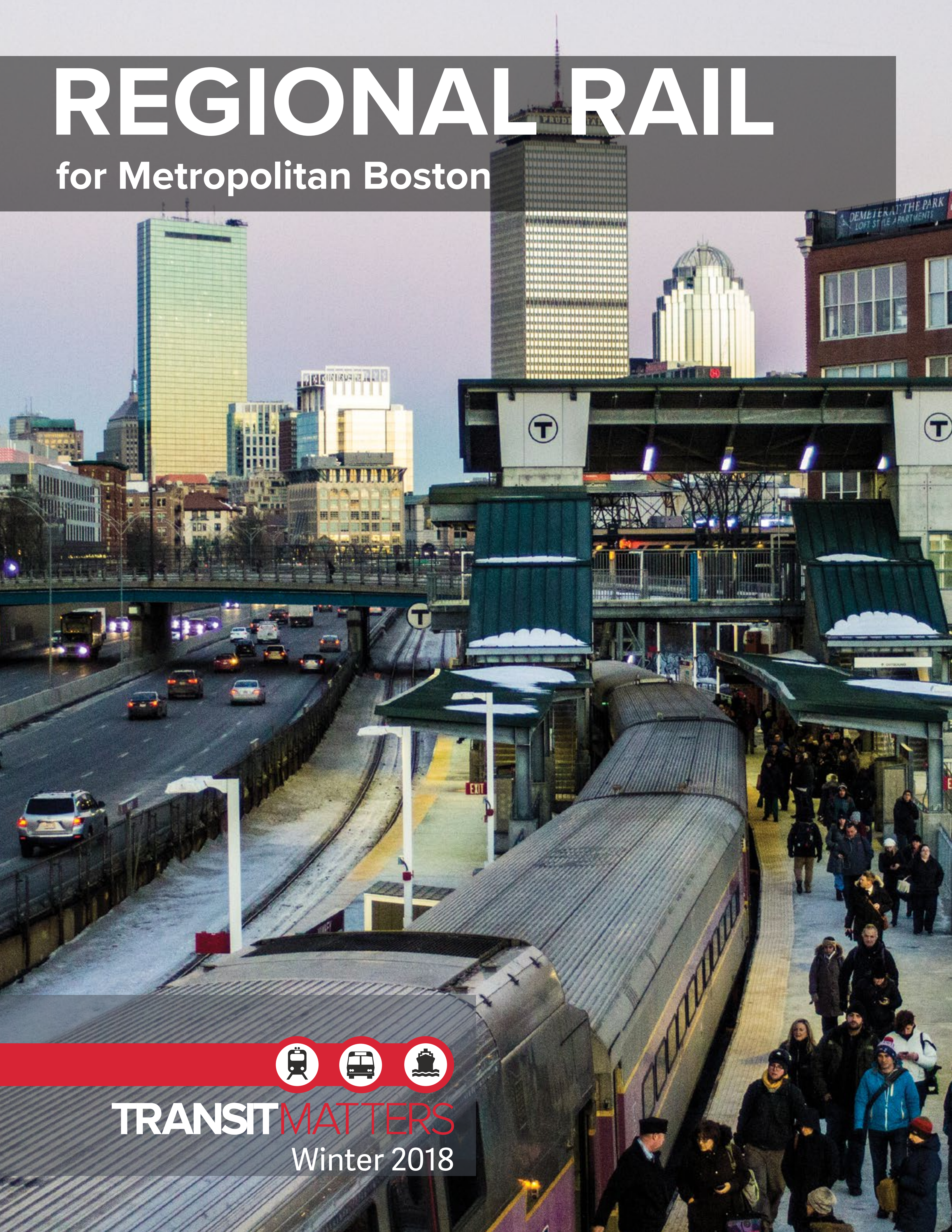
REGIONAL RAIL

for Metropolitan Boston



TRANSITMATTERS

Winter 2018

Foreword

The MBTA service area covered by the existing Commuter Rail service—an area roughly equivalent to the communities designated as "Metropolitan Boston" by the Metropolitan Area Planning Council (MAPC)—contains nearly 75% of the state's population and 75% of its jobs. This region deserves an intercity rail service that reflects these realities. Instead we are settling for a service delivery model that remains essentially unchanged from its mid-20th century origins. Massachusetts can and should embark on a transformative approach to regional mobility that more effectively supports a growing 21st century economy. This white paper outlines specific steps that can be taken in the short, middle, and long terms to fulfill this vision.

