor station.

Table 3 shows the observed and base year modeled ridership on the Hartford Line, New Haven Line, Shore Line East, and Northeast Corridor Amtrak services. The observed ridership is based on Fall 2016 New Haven Line On-Off counts, September 2018 CT *rail* and Amtrak Hartford Line counts, October 2017 Shore Line East counts, and FY 2013 Amtrak Intercity and Northeast Corridor counts. The model base year assumes 2015 model year trip tables[2] and uses current 2018 service plans (except for the Shore Line East which assumes 2017 service due to current issues with the service).

Table 3: Average Weekday Daily Ridership

Scenario	Observed (Boardings)	Model Base Year No Build (Boardings)
Line Totals		
Hartford Line (HFL - HFL/NHL/PSNY)	**1,673**	**1,620**
CT *rail* Operated	526	520
Amtrak Operated, CT *rail* Fare	270	270
Amtrak Intercity (HFL - NHL/PSNY)	877	830
New Haven Line (NHL-NHL/PSNY)	**139,769**	**143,230**
Metro North	139,220	142,560
Amtrak Intercity (NHL - PSNY)	549	670
Shore Line East (SLE-NHL/SLE/PSNY)	**2,074**	**1,990**
MNR Operated	283	280
Amtrak Operated	1,516	1,490
Amtrak Intercity (SLE - NHL/PSNY)	275	220
Amtrak Northeast Corridor (SLE/HFL/NHL-NEC)	**2,832**	**4,010**

Based on the observed data for the Hartford Line, the "CT *rail* Operated" and "Amtrak Operated, CT *rail* Fare" services were modeled together with a post processing distribution of 66% "CT *rail* Operated" to 34% "Amtrak Operated, CT *rail* Fare". Based on the observed data for the Shore Line East, the "MNR Operated" and "Amtrak Operated" services were modeled together with a post processing distribution of 16% "MNR Operated" to 84% "Amtrak Operated." As Table 3 shows, the modeled ridership is largely consistent with observed data. With the relevant model adjustments made based on these observed data, the study will proceed to Task 3.2 Market Analysis.

[2] New York Metropolitan Transportation Council (NYMTC) 2015 Socioeconomic/demographic data

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Memorandum

Topic:	Task 3.2 Market Analysis
From:	AECOM
To:	CTDOT
Date:	October 29, 2019

The Market Assessment Task (Task 3) of the Phase 2 New Haven Line Speed and Capacity Analysis examines existing rail service, current ridership demand, and identifies and assesses the future travel demands and patterns. As part the Market Assessment, Task 3.2 analyzes travel markets by examining population and employment projections as well as travel patterns. The goal is to describe the travel markets that underpin the trip making within the region and how demand for rail will change with expanded CT *rail* given the unique nature of the Connecticut travel market. Ridership forecasts were generated using the MTA's Regional Travel Forecasting Model (RTFM) for the New Haven Line and the NEC FUTURE Interregional Ridership Model for the Hartford Line, Shore Line East, and Amtrak Intercity services. The results of these two model forecasts were then combined to generate complete ridership forecasts.[1] The results of forecasts were presented at workshops held on July 24 and October 15, 2018. Subsequent discussions were held at the December 12, 2018 workshop and February 5, 2019 webinar.

This memorandum describes the following:

- Market Assessment Summaries
- Findings of the Market Assessment

Market Assessment Summaries

This section summarizes travel markets on the Hartford Line, New Haven Line, Shore Line East, and Amtrak Northeast Corridor. The metrics used for this analysis include: a review of demographic forecast data, dot density maps showing travel patterns with trip ends, and trip production and trip attraction maps.

Demographic Forecasts

Demographic forecasts provide both further validation for the Regional Transit Forecast Model (RTFM) and also act as a key input for 2025 model year ridership. Table 1 shows population and employment forecasts from the New York Metropolitan Transportation Council (NYMTC) and Connecticut MPOs.

[1] For more detail on how these model results were generated, see *Task 3.1 Model Selection and High Level Validation - Model Review Memorandum*

Table 1: Population and Employment Forecasts

AREA NAME	Total Population (in 000s)			Total Employment (in 000s)		
	2015	2025	2025/2015 Growth	2015	2025	2025/2015 Growth
NEW YORK CITY	**8,315.6**	**8,684.7**	**4.4%**	**4,776.8**	**5,239.9**	**9.7%**
Bronx	1,396.8	1,423.3	1.9%	364.5	406.9	11.6%
Brooklyn	2,529.6	2,624.0	3.7%	754.3	851.3	12.9%
Manhattan	1,620.7	1,699.8	4.9%	2,762.9	2,995.0	8.4%
Queens	2,287.5	2,430.6	6.3%	733.9	796.5	8.5%
Richmond	481.0	507.0	5.4%	161.2	190.2	18.0%
CONNECTICUT	**3,628.0**	**3,783.2**	**4.3%**	**1,984.6**	**2,150.1**	**8.3%**
Fairfield	944.7	985.5	4.3%	591.4	645.5	9.1%
Litchfield	198.2	220.8	11.4%	105.4	115.7	9.8%
New Haven	873.6	912.6	4.5%	487.2	531.2	9.0%
Hartford	898.9	923.0	2.7%	517.0	549.2	6.2%
Middlesex	166.5	172.3	3.5%	67.8	73.1	7.8%
New London	275.0	282.4	2.7%	131.1	142.5	8.7%
Windham	119.2	127.0	6.6%	42.4	46.8	10.3%
Tolland	152.0	159.7	5.1%	42.4	46.2	9.1%
MID-HUDSON	**2,369.5**	**2,534.7**	**7.0%**	**1,279.5**	**1,435.8**	**12.2%**
Dutchess	306.3	335.6	9.6%	161.6	186.6	15.5%
Orange	393.3	429.2	9.1%	186.0	207.7	11.7%
Putnam	104.2	112.1	7.6%	42.2	46.5	10.3%
Rockland	319.8	332.0	3.8%	162.6	181.7	11.7%
Sullivan	82.9	92.0	11.0%	40.4	45.2	12.0%
Ulster	192.2	213.4	11.1%	92.0	103.7	12.6%
Westchester	970.9	1,020.3	5.1%	594.6	664.4	11.7%

Source: NYMTC and CT MPOs via CTDOT

As Table 1 shows, from 2015 to 2025 the population growth of Connecticut is expected to largely mirror that of New York City (although lag Mid-Hudson growth). The projected employment growth, while significant, is slower than that of New York City or the Mid-Hudson counties. Consistent with other areas in the region, the employment growth (8.3 percent) is expected to far outpace population growth (4.3 percent). While more densely populated counties like Fairfield and New Haven will add more people and jobs, less populated counties like Litchfield and Windham are expected to grow at a faster pace (both in terms of population and jobs). These growth patterns are expected to generate new rail ridership.

Table 2 shows modeled ridership for the model base year no build and the 2025 no build, as well as the rate of anticipated growth between these time frames. The RTFM forecasts a 5 to 6 percent increase on each lines' ridership from the base year to the 2025 no build scenario.

Table 2: Average Weekday Peak Period Ridership

Line Totals	Model Base Year No Build (Boardings)	2025 No Build (Boardings)	2025 No Build – Model Base Year No Build (% Change)
Hartford Line (HFL - HFL/NHL/PSNY)	**1,620**	**1,710**	**6%**
CT *rail* Operated	520	560	8%
Amtrak Operated, CT *rail* Fare	270	280	4%
Amtrak Intercity (HFL - NHL/PSNY)	830	870	5%
New Haven Line (NHL-NHL/PSNY)	**143,230**	**150,980**	**5%**
Metro North	142,560	150,260	5%
Amtrak Intercity (NHL - PSNY)	670	710	6%
Shore Line East (SLE-NHL/SLE/PSNY)	**1,990**	**2,100**	**6%**
MNR Operated	280	290	4%
Amtrak Operated	1,490	1,570	5%
Amtrak Intercity (SLE - NHL/PSNY)	220	240	9%
Amtrak Northeast Corridor (SLE/HFL/NHL-NEC)	**4,010**	**4,250**	**6%**

As Table 1 and Table 2 show, the demographic forecasts (roughly 4 percent population growth and 8 percent employment growth for Connecticut) are consistent with modeled ridership growth (5 to 6 percent along the various lines). These data are key inputs into the RTFM.

This projected ridership is also consistent with the recent historical pattern of ridership growth along the New Haven Line since 2007. Table 3 shows the ridership activity reported by Metro-North in 2007 and 2016 along the New Haven Line as measured by boardings and alightings (i.e. ons and offs) in both the inbound and outbound direction. Ridership has grown substantially along the line (19 percent) with growth on the Main Line (20 percent) significantly outpacing that of the Branch Lines (8 percent).

