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Resilience of Rail Infrastructure in the U.S. Northeast Corridor

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Abstract

The New Haven Line reports a record number of passengers every year as it continues to experience a steady increase in ridership. In 2012, the railroad reported 39 million passengers, with a further increase of 46% predicted over the next 18 years eventually reaching 57 million trips annually by 2030. Despite the great importance of the rail infrastructure for the region, problems exist for operating under harsh weather-related conditions, and when congestion or frequent malfunctions disrupts system timeliness with speed restrictions. These on-time performance and reliability issues have significant economic, environmental, and societal impacts. The aim of this study was a comprehensive analysis of the history, current operation, and projected future of the New Haven Line in order to overcome its current vulnerabilities and improve its resilience as a viable transportation system. Strategies were explored to advance the resilience of U.S. rail network with an awareness of safety, sustainability, and timeliness. Metro-North and Amtrak were the focus of the study, specifically the seventy-two mile stretch of the New Haven Line providing passenger and freight service between New York and Connecticut. To that end, the existing rail transport infrastructure of the Northeast Corridor of the U.S. has been analyzed, causes of current problems and future potential hotspots have been discussed, and strategies to improve the overall system resilience has been proposed as part of the study. The recommended changes include incorporating existing technologies to withstand inclement weather and making structural upgrades to the tracks and bridges that form the New Haven Line. The current status of each factor together with recommended changes have been discussed.

Keywords: rail network; rail transport; infrastructure resilience; climate change

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1. Introduction

Compared to other developed countries around the globe, the U.S. has been lagging behind in rail transportation, which is a more efficient form of transportation for both freight and passengers when the necessary infrastructure has been well planned. Proposed plans to expand the reach of the existing rail network in the U.S. include projects to develop a high-speed rail network across the country by 2030, where speeds of up to 220 mph could be achieved along tracks built in 4 phases leading up to 2030. While such projects are important to improve the state of rail infrastructure and transportation in the U.S., parts of the existing rail infrastructure is in critical condition due to decades of postponed upgrades.

The New Haven Line reports a record number of passengers every year as it continues to experience a steady increase in ridership. In 2012, the railroad reported 39 million passengers on the New Haven Line, a 69% increase compared to 1984, the year corresponding to Metro-North's inception. During weekdays, Metro-North runs 336 trains daily. Additionally, Amtrak operates 44 intercity trains on the main line between New Haven and New Rochelle, bringing 3 million additional intercity passengers onto the New Haven Line each year. Statistical forecasts indicate continued growth in ridership, while Metro-North predicts an increase of 46% over the next 18 years reaching 57 million trips annually by 2030. There are also two freight railroads hosted on the New Haven Line that provides both local and through service: CSX, and Providence & Worcester (P&W).

The focus of this study was a comprehensive analysis of the history, current operation, and projected future of the New Haven Line in order to overcome its current vulnerabilities and improve its resilience as a viable transportation system. The existing rail infrastructure of the U.S. Northeast region has been analysed in this study, and causes of current problems and future potential hotspots have been discussed. Metro-North, operated by the Metropolitan Transportation Authority, and Amtrak were the focus of the study, and specifically the seventy-two mile stretch of the New Haven Line, shown in Figure 1, considered one of the busiest regional rail and freight rail service operating between New York and Connecticut [1].

Fig. 1. Map showing the New Haven Line; a 72-mile stretch of rail that connects New York and Connecticut with numerous stations along its route. (Metro North Map © Metropolitan Transportation Authority. Used with Permission.)

2. Rail Infrastructure on the New Haven Line

2.1 Ownership

The infrastructure of the New Haven Line includes its supporting structures, rolling stock, unique electrification, and maintenance facilities required for its daily operation. Approximately 75% of the New Haven Line right-of-way and physical infrastructure is in Connecticut and owned by the Connecticut Department of Transportation (CDOT). The remaining 25% is owned by the State of New York. Although MetroNorth assumes all operational responsibilities, CDOT and the Metropolitan Transportation Authority (MTA) share a respective 65% and 35% responsibility for maintaining, replacing, and upgrading the New Haven Line. In 2011, CDOT and the MTA reported \$71.5 million and \$28 million respectively in spending for capital expenses. Nearly all projects along the line are ineligible to receive the Amtrak annual federal capital assistance, which means there has been minimal federal dollars available to the New Haven Line since the 1970s [1].