The current Massachusetts Commuter Rail system operates on the long-outdated 20th century belief that intercity rail service exists primarily for suburban workers who need to get in and out of the city on traditional 9 to 5 rush hour schedules. This approach diminishes the utility of our intercity rail assets and ignores how people work and live in this century. Our regional rail vision is practical, cost-effective, and based upon national and global experience and best practices. *See Appendix A and the Lessons Learned from International Best Practices referenced there for examples of these principles in action.* It is a forward-looking vision, one that recognizes the untapped power of rail to move large numbers of people throughout the day in a relatively low-carbon and efficient manner. Massachusetts has most of the tools, and a good deal of the infrastructure, necessary to implement this plan; what is now needed is the commitment to make it happen.

This report is the product of a collaborative effort among TransitMatters members. We hope it will inform MBTA and regional policymaking, and spark earnest dialogue and discussion among all stakeholders. Our rail network looms as the most important, and most poorly utilized, mobility asset we have. This can—and should—be an opportunity to cast away old ways of thinking about rail and move toward implementation of a forward-looking Regional Rail system.

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This Regional Rail White Paper is the product of a collaborative effort by TransitMatters members.

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Regional Rail

for Metropolitan Boston

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Executive Summary

Metropolitan Boston has two transit systems. One system, primarily served by buses and subways, runs with frequent service to many destinations within the inner urban core. The other system, the Commuter Rail network, serves suburban commuters, with service largely at rush hour, and one- or two-hour service gaps between trains at other times.

MBTA Commuter Rail operates as a mid-20th century service and reflects all of that era's biases about where people and jobs are located, and about individual mobility preferences. It assumes everyone works 9 to 5 on weekdays, and that travelers must be lured from their cars with ample parking. As a result, it does not adequately serve people in 21st-century Metro Boston who work weekends or non-traditional hours, many of whom are low-income service workers. The current approach to Commuter Rail service contributes to the region's chronic and worsening traffic congestion. It also exacerbates income inequality, since the inadequate service for lower-income workers forces them to drive; for many lower-income households, vehicle expenses are a large fraction of household spending, requiring difficult cutbacks elsewhere.

To make matters worse, the Commuter Rail system is not functioning at a high level even during peak travel times. During rush hour, office workers commute to Downtown Boston on crowded trains that too often provide unreliable and uncomfortable service. Expanding peak Commuter Rail capacity has run into significant construction and operating costs. And the current system itself is expensive to run, with fully loaded annual operating costs of ~$400 million. We agree with the concern recently expressed by the Chairman of the MBTA's Fiscal Management and Control Board (FMCB): the current Commuter Rail paradigm costs "way too much money for way too little ridership."[1] In the spirit of problem solving, TransitMatters offers this vision—both a planning vision and a business model vision—for making smart investments that will reduce costs over time and increase ridership.

Regional Rail is a reliable and more cost-effective intercity rail system based on a 21st century business model. Rail offers unparalleled capacity: ten times as much as a single freeway lane.[2] Making Regional Rail a reality means reimagining the existing Commuter Rail system as a more subway-like service, with frequent service all day.

Transitioning to and investing in a fully functional Regional Rail system will dramatically increase reliability and capacity, and offer substantial cost and service benefits and savings over time. This investment would dramatically increase reliability and capacity. It would generate significant operating cost savings, since electric trains cost half as much as diesel trains on a lifecycle basis,[3] and off-peak trains have lower marginal costs than peak trains. Moreover, this investment would eliminate the need for South Station Expansion, a proposed $2 billion project doubling down on the outdated 19th and 20th century stub-terminal inter-city rail model that would further ossify Commuter Rail as a peak-only service. The money intended for South Station expansion should be diverted to regional rail modernization.