Table 3 New Haven Line Ridership 2007-2016

	Weekday Ridership Activity (On + offs; Inbound + Outbound)		
Service	**2007**	**2016**	**% Change**
Branch Line Stations	7,698	8,307	8%
Grand Central Terminal	83,869	97,745	17%
Main Line Stations	226,150	270,693	20%
New Haven Line Stations	233,848	279,000	19%

Source: Metro-North Railroad Fall 2016 On/Off Counts New Haven Line

Trip Ends

Dot density maps visualizing trip ends (origins and destinations) were created to better understand market flows and travel patterns for Hartford Line, Shore Line East, and Amtrak Intercity trips. Figure 1 through Figure 6 show dot density maps generated using base year (from the NEC FUTURE model) travel patterns for trips with an origin and/or destination in Connecticut.

For each service, the first map shows trip ends (either origin or destination) within Connecticut for inter/intra-Connecticut trips. The second map shows trip ends (either origin or destination) outside Connecticut for inter-Connecticut trips. **Both figures show trip ends for intra-Connecticut trips (i.e. trips that start and end in Connecticut).**

Hartford Line

Figure 1: Hartford Line Trip Ends (Origins or Destinations) Within Connecticut for Inter/Intra-Connecticut Trips

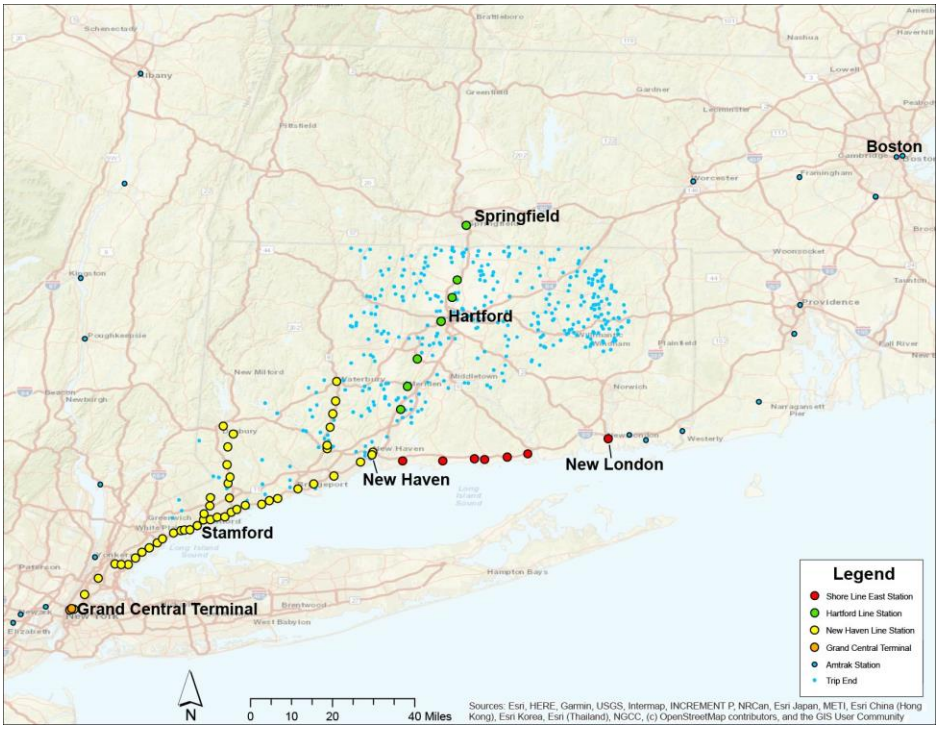


Figure 1 shows that for Hartford Line trips, trip ends in Connecticut are primarily located along the northern portion of the Hartford Line closer to Hartford, rather than the southern portion of the Hartford Line close to New Haven.

Figure 2: Hartford Line Trip Ends (Origins or Destinations) Outside Connecticut for Trips to/from Connecticut and all Hartford Line Trip Ends for Intra-Connecticut Trips

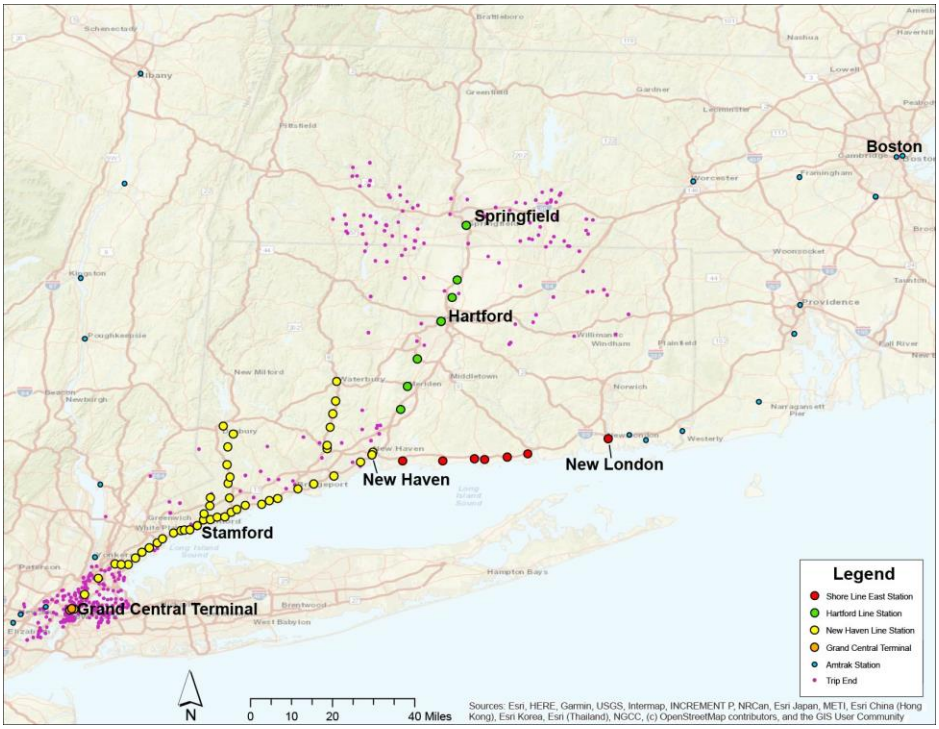


Figure 2 shows that for Hartford Line trips, trip ends outside Connecticut are primarily located in the New York metropolitan area (NY Metro area) with a smaller cluster around Springfield, MA.

Together, Figure 1 and Figure 2 demonstrate that trips along the Hartford Line connect areas around Hartford with the NY Metro area and, to a lesser extent, Springfield, MA.

Shore Line East

Figure 3: Shore Line East Trip Ends (Origins or Destinations) Within Connecticut for Inter/Intra-Connecticut Trips

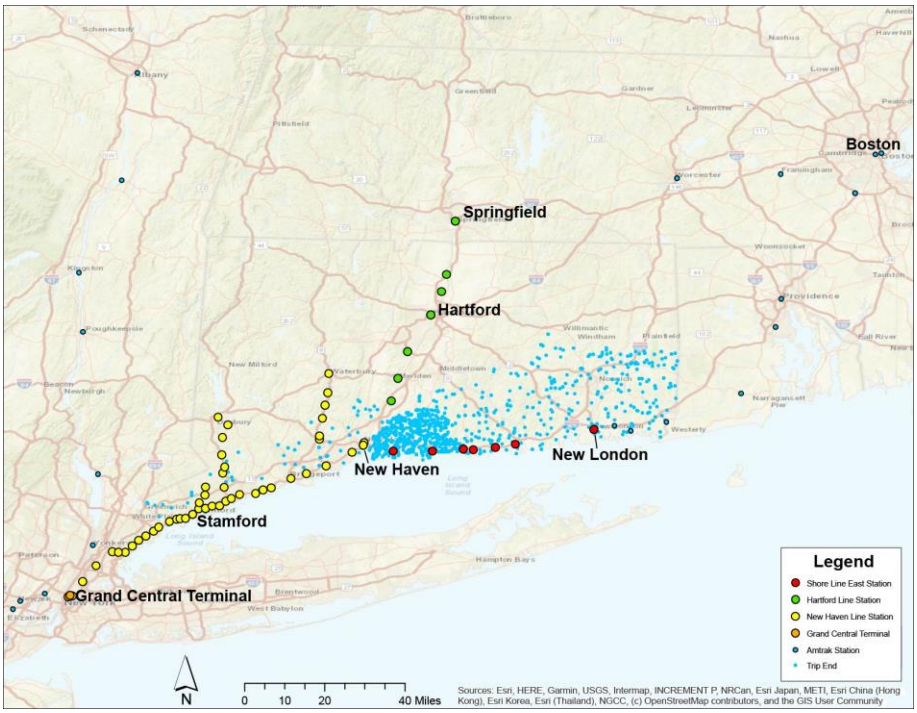


Figure 3 shows that for Shore Line East trips, trip ends in Connecticut are primarily located along the western-most portion of the line.