2.2 Track

The New Haven Line navigates approximately 72 miles on its four track mainline. Subject to significant wear and tear from a high volume of traffic, the rail is required to be routinely inspected and replaced. Rails, ties, and other track elements follow a specific cycle and must be inspected and replaced regularly. Curved tracks require replacement every 20 years and straight tracks require replacement every 40 years. The tracks are constructed with continuously welded rail and are maintained at FRA Class 4 track standards. This standard calls for roadbed, track geometry, and track structure to safely support passenger trains running speeds not exceeding 80 miles per hour for passenger trains and 60 miles per hour for freight trains. The geology of the rail line's supporting ground influences the quality of the soil beneath the tracks. Since the New Haven Railroad was built along the coast of Long Island Sound, it rests on wet and swampy areas and makes upgrades difficult and expensive. Other factors such as ballast material, drainage, crosstie selection, and strength of the running rails can influence the weight limit of the rail line. The track is one of the greatest factors for a railway's capacity, speed, frequency, reliability, and safety [1].

2.3 Signal System

The fundamental requirement of any signal system is to recognize a hazard or failure of any sort, such as an interruption of power, stray foreign current, broken rail, defects of apparatus, and track occupation. The design of signal systems reduces to the display of a restrictive aspect in place of a "clear" aspect that might result in a very serious accident. Operating in the background, railroad signals are the forefront of safe system wide operation. At full speed, a train requires a considerably long and timely stopping distance. An operating timetable and the engineer's line of sight cannot be solely relied on to ensure two trains will not collide.

The New Haven Line relies on centralized dispatching from rail traffic control (RTC) districts and an automatic block system. An engineer of a train will communicate with a corresponding district in the RTC office to convey location information, train status, and permissions. The automatic block system consists of a series of track circuits that control and secure locations with automatic signals. The railroad is divided into blocks that range from fractions of a mile to several miles. The length of a block is dependent on traffic densities and infrastructure considerations. Electrical pulses at a specific frequency are sent through the rail and to convey a corresponding signal speed. When a train occupies a block, it creates a short circuit. One block control is overlapped with the adjacent to provide advance information to the approaching train. Through electrical logic, blocks automatically communicate with each other and ensure trains traverse safely. MetroNorth enforces four signal aspects: Normal (Maximum Authorized Speed), Limited (45 MPH), Medium (30 MPH), and Restricted (not exceeding 15 MPH prepared to stop within half sight's distance). Each aspect has a unique frequency except for "Restricted". As a fail-safe, the aspect "Restricted" is enforced when there is no code in the rail. There are two main types of signals, wayside and cab. As the names imply, wayside signals are displayed alongside the right-of-way, whereas cab signals are displayed in the operating cab of the train. Currently, MetroNorth operates solely on cab signalling with wayside signals only to protect

interlockings and its six movable bridges. The infrastructure currently is limited because the system is not optimized for maximum train occupation between blocks.

2.4 Moveable Bridges

The New Haven Line has three moveable bridges from the early 20th century and one from the 19th century. The Walk bridge in Norwalk, CT, the Saga Bridge in Westport, CT, the Cos Cob Bridge in Greenwich, CT, and the Devon Bridge in Milford, CT are aged 119, 111, 111, and 110 years old respectively. The Pelham Bay Bridge is the fifth movable bridge that is on the Hell Gate Line, a branch that diverges from the New Haven mainline to access Penn Station. The estimated cost of entirely replacing or rehabilitating the five movable bridges was set at $2.8 billion. The locations of the bridges feature both high rail and marine traffic volumes. By U.S. Coast Guard mandate, CDOT must open its movable bridges for passing marine traffic. Because of their old age and tender condition, they have a tendency to malfunction and fail to close. In 2010, the bridges were opened 747 times and malfunctioned 70 times. In other terms, approximately one in every ten openings resulted with a bridge that remained disabled in the open position. This causes an array of train delays and limits the capacity of the main line for MetroNorth and its mutual railroads. The bridges handle more rail traffic than originally designed, have exceeded their useful life, and are integrated into the backlog of repairs on the Northeast Corridor railroad infrastructure. While the New Haven Line only constitutes 9% of the overall Northeast Corridor rail infrastructure, it requires 39% of the funds needed for repair [1].