A highly functioning Regional Rail system includes five critical components:

Systemwide electrification and the purchase of high-performance electric trains.

High platforms, providing universal access and speeding up boarding for everyone.

Strategic Infrastructure investments to relieve bottlenecks.

Frequent service all day: every 30 minutes in the suburbs and every 15 minutes in denser neighborhoods.

Free transfers between regional trains, subways, and buses, and fare equalization with the subway in the subway's service area.

And one useful component that will complete cross-region mobility:

While not critical to implementing a Regional Rail system, the North-South Rail Link (NSRL) between North and South Stations, allowing service between any two stations with either a direct trip or a single, seamless transfer, would be a highly useful enhancement providing the flexibility and connectivity to which many riders and potential riders would be drawn.

Regional Rail:

A New Vision and Business Model

"Commuter Rail is Commuter Rail. It's not transit. It's designed to bring people into the city in the morning and take them home at night."[4] That statement, made not long ago by a former MBTA General Manager, reflects a mid-20th century view of intercity rail. It is not a vision that responds to today's realities or the future, nor is it a business model that makes sense.

> Regional Rail is about extending freedom from car dependence to a greater portion of Metropolitan Boston.

It shortchanges the potential of our rail network and reinforces the system's current emphasis on providing service only to a privileged niche of society. Instead of solely using Commuter Rail to serve 9-to-5 suburban commuters, the MBTA should be employing every available tool to improve public transportation in the region.

With traffic congestion worsening with each passing month, the need for fast, flexible, and affordable mobility alternatives is more apparent than ever. Regional Rail promises passengers freedom of access by transit from wherever they are to wherever they are going across the region. With train service at frequent intervals, passengers won't be burdened by multi-hour waits. Regional Rail makes strategic investments in infrastructure and equipment to provide the best possible schedule. We expect many suburban residents will be attracted to a more schedule-friendly service and will choose to rely on Regional Rail, reducing automobile dependence throughout the region, with an associated positive impact on roadway congestion and vehicular emissions.

Regional Rail is therefore about extending freedom from car dependence to a greater portion of Metropolitan Boston. It is also about opening up opportunities in the Gateway Cities—older urban centers that will find it easier to attract jobs and development if linked to the urban core by a more reliable, speedy, and convenient intercity rail system. This vision and business model gives passengers throughout the region access to good public transportation all day, connecting cities in the eastern third of Massachusetts to one another.

MBTA Commuter Rail operates on eight high-quality rights-of-way entering Downtown Boston from the north, west and south, connecting to the suburbs and to neighboring cities like Providence and Worcester. It is imperative that the MBTA maximize their utility to support a 21st century Regional Rail system. The basic elements of the Regional Rail vision and business model are summarized on the following pages.