Figure 4: Shore Line East Trip Ends (Origins or Destinations) Outside Connecticut for Inter-Connecticut trips and all Trip Ends for Intra-Connecticut Trips

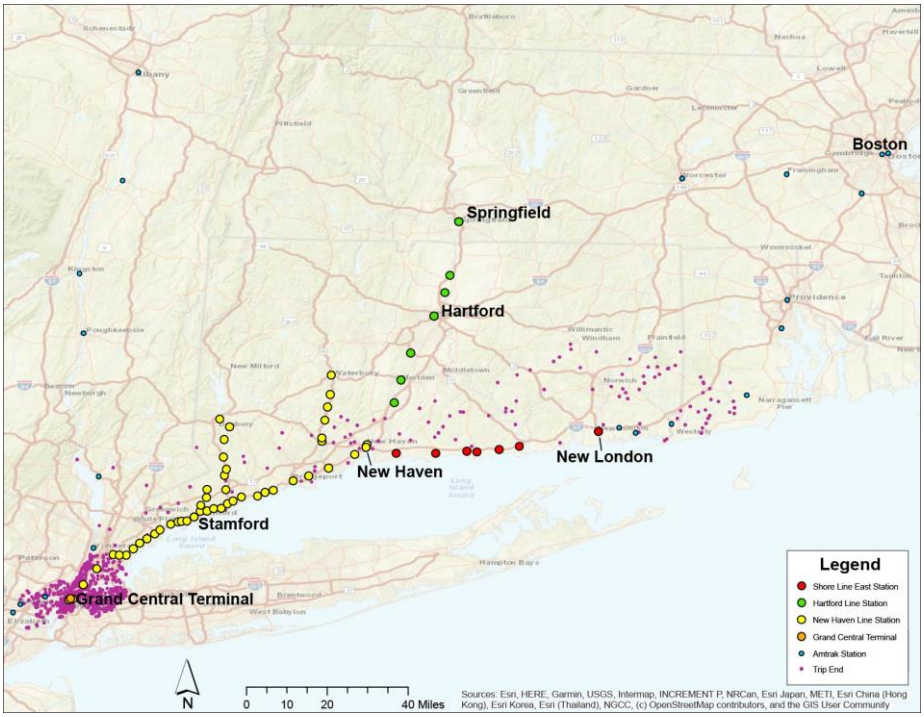


Figure 4 shows that for Shore Line East trips, trip ends outside of Connecticut are primarily located in NY Metro area.

Together, Figure 3 and Figure 4 demonstrate that most of the origins and destinations within Connecticut along the Shore Line East are clustered in the western portion of the line with these trips linked to origins and destinations almost entirely in the NY Metro area (with large clusters in Manhattan, the Bronx, Queens, and northern New Jersey).

Amtrak

Figure 5: Amtrak Intercity Trip Ends (Origins or Destinations) Within Connecticut for Inter/Intra-Connecticut Trips

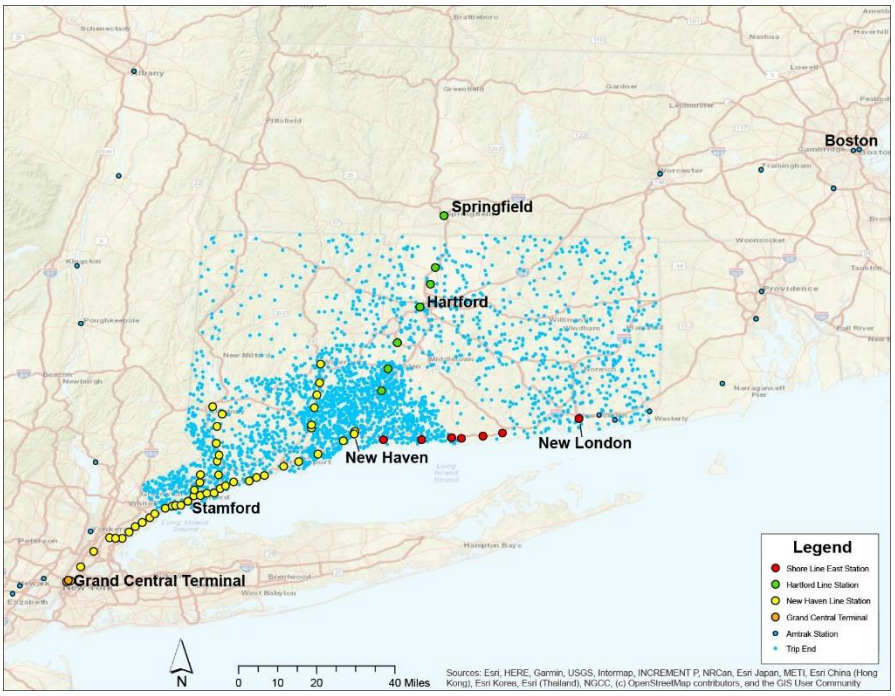


Figure 5 shows that for Amtrak trips, trip ends in Connecticut are primarily located in southwestern Connecticut, especially around New Haven.

Figure 6: Amtrak Intercity Trip Ends (Origins or Destinations) Outside Connecticut for Inter-Connecticut trips and all Trip Ends for Intra-Connecticut Trips

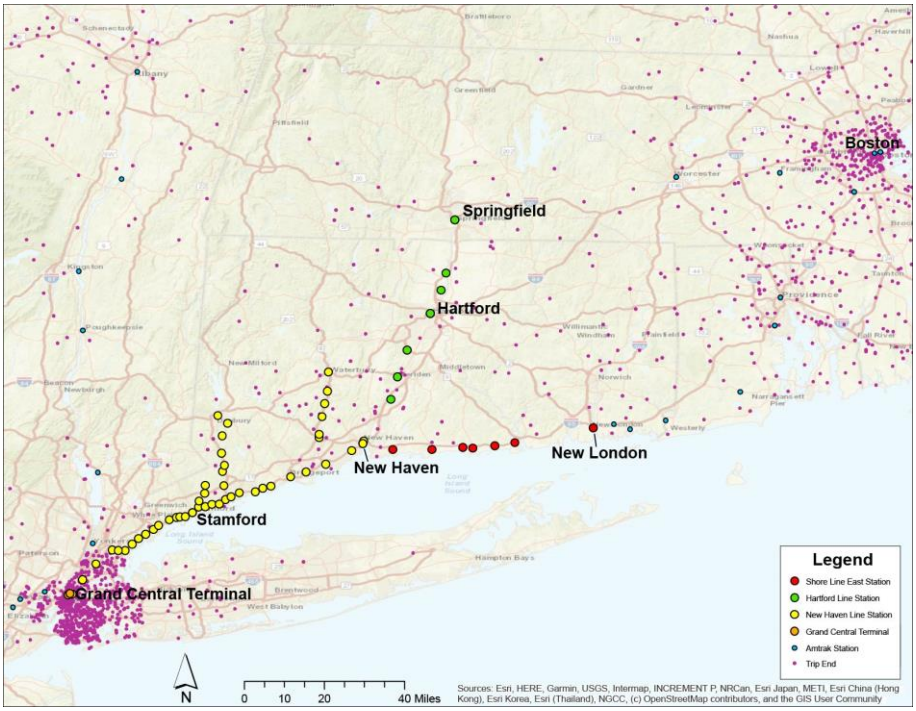


Figure 6 shows that for Amtrak trips, trip ends outside Connecticut are in the NY Metro area and around Boston.

Together, Figure 5 and Figure 6 demonstrate that both Boston and the NY Metro area are major origin and destination hubs for Amtrak intercity trips and that these trips seem to primarily be serving origins and destinations in Southwestern Connecticut, especially around New Haven.

Trip Production and Trip Attraction – New Haven Line

Trip production and attraction analysis was also performed in order to better understand travel patterns along the New Haven Line in both peak and reverse peak directions. Figure 7 and Figure 8 show the trip production and attraction ends of peak direction travel for the New Haven Line (generated using the RTFM model). These trips reflect productions and attractions for trips traveling southbound towards Manhattan in the AM peak period. Figure 9 and Figure 10 reflect reverse peak productions and attractions for reverse commuters on the New Haven Line. These trips reflect travel in the northbound from Manhattan direction in the AM peak period.