2.5 Electrification

Electrification of the New Haven Line was a result of a congressional enactment created in May 1903 banning motive power that relied on combustion and created any sight-limiting emissions. As stated by Westinghouse, railroad electrification was considered an achievement of steady and rapid development in methods of transportation.

> "The thought of railroad electrification today suggests a modern railroad with perfectly aligned tracks on a well dressed roadbed, surmounted by graceful caternary structures, and brilliant daylight signals, with a highly varnished train, propelled by a powerful electric locomotive operating on a high speed schedule... This present day achievement is the result of steady and rapid development in methods of transportation during the past two hundred and fifty years" [Westinghouse, 1924]

This was a pioneering venture for mainline railroads and was a proving ground for railroad electrification technology. It established single-phase alternating current as a technical and economical alternative to direct current and exerted considerable influence over subsequent systems both in the United States and abroad. The engineering workforces of the New York, New Haven & Hartford Railroad and the Westinghouse Electric and Manufacturing Company developed the system. The electrification of the New Haven Line has added to the economy of operation and provided the railroad with efficient and effective operation of suburban multiple units, high-speed regional trainsets, and freight service. Historically, the New Haven Line has hosted the heaviest main line traffic of any electrified railroad of its length in the world, but currently experiences electrical and structural challenges [2].

2.6 Rolling Stock

The performance of the railcars must promise the timely operation of the New Haven Line using effective acceleration and deceleration between the numerous station stops along its line. For its commuter operations on the New Haven Line, MetroNorth recently transformed its backbone fleet from M-2 to M-8 railcars. Figure 2 shows he two railcars side by side. The M-8 had its first revenue run in March 2011, was produced by Kawasaki Heavy Industries, sports four 265 HP AC Motors (1060 HP total per car) and uses a Variable Voltage Variable Frequency

(VVVF) drive with Insulated Gate Bipolar Transistor (IGBT) inverters for traction control. 380 M-8 powered cars arranged in pairs and 25 unpowered single cars complete the 405 M-8 railcar fleet. Twenty-four cars of the M-2 fleet remain available as a surplus and are only run on an as-needed basis.

Fig. 2. M-2 and M-8 railcars that form the backbone fleet of the New Haven Line

For its two branches not electrified and for operation when the overhead wire requires maintenance, the New Haven Line utilizes a small fleet of push-pull coaches powered by a diesel-electric locomotive. The P32ACDM, known as the "Genesis", is the only dual-mode locomotive that serves the system. The dual-mode provides the option of electric generation by diesel generation or by direct collection via third rail. Since trains entering Grand Central are prohibited from creating any sort of emission, the Genesis is the only locomotive permitted to provide regular passenger service into the terminal due to its dual-mode functionality.

3. Strategies to Improve Rail Infrastructure Resilience

3.1 Call for Repair

The principal initiative of the Northeast Corridor must endeavour to match its rising ridership with a forward thinking and fiscally responsible plan. In order to support reliable passenger rail service, engineers cite the necessity of capital investment in its infrastructure. Statistics forecast a near certain ridership boost in the future demonstrated through previous and current growth. The backlog of repair and restoration projects will inhibit ambitious progression plans of the line and will continue to negatively affect the reliability of its service. The cooperation of policy makers and support of the public is necessary in order to enable such an important change.

3.2 Track Resilience

The interaction between the railcar and its track plays a critical role in railroad operation. Vibrations in the track are mainly due to irregularities in the rail and wheels of the train. Esveld cautions that it is important to limit these kinds of deviations to confine dynamic impact and damage to the track. Wheel geometry is especially disturbed during "slip-slide" seasons where trains are subject to flat spots. To prevent track damage or a derailment, the trains have to be removed from revenue service for wheel truing, which affects railcar and shop availability. Additionally, MetroNorth has decided to heighten its focus on track maintenance and set an industry standard by upgrading its railroad ties to concrete. Concrete ties have a 50-year expectancy and are sustainable in comparison to traditional wood ties. However, in areas with poor drainage, MetroNorth has found mud spots and its concrete ties crumbling and prematurely deteriorating. The railroad now leaves the wood ties in areas with specific conditions. The Vice President of engineering notes that proper maintenance and capital support is required on the concrete ties to prevent issues. Finally, when completed, Penn Station Access will offer MetroNorth resiliency benefits by providing a different route into Manhattan. Superstorm Sandy and other recent events that impair track function and availability made the need for additional resiliency on the MetroNorth system clear. The regional and national economies are unfavourably affected when MetroNorth service is cut-off. Using existing tracks, Penn Station Access would re-establish an existing link for MetroNorth's New Haven Line to avoid a service disruption [3-5].