Figure 7: New Haven Line Peak Direction Trip Productions

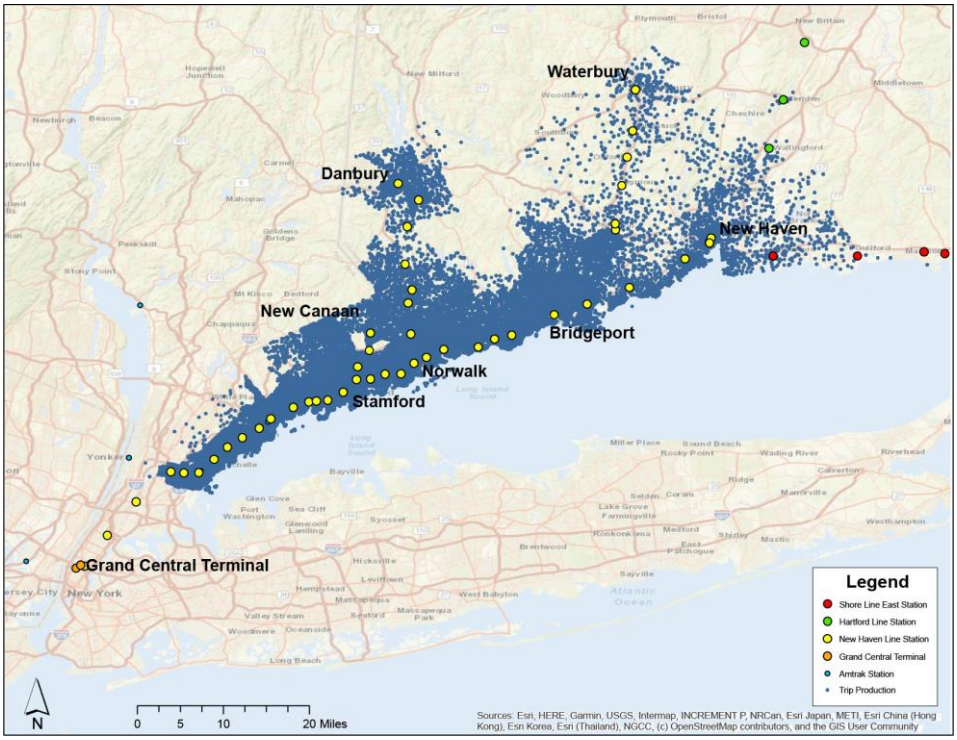


Figure 8: New Haven Line Peak Direction Trip Attractions

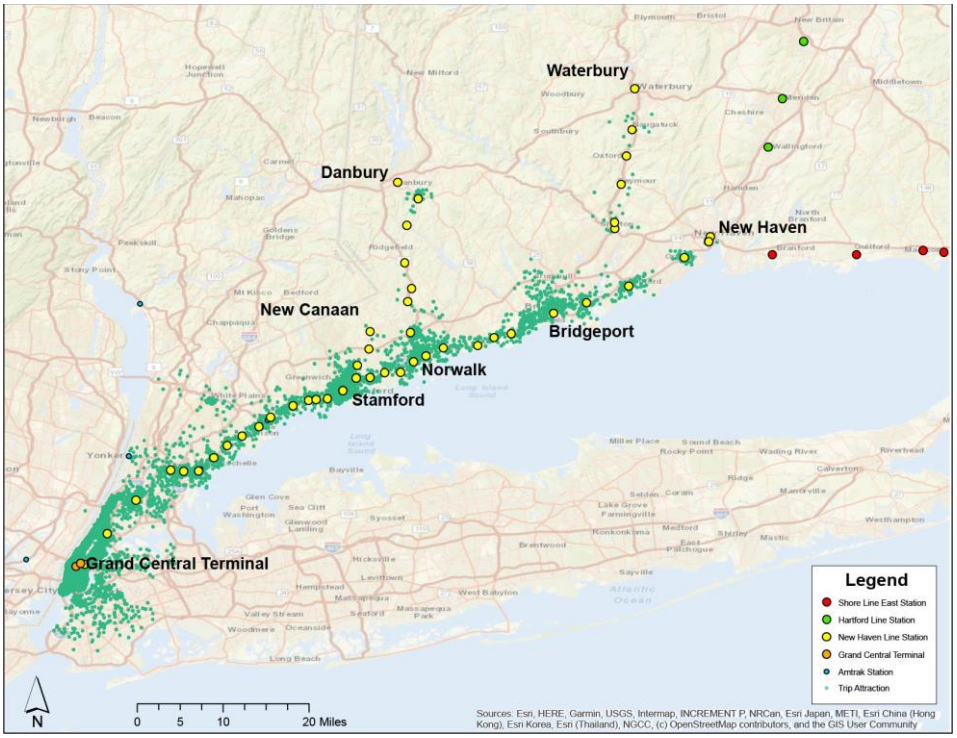


Figure 7 and Figure 8 demonstrate that while both attractions and productions tend to cluster along the Main Line, areas along the Branch Lines feature many more productions than attractions, suggesting possible peaking issues and opportunities for land use diversification tied to Transit Oriented Development (TOD). There are also many more trip productions along the New Canaan and Danbury Branches than the Waterbury Branch. Most peak direction trip attractions are clustered in New York City and along the Main Line, with particularly strong clusters in the established urban areas of Stamford, Norwalk, and Bridgeport.

Figure 9: New Haven Line Reverse Peak Direction Trip Productions

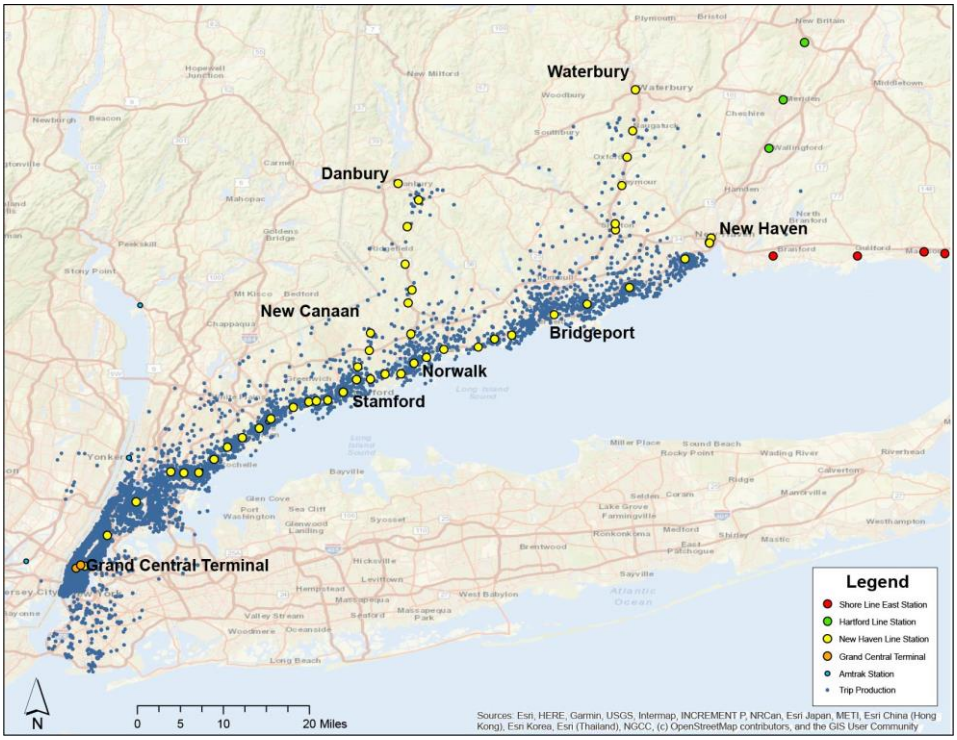


Figure 10: New Haven Line Reverse Peak Direction Trip Attractions

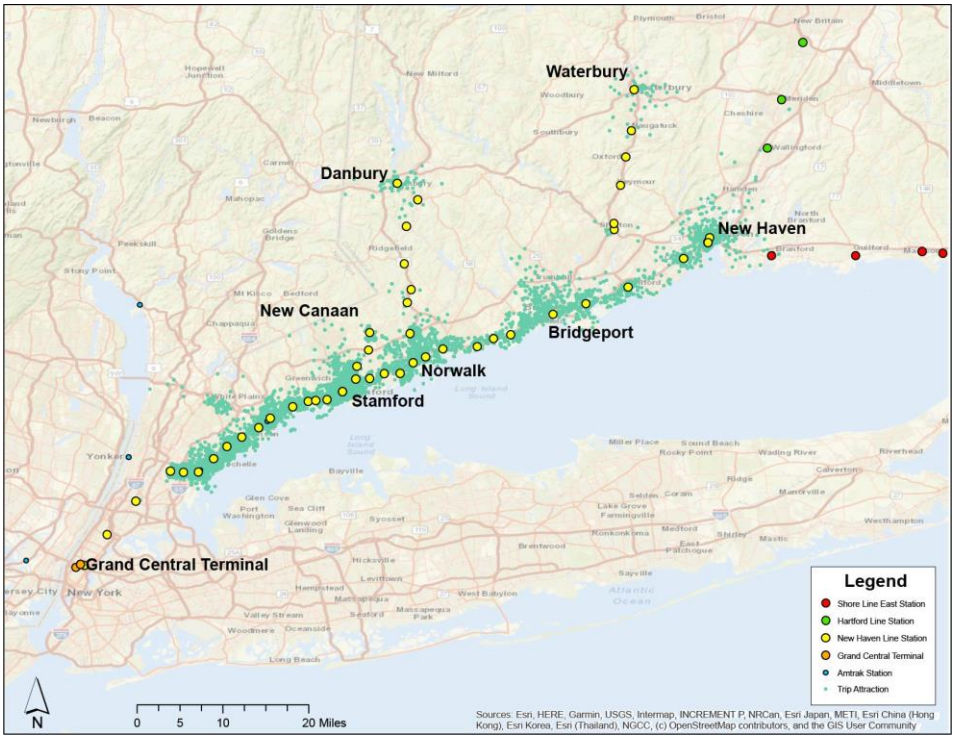


Figure 9 and Figure 10 demonstrate that, as is the case for peak direction, reverse peak attractions and productions cluster along the Main Line. However, areas served by the Danbury and Waterbury Branch Lines host few reverse peak attractions or productions with the exception of small clusters of attractions near Danbury and Waterbury stations. Reverse peak attractions have dense clustering around the Main Line stations in established urban areas such as White Plains, Stamford, Norwalk, Bridgeport, and New Haven. Productions cluster in New York City (especially Manhattan and the Bronx).