3.3 Signal Reliability

Signal problems are one of the most common culprits of service disruption on a rail network. While a centralized signal system streamlines operation and is financially cheaper, it offers little redundancy in the event of failure. If a cab signal fails or if the wayside signals malfunction, trains are typically prohibited from exceeding restrictive speeds. Implementation of redundant wayside signals would prevent system shutdown should the cab signal fail.

While originally intended just to inform the engineer that the track ahead was intact and unoccupied, automatic signalling systems have evolved to enforce both signal and civil speed restrictions. In 1988, the Rail Safety Improvement Act required Automatic Train Control (ATC) for a number of freight and commuter trains. ATC works on-board the train to enforce cab signals should the engineer fail to comply with a signal. Consequently, the system cannot enforce civil speed restrictions, which derive from fears of civil engineering such as curves, bridges, and specific track conditions. In 2008, Congress passed a mandate requiring Class 1 railroads to implement Positive Train Control. MetroNorth has begun installing its PTC developed by Amtrak called Advanced Civil Speed Enforcement System (ACSES). Currently, it is operating on all 401 miles of track that Amtrak is responsible for on the Northeast Corridor. ACSES enhances and works cooperatively with ATC. Among other things, it can automatically bring a train to a stop at a red signal, enforce civil speed restrictions on curves, and can approximate a train's exact location within the system. ACSES is expected to optimize track occupation throughout the system and increase the system's overall reliability. MetroNorth will continue upgrading its signal system and expediting its PTC implementation in order to comply with the 2018 deadline.

3.4 Case of Walk Bridge

Movable bridges along the line, one of which has been in use since the 19th century, are especially vulnerable to failure. The Walk Bridge is the oldest movable span along the New Haven Line. It was constructed in 1896, spans 564 feet across the Norwalk River, and carries 140 trains per day in addition to light freight traffic. The structure has exceeded its intended design life, and even minor damage as a result of a climate hazard could yield the track section unusable. There is no redundancy in the current bridge because all four tracks are installed on a single span. Therefore, all four tracks that the New Haven Line depends on are forced out of service if the bridge sustains any damage from climatic events or malfunctions. Proper functioning of the bridge is critical to commercial businesses in Norwalk. On average, every time the movable bridge malfunctions, it requires two hours of repair, preventing all rail traffic to come to a halt.

If Walk Bridge were to fail as a result of a weather-related event, such as following a storm or a hurricane, its effects would ripple through both the local region and the nation economically and socially. The New Haven Line is perhaps the most critical artery of the Northeast Corridor, which facilitates one-fifth of the nation's gross domestic product, and is home to 17% of the nation's population. While the vulnerable Walk Bridge did not sustain damage during Superstorm Sandy and Irene, should the bridge fail and stop operation of the New Haven Line, the alternative mode of transportation by cars on the already constrained I-95 corridor would result in direct and indirect economic losses and environmental impacts [6].

An interesting attempt to reduce the incidences of heat-related failure was to paint the bridge white to utilize an albedo effect and reduce overheating. However, looking into the future through climate models, research on climate change suggests that the number of days exceeding 90 degrees will triple through 2050, which would likely increase heat-related failures if the bridge were to continue to be used then.

3.5 Electrical Infrastructure Reliability

Since the 1990s, MetroNorth has been upgrading its overhead catenary wire in an effort to make its electrical infrastructure resilient to mechanical damage. The century-old system was subject to temperature-related tension issues. If the wire sagged in hot temperatures or became brittle in cold temperatures, it was subject to breakage and entanglement with the train's power collection system. The new constant-tension system attaches a counterweight to the wire every few miles to maintain a firm tautness. The tension is automatically maintained by gravity, as the free-hanging counterweight will correct sagging and contracting conditions. The project was expected to finish by 2017.

A failure of the electrical infrastructure in September 2013 that lasted for days revealed the vulnerability of the system as electric trains came to a halt and the Line had to revert to 24 diesel-powered trains, effectively reducing the operational capacity to 33%. A critical segment of the line lost electrical power, crippling rail service and stranding passengers for nearly two weeks when a 138,000-volt feeder cable unexpectedly failed. The feeder cable that failed had a design life of 30 years and was installed 36 years ago. This incident exemplifies the effect of a power failure and a need for redundancy in the systems [1].

3.6 Railcar Availability

In 2011, MetroNorth drastically cut service on the New Haven Line because of a weather-damaged fleet. With half of the rolling stock out of service, commuters saw regular weekday service indefinitely reduced. The New Haven Line cannot borrow equipment from sister railroads due to the complexity of its electrical system. It can allocate several of its diesel trains, but not enough for full service on the mainline. Small and inadequate repair facilities create a backlog of repairs. When there are not enough working cars, a trainset becomes short cars and causes crowding. The problem is intensified when fewer cars are available to make into complete train sets. On any given day in winter, a number of cars are sidelined due to snow, ice and cold. In winter of 2011, it was reported that over half of the New Haven fleet was out of service. The anticipated opening of the updated New Haven Yard should enhance and expedite maintenance and repair routines to ensure maximum railcar availability [7].

3.7 Feasibility

The investigation of rail infrastructure on the New Haven Line reveals environmental, economical, and societal benefits in long-term investment. The American Society of Civil Engineers (ASCE) runs a delay analysis on America's highway systems to show how many hours Americans lose due to traffic. When taking a similar perspective of a rail network, the MetroNorth commuter train sits seven hundred people on average. If the train runs just ten minutes late, 117 collective hours are lost. This has a ripple effect on a city and its respective economy. To address this issue, MetroNorth has placed a high priority on improving reliability through improved car maintenance strategies and strong performance of a renewed rail car fleet. Recently, MetroNorth completed its M-8 railcar procurement to update its backbone fleet of electric railcars on the New Haven Line with 405 state-of-the-art electric railcars. In 2015, all Metro-North rail cars averaged a distance of 199,838 miles before breaking down and causing a delay, enough miles to circle the earth eight times. The railroad reports that it is the highest "mean distance between failures" (MDBF) performance since Metro-North first started tracking the figure in 1989. The M-8 railcars exceeded their mileage goal for the year by 2.4%. Timely and reliable operation of infrastructure will continue to foster a healthy environment to operate an efficient economy [8].

The next suggested strategy for MetroNorth would be to place a high implementation priority on the complete replacement of the Walk Bridge. A more resilient bascule bridge structure will significantly enhance the safety and reliability of commuter and intercity passenger rail. The replacement structure will minimize delays, increase the efficiency of rail service, create additional capacity to meet projected increase in demand for services between New York and Boston, and will result in benefits to marine traffic navigating the Norwalk River. A new bridge will eliminate the 45 MPH speed restriction and may permit up to 60 MPH operation, increasing the capacity for travel and potential to meet standards for higher speed rail service. The new superstructure will also benefit freight service by increasing the maximum load from 263,000 pounds per car to 286,000 pounds per car. This project would replace the existing swing bridge with a modern and resilient single span split leaf bascule bridge. The four tracks on the bridge will be split between two separately movable structures, which will provide needed redundancy during a climate event or maintenance efforts [6].

4. Conclusion

The reliability of service suffers under an overburdened system, where the necessary upkeep has been lagging. Train delays are the inevitable result exacerbated by track conditions, weather-related issues, and traffic congestion,

most of which could be preventable. Strategies that promote safe, sustainable, and time effective considerations would lead to systematic reliability and resilience of railroads operating on the Northeast Corridor. Railroads are a staple of commerce that connects cities, suburbia, and industries. Since their adoption in the 19^{th} century, railroads have played critical roles in development, commerce, and transportation. But business cannot continue as usual. Disruptions disturb the system's timeliness and as delays increase, riders will seek alternatives to unreliable rail service. Railroads in the U.S. are longing for a compelling vision that will drive future investment towards world-class passenger rail service. The current pace of investment is far too slow to meet the growing ridership demand. The New Haven Line's strength rests in its ability to haul thousands of passengers and commuters along its main line. The New Haven Line needs strategies to improve the overall system resilience for faster, more frequent, and reliable service. Recommended changes include prioritizing the maintenance and performance of the rolling stock, incorporating existing technologies to withstand inclement weather, and making structural upgrades to the tracks as well as the bridges that form the New Haven Line.

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