Findings of the Market Assessment

This section summarizes they key findings of the market assessment.

Demographics

Both jobs and population are expected to experience continual growth in Connecticut, with the growth of jobs outpacing that of population. This, combined with historical ridership trends, suggest continued ridership growth.

Hartford Line, Shore Line East, and Amtrak Intercity

The Hartford Line, Shore Line East, and Amtrak trips are primarily connecting Connecticut passengers to the NY Metro area. Hartford Line trips primarily connect areas around Hartford with the NY Metro area and, to a lesser extent, Springfield, MA. Shore Line East trips primarily connect the westernmost stations of the Shore Line East with the NY Metro area. Amtrak Intercity trips primarily connect southwestern Connecticut with the NY Metro area, and to a lesser extent, Boston, MA.

New Haven Line

The Main Line hosts many attractions and productions along the entire length of the line, with major urban areas such as Stamford, Norwalk, Bridgeport, and New Haven generating robust trip patterns in both peak and counter-peak directions.

Areas that the Branch Lines serve (especially Danbury and Waterbury) generate many more peak productions than peak attractions and few reverse peak productions or attractions. This suggests possible underutilized capacity and opportunity along these lines.

New York City is a major hub both for jobs that peak direction commuters travel to and residences that reverse peak commuters travel from.

CT*rail*Strategies

Memorandum

Topic:	Task 3.3 Assess Future Needs and Demands
From:	AECOM
To:	CTDOT
Date:	October 14, 2019

The Market Assessment Task (Task 3) of the Phase 2 New Haven Line Speed and Capacity Analysis examines existing rail service, current ridership demand, and identifies and assesses the future travel demands and patterns. As part the Market Assessment, Task 3.3 assesses future needs and demand. Future needs and demands were analyzed using two series of forecasts: one using base demographic inputs determined by approved regional demographic forecasts (e.g. NYMTC, Moody's, etc.) and one using demographics inputs generated by a scenario planning exercise to estimate the longer-term potential for TOD development along the Hartford Line. The base forecast findings were presented at a workshop held on December 12, 2018 and a webinar on February 5, 2019.

This memorandum describes the following:

- Summary of the service plan concepts developed in Task 4 and tested as part of Task 3
- Results of the base demographics ridership forecasts
- Results of the future scenario longer-term TOD potential ridership forecasts

Service Plan Concepts

This section summarizes the service plan concepts developed in Task 4 and tested in Task 3. These two concepts, along with a 2025 No Build scenario, were modeled using the base demographics. Only Concept 1 was modeled as an example for the longer-term TOD scenario.

Concept 1 – Penn Station Express/ Keystone Extension (NYX)

The Penn Station Express (NYX) concept focuses on extending Amtrak Keystone trains with service to Hartford. The concept includes 10 new trips per day from Penn Station, six of which are extensions from Philadelphia which will have limited increase in one seat rides along the Amtrak portion of the New Haven Line and 10 new trips serving the Hartford Line with new trips in the AM and PM peaks.

Concept 2 – Grand Central Terminal Focus/ GCT Limited (GCX)

The GCT Limited (GCX) concept focuses on increasing service to Grand Central Terminal along the Metro North operated New Haven Line and CT *rail* operations on the Hartford Line. The concept includes 12 new trips per day with service to Grand Central Terminal, 10 of which will provide new service on the Hartford Line and replacing two existing CT *rail* trains. This concept increases a range of one-seat rides on the MNR operated New Haven Line with new trips in the Peak and Off-Peak Periods.

Base Demographics Ridership Forecasts

This section documents the forecast results using the base demographic inputs. Using these demographic inputs, 3 scenarios were modeled: 2025 No Build, 2025 NYX, and 2025 GCX.

The results of these forecasts are described by several measures including:

- Average weekday ridership by selected station pair
- Average weekday ridership at key stations
- Summaries of Intra-State and Inter-State Connecticut Trips
- Average weekday ridership through key screenline locations
- Thematic maps of flows for key markets

Base Demographics Ridership Forecast Results

Table 1 shows the 2025 average weekday ridership between key station pairs in the travel market with total trips between the Manhattan stations of Penn Station (PSNY)/Grand Central Terminal (GCT) and stations in New Haven and Hartford in Connecticut. In the NYX scenario, the largest growth is between Hartford and PSNY with increased Amtrak service in the scenario. For the GCX scenario trips increase to GCT from both Hartford and New Haven with the increased service along the MNR New Haven Line and up through the Hartford Line.

Table 1 – 2025 Average Weekday Ridership between Station Pairs

	Scenario				
Station Pairs (Total)	2025 No Build	2025 NYX	2025 NYX – 2025 No Build (% Change)	2025 GCX	2025 GCX - 2025 No Build (% Change)
PSNY - New Haven	440	460	5%	440	0%
PSNY - Hartford	250	360	44%	250	0%
GCT - New Haven	3,960	3,960	0%	4,070	3%
GCT - Hartford	250	290	16%	310	24%

Table 2 shows the 2025 total average weekday ridership at selected key stations in the travel market. The ridership is a total of trips to and from the stations. For the NYX scenario, ridership mainly increases at Hartford and Penn Station with limited increases along the New Haven Line as the increased trains are Amtrak operated with higher fares and less stops than the MNR operated services. For the GCX scenario there is a more moderate increase in ridership at Hartford than the NYX scenario, but ridership increases at New Haven Line stations are more significant with the new MNR and CT *rail* operated services.

Table 2 – 2025 Average Weekday Ridership at Key Stations

Key Stations (Total)	Scenario				
	2025 No Build	2025 NYX	2025 NYX – 2025 No Build (% Change)	2025 GCX	2025 GCX – 2025 No Build (% Change)
Penn Station	27,230	27,440	1%	27,220	0%
Grand Central Terminal	116,120	116,180	0%	116,730	1%
Greenwich	8,190	8,200	0%	8,140	-1%
Stamford	31,020	31,060	0%	31,220	1%
New Haven (Union & State Street)	10,390	10,440	0%	10,800	4%
Hartford	860	1,090	27%	940	9%

Table 3 shows the 2025 average weekday intra-state and inter-state ridership of Connecticut rail trips. Approximately 20 percent of rail trips from Connecticut stations are intra-state trips while the remaining 80 percent are inter-state trips either to New York or other North East Regional destinations. The NYX scenario primarily increases inter-state travel (Amtrak trips) with limited connectivity to the Connecticut portion of the New Haven Line. The GCX scenario has a more significant increase in intra-state ridership with the additional MNR and CT *rail* service in Connecticut.

Table 3 – 2025 Average Weekday Intra-State and Inter-State Connecticut Trips

Trip Types	Scenario				
	2025 No Build	2025 NYX	2025 NYX - 2025 No Build (% Change)	2025 GCX	2025 GCX - 2025 No Build (% Change)
Intra-State Trips within CT	21,290	21,370	0%	21,990	3%
Inter-State Trips to/from CT	92,130	92,740	1%	92,550	0%
Total Connecticut Trips	*113,420*	*114,110*	*1%*	*114,540*	*1%*

Table 4 shows the 2025 average weekday ridership traveling through screenline locations at New Rochelle, Stamford, and New Haven for trips traveling along the New Haven Line on MNR or Amtrak intercity trains for trips between Connecticut and the New York metropolitan area. The screenline volumes include all trips entering, exiting, or traveling through the stations at these locations. In the NYX scenario both New Haven and Stamford increase in ridership by about 300 trips per day on Amtrak intercity trips to/from Penn Station from the Hartford Line. For the GCX scenario there is a more significant increase in volume at Stamford than New Haven with the new services attracting New Haven Line ridership.

Table 4 – 2025 Average Weekday Ridership through Screenline Locations

Trips Traveling Through Screenline	Scenario				
	2025 No Build	2025 NYX	2025 NYX - 2025 No Build (% Change)	2025 GCX	2025 GCX - 2025 No Build (% Change)
New Rochelle	122,010	122,310	0%	122,460	0%
Stamford	86,480	86,820	0%	87,190	1%
New Haven - SLE	2,060	2,060	0%	2,060	0%
New Haven - Hartford Line	1,500	1,840	23%	1,660	11%

Figure 1, Figure 2, and Figure 3 show average weekday trip flows between and within the New Haven Line (NHL), the Hartford Line (HFL), Shore Line East (SLE), and and the Northeast Corridor (NEC) in the area for the No Build, Penn Station Express, and GCT Limited scenarios for year 2025. The Penn Station Express primarily sees growth on the Hartford Line to Hartford Line, New Haven Line, and Northeast Corridor trip flows. The GCT Limited scenarios has its primary growth on New Haven Line trips with some growth on Hartford Line to New Haven Line flows.

Figure 1 - Year 2025 No Build Average Weekday Trip Flows

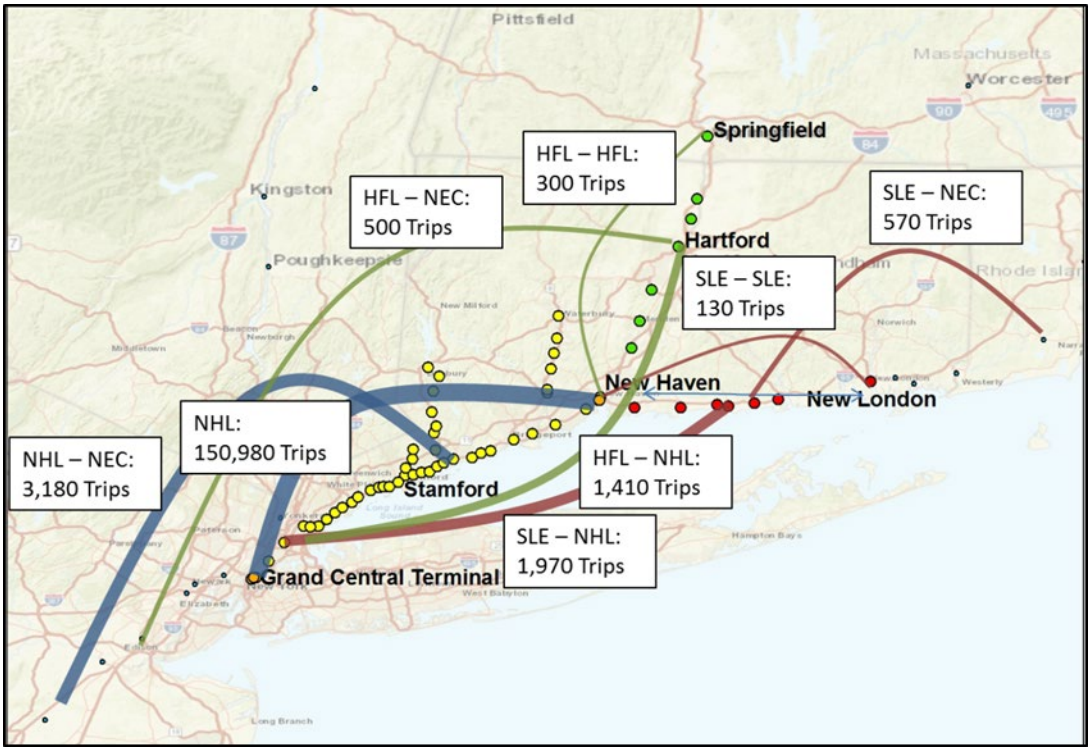


Figure 2 - Year 2025 Penn Station Express Daily Trip Flows

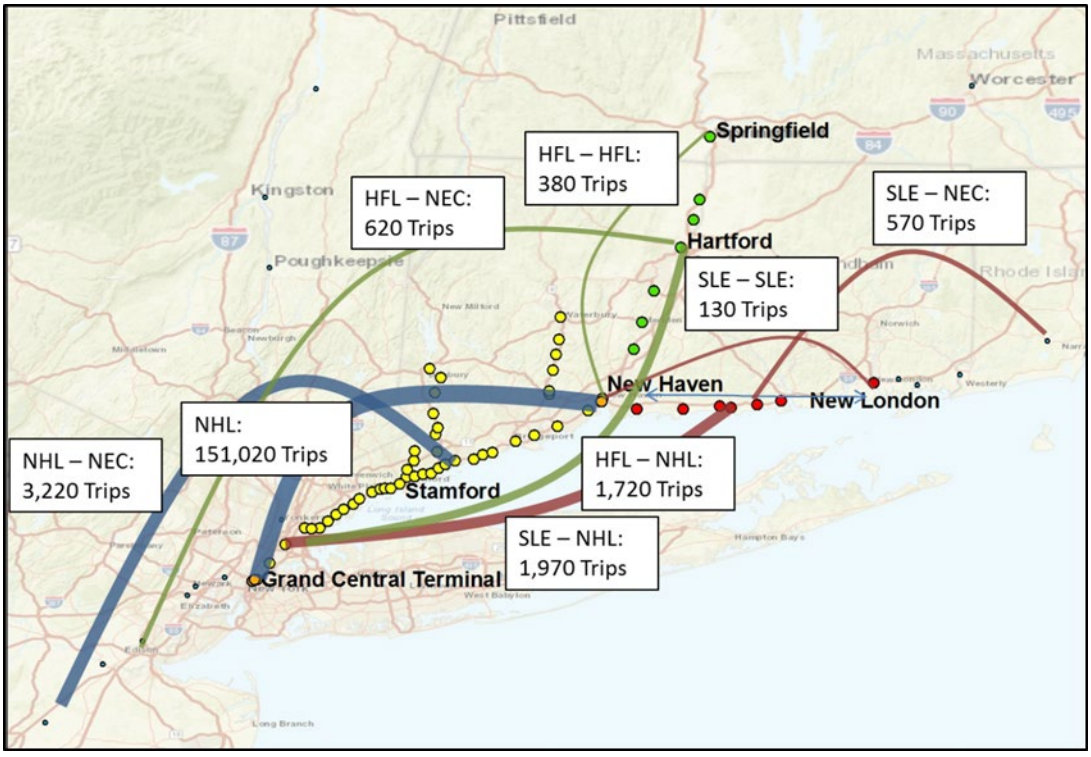


Figure 3 - Year 2025 Grand Central Limited Daily Trip Flows

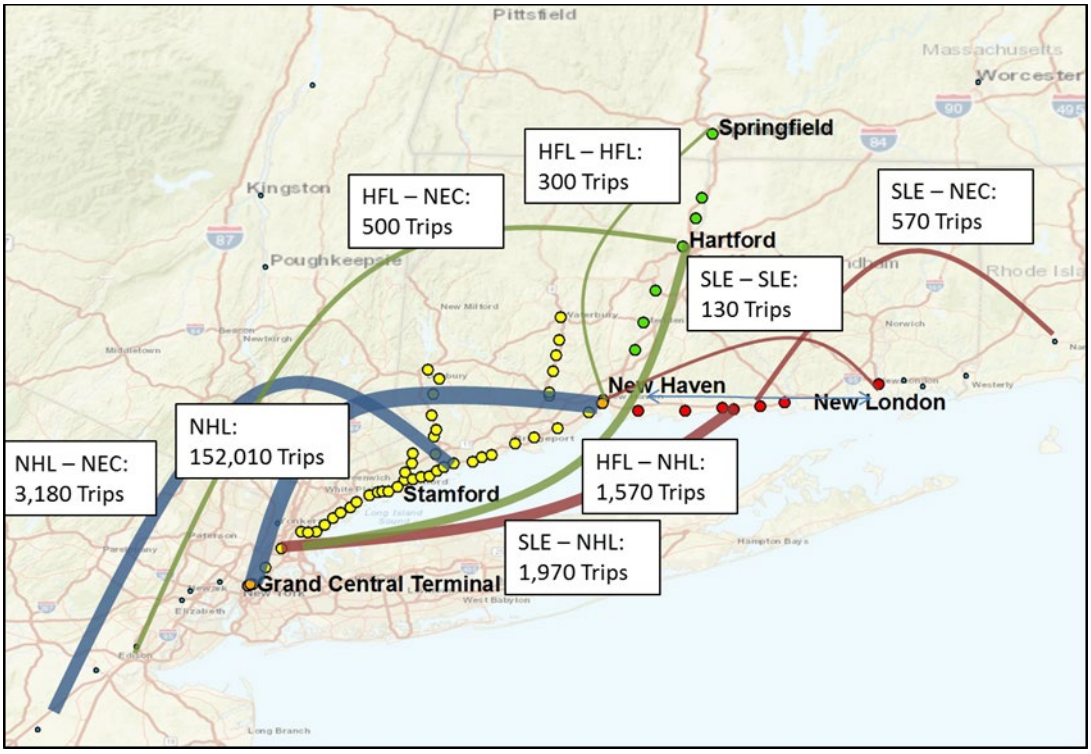


Table 5 shows the average weekday ridership by line for the Base Year, the 2025 No Build scenario, and each of the tested concepts for the base demographic forecasts. For comparison, ridership is included as:

- Hartford Line ridership if it has at least one trip end at a Hartford Line station and the other end at a Hartford Line station, New Haven Line station, Penn Station, or Grand Central Terminal,
- Shore Line East ridership if it includes ridership that has at least one trip end at a Shore Line East station and the other end at a Shore Line East station, New Haven Line station, Penn Station, or Grand Central Terminal.
- New Haven Line ridership if it includes ridership that has at least one trip end at a New Haven Line station and the other end at a New Haven Line station, Penn Station, or Grand Central Terminal.
- Amtrak Northeast Corridor if it has one trip end at a Shore Line East, Hartford Line, or Connecticut New Haven Line station and the other at a non-Connecticut, New Haven Line, or Grand Central/ Penn Station Amtrak Northeast Corridor station.

The Hartford Line has a 23% increase in ridership relative to the No Build in the NYX scenario primarily coming from the Amtrak Intercity ridership with extended trains from Penn Station to Hartford. The GCX has more modest increases in Hartford Line ridership, though there is a more significant increase in New Haven Line ridership with the additional MNR trains servicing the line. The Shore Line East does not have any service changes in these scenarios and has consistent ridership with the No Build.

Table 5 - Average Weekday Ridership by Line

	Scenarios						
Line Totals	**Base Year No Build**	**2025 No Build**	**2025 No Build - Base No Build (% Change)**	**2025 NYX**	**2025 NYX - 2025 No Build (% Change)**	**2025 GCX**	**2025 GCX - 2025 No Build (% Change)**
Hartford Line (HFL - HFL/NHL/PSNY)	1,620	1,710	6%	2,100	23%	1,870	9%
CT *rail* Operated	520	560	8%	610	9%	670	20%
Amtrak Operated, CT *rail* Fare	270	280	4%	320	14%	340	21%
Amtrak Intercity (HFL - NHL/PSNY)	830	870	5%	1,170	34%	870	0%
New Haven Line (NHL-NHL/PSNY)	143,230	150,980	5%	151,020	0%	152,010	1%
Metro North	142,560	150,260	5%	150,260	0%	151,300	1%
Amtrak Intercity (NHL - PSNY)	670	710	6%	750	6%	710	0%
Shore Line East (SLE-NHL/SLE/PSNY)	1,990	2,100	6%	2,100	0%	2,100	0%
MNR Operated	280	290	4%	290	0%	290	0%
Amtrak Operated	1,490	1,570	5%	1,570	0%	1,570	0%
Amtrak Intercity (SLE - NHL/PSNY)	220	240	9%	240	0%	240	0%
Amtrak Northeast Corridor (SLE/HFL/NHL-NEC)	4,010	4,250	6%	4,410	4%	4,250	0%

Order of magnitude "planning level" estimates of revenue for each scenario were also generated. Table 6 shows the 2018 average revenue generated per ride on the MNR New Haven Line, **CT *rail*** Hartford Line, and Shore Line East. These average revenues per ride were used to estimate the additional revenue per trip from each tested concept with NHL rides generating about $8.77, Hartford Line rides generating about $6.01 and Shore Line East generating about $4.30. Table 7 shows estimated revenue per ride from each line for Amtrak Intercity services. In order to estimate the Amtrak revenue, 2013 station to station fare assumptions were used and scaled to 2018 dollars. These station to station fares were then applied to modeled ridership to estimate total revenue.

Table 8 shows the estimated change in revenue for the 2025 modeled concepts relative to the No Build scenario using the average fare per ride for MNR and **CT *rail*** services and station to station fare assumptions for Amtrak Intercity. The NYX scenario generates most of its revenue on increase of NEC Regional trips with the extended Keystone services to Hartford creating an extended travel market. The GCX scenario generates more total trips, but less revenue as most are on the MNR New Haven Line.

Table 6 – Average Revenue per Ride on CT *rail* and Metro North Services in 2018 Dollars

	New Haven Line	Hartford Line	Shore Line East
	2018 Total	Year 18	Year 18
Revenue	$ 353,690,840	$ 853,721	$ 2,258,611
Tickets	16,091,981	N/A	N/A
Rides	40,298,687	142,096	524,981
Revenue/Ride	$ 8.78	$ 6.01	$ 4.30

Table 7 – Average Revenue per Ride on Intercity Amtrak Services in 2018 Dollars

	2025 No Build	2025 NYX	2025 GCX
New Haven Line	$ 38.87	$ 37.60	$ 38.87
Hartford Line	$ 44.14	$ 40.17	$ 44.14
Shore Line East	$ 57.92	$ 57.92	$ 57.92
Northeast Corridor	$ 99.84	$ 99.09	$ 99.84

Table 8 – Average Weekday Revenue by Line

Average Weekday Forecasts	2025 No Build		2025 NYX				2025 GCX			
	Ridership	Revenue ($ 2018)	Ridership	Revenue ($ 2018)	Ridership Change	Revenue Change	Ridership	Revenue ($ 2018)	Ridership Change	Revenue Change
Hartford Line										
CT Rail Operated + Amtrak Operated, CT Rail Fare	840	$ 5,050	930	$ 5,590	90	$ 540	1,010	$ 6,070	170	$ 1,020
Amtrak Intercity	870	$ 38,400	1,170	$ 47,000	300	$ 8,600	870	$ 38,400	0	$ 0
New Haven Line										
Metro North	150,260	$1,318,790	150,260	$1,318,790	0	$ 0	151,300	$1,327,920	1,040	$ 9,130
Amtrak Intercity	710	$ 27,600	750	$ 28,200	40	$ 600	710	$ 27,600	0	$ 0
Shore Line East										
MNR Operated + Amtrak Operated	1,860	$ 8,000	1,860	$ 8,000	0	$ 0	1,860	$ 8,000	0	$ 0
Amtrak Intercity	240	$ 13,900	240	$ 13,900	0	$ 0	240	$ 13,900	0	$ 0
Amtrak Northeast Corridor	4,250	$424,300	4,410	$ 437,000	160	$ 12,700	4,250	$ 424,300	0	$ 0

Transit Oriented Development (TOD) Demographics Ridership Forecasts

In order to better understand how development patterns around existing and planned mass transit stations along the Hartford Line may impact future ridership, a future scenario with hypothetical assumptions about changes in demographics with a transit-oriented development emphasis (TOD scenario) were developed to test the effect on overall ridership.

TOD Demographic Input Estimation Methodology[1]

The approach to estimating population and employment changes based on a potential TOD scenario was derived from a 2017 study by the Regional Plan Association (RPA), which assessed TOD potential for 328 commuter rail stations across three states in the New York Metro Area.[2] The RPA study estimated available developable space by calculating the average amount of land dedicated to surface parking within ½-mile of the 97 stations located within a 45-minute commute shed of New York City.

The approach used for this task started by identifying, measuring, and cataloging all sites with significant amounts of surface parking (or undeveloped lots) within a ½-mile radius of each station. Parcels that were strong candidates for TOD but located just outside the ½-mile radius were also included. Sites smaller than 20,000 sf or known to have significant redevelopment challenges were eliminated. Windshield surveys were then conducted

[1] A high-level summary of the TOD methodology is presented here. See Appendix A for a more detailed description of this process
[2] Regional Plan Association. *Untapped Potential. Opportunities for Affordable Homes and Neighborhoods Near Transit*. November 2017.

by a two-person team resulting in 20 sites deemed unsuitable for TOD due to recent development or incompatible surrounding land uses.

Parcels that were included in existing planning documents were consolidated into one potential development area for each plan (e.g. 24 discrete parcels identified in New Haven's Hill to Downtown Plan were replaced with one site designated "Hill to Downtown Plan"). Sites that were designated as part of local development plans were assigned FAR and land uses based on the relevant study.

The 71 remaining sites that were not included in any municipal planning documents were evaluated on three metrics:

- *Urban Center Typology* - Each station area was assigned one of three urban center typologies based upon the typologies developed in the RPA study: stations in New Haven and Hartford were categorized as "jobs center large," sites in Meriden and West Hartford were categorized as "jobs center medium," and sites in Wallingford and Newington were categorized as "village centers."

- *Distance from Station* - Sites were designated as either "periphery" or "adjacent" depending on their proximity to the station. Sites adjacent to the station were assumed to be able to support a higher FAR than those on the periphery.

- *Utilization* - Sites that were undeveloped, fully occupied by surface parking, or contained buildings that were considered able to be demolished were categorized as "vacant," with 100 percent of the land considered available for TOD. Sites that had buildings on site that would be difficult or unlikely to demolish were categorized as "underutilized," with only 65 percent of the land considered available for TOD. In both cases, 90 percent of the land available for TOD was considered to be available for development. The remaining 10 percent was reserved for right-of-way and public spaces and was removed from developable area calculations.

Total square footage of developable floor area was calculated for each station site using the area, factor of land availability, and assumed FAR. Based on the urban center typology previously assigned, square footage was divided into three potential uses: residential, commercial, and high-tech manufacturing. Residential uses were divided by 1,165 sf[3] to determine an estimated number of dwelling units, which was then multiplied by 2.5 to determine an estimated number of residents. The number of jobs[4] created was estimated by assigning four jobs for every 1,000 sf of commercial space and two jobs for every 1,000 sf of high-tech manufacturing space. These estimates were then combined with estimates from parcels that were part of local development plans.

The results of these estimates are summarized by municipality in Table 9.

[3] Average size of new multi-family housing units built in the northeast region in 2017, according to the Census Bureau's 2017 Characteristics of New Housing Report.
[4] Jobs are new, permanent, non-construction jobs estimated to be created in commercial and high-tech manufacturing establishments.

Table 9 TOD Demographics Estimates by Municipality

Municipality	Total Developable Area (sf)	Population	Jobs
New Haven[1]	16,758,005	21,405	17,213
Wallingford	216,893	140	152
Meriden	1,443,143	2,898	3,151
Hartford	2,320,256	13,263	11,391
Newington	1,321,761	1,378	1,499
West Hartford[2]	2,190,625	8,610	9,362
TOTAL	**24,250,683**	**47,694**	**42,768**

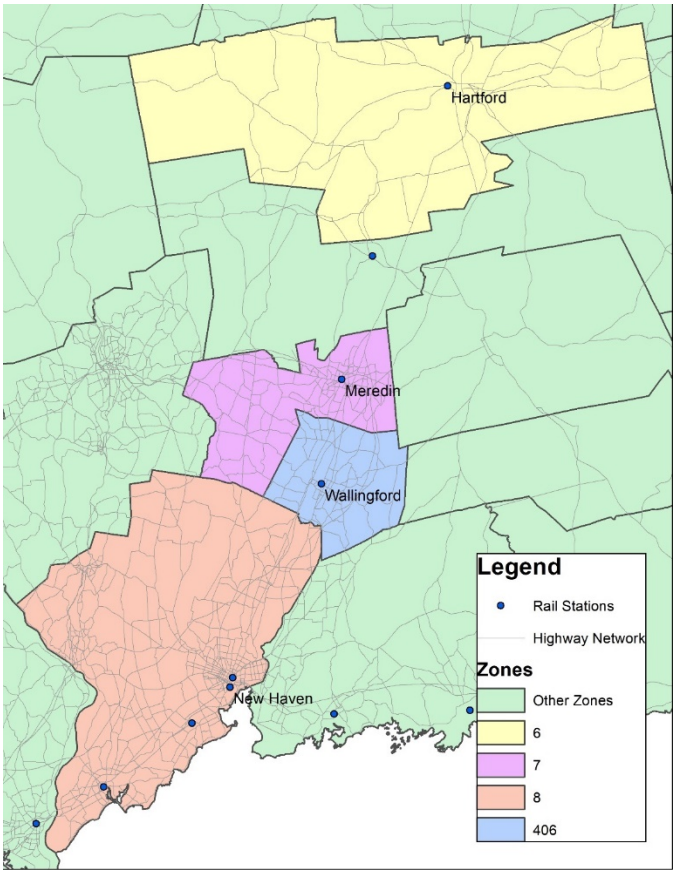
(1) Summary includes all sites that are within 1/2 mile of Union Station and/or State Street Station

(2) Because the proposed West Hartford station is on the town's border with Hartford, some sites listed in this row are located within the City of Hartford

TOD Demographics Ridership Forecasts Methodology

These estimates were then used as demographic inputs for a ridership forecast using the NEC FUTURE Interregional model in order to estimate changes in ridership as a result of the TOD development. Only four Traffic Analysis Zones (TAZs) were affected by the updated demographic estimates. Figure 4 shows the NEC FUTURE TAZs affected by the TOD estimates.

Figure 4 NEC FUTURE TAZs affected by TOD Demographic Input Changes



In order to account for the comparatively high station access (and thus higher propensity to travel) that characterizes these TOD developments, the added jobs and population numbers were weighted in order to generate more total trips. Table 10 compares the model's 2025 base demographic inputs with the 2025 TOD demographic inputs.

Table 10 NEC FUTURE Model Demographic Inputs

	2025 Base Demographics		2025 TOD Demographics		Increase (%)	
TAZ	**Population**	**Employment**	**Population**	**Employment**	**Population**	**Employment**
6	500,119	297,161	534,997	330,538	7%	11%
7	92,465	39,326	96,812	44,053	5%	12%
8	372,331	196,894	415,141	231,320	11%	17%
406	47,415	29,951	47,625	30,179	0%	1%

Table 11 shows the mode share of annual trips for the 2025 Base Year. Corridor Rail has between 2-6 percent mode share in the 2025 Base Year, with auto being the overwhelmingly dominate mode at approximately 90 percent of all trips. As the service being modeled has not changed, the difference between the two model runs is an increase in trips overall while the mode shares remain the same.

Table 11 Mode Share applied for 2025 Base Demographics and TOD Demographics

TAZ	Auto	Air	Intercity Bus	Express Rail	Corridor Rail	Commuter Rail	Total
6	93%	2%	3%	0%	2%	1%	100%
7	92%	0%	2%	0%	3%	3%	100%
8	89%	0%	1%	0%	6%	3%	100%
406	92%	1%	3%	0%	4%	1%	100%

The results of the model runs are shown in Table 12, aggregated for all four TAZs.

Table 12 Annual Trips for 2025 Base Demographics and 2025 TOD Demographics

	Auto	Air	Intercity Bus	Express Rail	Corridor Rail	Commuter Rail	Total
2025 Base	8,463,779	66,050	202,420	7,408	384,693	162,695	9,287,043
2025 TOD	8,996,195	69,711	213,756	7,867	411,728	174,711	9,873,968
2025 Base – 2025 TOD (Increment)	532,416	3,661	11,337	459	27,036	12,017	586,925
2025 Base – 2025 TOD (% Change)	6%	6%	6%	6%	7%	7%	6%

TOD Demographics Ridership Forecast Results

The results of the NEC FUTURE model run were combined with the MTA's RTFM model (commuter rail ridership) results to generate a 2025 TOD Demographics Ridership Forecast for the NYX scenario. The results of this forecast and the comparison to base demographics ridership forecasts are shown in Table 13.

Table 13 TOD Demographics Ridership Forecasts Results (Average Weekday Daily Boardings)

Scenario	2025 Base No Build	2025 Base NYX	2025 TOD NYX	2025 TOD NYX - 2025 Base NYX (Increment)	2025 TOD NYX - 2025 Base NYX (% Change)
Line Totals					
Hartford Line (HFL - HFL/NHL/PSNY)[8]	1,710	2,100	2,140	40	2%
CT *rail* Operated[4,7]	560	610	620	10	2%
Amtrak Operated, CT *rail* Fare[4,6]	280	320	320	0	0%
Amtrak Intercity (HFL - NHL/PSNY)	870	1,170	1,200	30	3%
New Haven Line (NHL-NHL/PSNY)[9]	150,980	151,020	151,040	20	0%
Metro North[3]	150,260	150,260	150,260	0	0%
Amtrak Intercity (NHL - PSNY)	710	750	780	30	4%
Shore Line East (SLE-NHL/SLE/PSNY)[10]	2,100	2,100	2,110	10	0%
MNR Operated[3,5,7]	290	290	290	0	0%
Amtrak Operated [5]	1,570	1,570	1,580	10	1%
Amtrak Intercity (SLE - NHL/PSNY)	240	240	240	0	0%

Notes:

1. Fall 2016 New Haven Line On-Off Counts, September 2018 CT rail and Amtrak Hartford Line counts, October 2017 SLE counts, FY 2013 Amtrak Intercity and Northeast Corridor
2. Assumes a 2015 model year for RTFM; 2015 for NEC Future; and a current (2018) service plan except for Shoreline East which has 2017 to account for current issues with the service
3. New Haven Line Counts include ridership on MNR operated SLE trains for proportion that does not go through to SLE stations, through traffic included as MNR Operated SLE ridership
4. Hartford Line CT rail Operated and Amtrak Operated, CT rail Fare modeled as single service with estimated distribution matching observed distribution of 66% CT rail Operated and 34% Amtrak Operated
5. SLE MNR Operated and Amtrak Operated modeled as single service with estimated distribution matching observed distribution of 16% MNR Operated and 84% Amtrak Operated
6. Includes riders on Amtrak trains between Springfield and New Haven who pay a CT rail fare. These riders do not have the option to transfer to MNR at New Haven.
7. Includes riders who transfer to MNR at New Haven.
8. Includes ridership that has at least one trip end at a Hartford Line station and another trip end at a Hartford Line, NHL, or GCT/PSNY Station
9. Includes ridership that has both trip ends at an NHL station or GCT/PSNY
10. Includes ridership that has at least one trip end at a Shore Line East station and another trip end at a Shore Line East, NHL, or GCT/PSNY Station
11. Includes ridership that has at least one trip end at a Shore Line East, Hartford Line, or Connecticut NHL station and another trip end at a non-Connecticut, NHL, or PSNY Amtrak Northeast Corridor Station

TOD demographics ridership forecasts were not generated for the 2025 No Build or 2025 GCX scenarios as the preliminary results from the NYX scenario were very low.

Preliminary Findings of the TOD Forecasts

The TOD demographic input estimates represent a sizable increase in population and jobs as a result of TOD development: 42,768 new jobs and 47,694 new people. However, the initial findings of the ridership forecast

using these inputs found that the impact on ridership was minimal (0-4 percent increase in daily boardings). These results may be due to constraints of the methodology applied.

Because the NEC FUTURE model is an interregional model, it utilizes large TAZs that are not well-suited to account for more micro-level considerations such as TOD station access. The model calculates an average station access time across the entire TAZ and applies that access time to all jobs and people within that TAZ. This station access time is then used to determine mode share. Therefore, people living 8 miles from a station may be assumed to have the same propensity to travel by rail as someone who lives within walking distance from that station. Given that the added jobs and population associated with TOD development are, by definition, more transit accessible, the results of the 2025 TOD demographics ridership forecasts likely underrepresent the number of trips that would be generated as a result of this development.

If these constraints are adjusted (e.g. accounting for a different mode split for trips generated by these TOD developments or smaller geographic units of analysis) the model might be better suited to capture these behavioral nuances and enable ridership estimates to better capture the impact of TOD development.