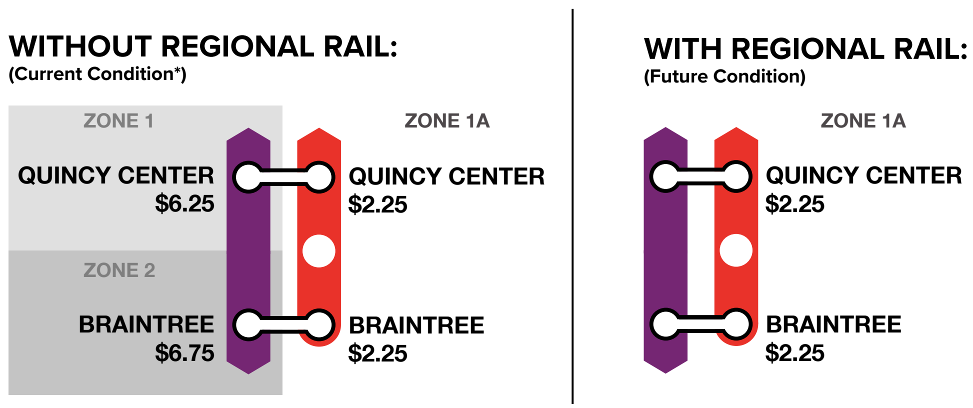
Frequent All Day Schedules

The fastest regional train in America would still not be useful if it didn't come when people wanted to ride it. A successful business model employs strategies to attract more customers. So too, our intercity rail system cannot expect to grow ridership (a modal shift goal we assume is a top priority for state policymakers) without offering a service that responds to the mobility needs of those riders.

Public transit must be frequent all day, not just at rush hour. Commuter Rail is stuck in a "chicken-and-egg" dilemma today: trains running every two hours off-peak are not reliable enough for people to choose to depend on them, so people drive when they might otherwise use transit. Regional Rail solves this dilemma. Trains would run at least every half hour all day in the suburbs and *at least* every fifteen minutes in Boston and surrounding suburbs like Newton, Waltham, and Lynn.

Fare Integration

We can build world-class train service, but low- and moderate-income residents of the region will not ride it if the fares are too high. *Regional Rail is incomplete without full fare integration*: service between two stations in the subway's service area should cost the same by subway or Commuter Rail, with free transfers. The success of this concept is evident on the Fairmount Line, *where ridership has tripled since 2012 after most of its stations were placed into Zone 1A, which lets users ride for the same fare as the subway.*[5] Passengers should be able to get on a bus in an outlying city like Worcester or Lowell, take it to the train station, ride a train to Boston or another city, and connect to their final destination by bus or subway, on one fare.



Prices listed are based off a one-way trip originating at South Station.
**As of January 2018, Quincy Center fares have been temporarily adjusted to Zone 1A as mitigation for the station closure associated with the Wollaston Station Improvements project. The need to permanently rationalize the zone fare structure systemwide remains.*

Electrification and Step-Free Access

Subways—designed to provide frequent service throughout the day—are powered by electricity. They also allow level boarding (step-free access) from the platform to the train. To transform Commuter Rail into a modern Regional Rail network, the Commonwealth must invest to equip the system with both of these features.

> Electrification and level boarding can cut travel time by 40%

Electrification makes the trains cleaner and quieter; self-powered electric trains, called electric multiple units (EMUs), also accelerate much faster than diesel locomotives and are significantly more reliable than current equipment.[6] Level boarding and wider doors provide ADA-compliant access for wheelchair users and also let able-bodied passengers board faster, reducing the amount of time a train has to dwell at each station. We estimate that on most lines, *electrification and level boarding can cut travel time by 40%*.[7]

North-South Rail Link (NSRL)

With the exception of the Blue Line, Boston's subway lines don't terminate in Downtown Boston; they run through to the opposite side of the city. So should Commuter Rail lines to function properly as Regional Rail. The North-South Rail Link (NSRL), a short tunnel connecting North Station with South Station, would be an effective way to complete a comprehensive Regional Rail network that offers high-quality rail service across the region. The combination of NSRL and the other elements of our Regional Rail vision function as a virtual subway system for Metro Boston and an actual new subway system for the Inner Core. NSRL can be built for a reasonable cost because the fundamental infrastructure for the entire network already exists, except for a few crucial miles in Downtown Boston. Unlike the proposed expansion of South Station, which proposes to spend billions of dollars to support an outdated, costly 20th century business model, NSRL looks to the future and responds to it.

Pictured: Wedgemere Station, 2010

The Batty Family launched a campaign supported by the Spina Bifida Association and worked closely with the MBTA, FTA and local officials to secure the funding needed to make Wedgemere an accessible station.[9, 10] Ultimately they were successful when in 2013, Wedgemere reopened after renovations as a fully accessible station.[11]

Large portions of the MBTA Commuter Rail network are not ADA-compliant, restricting access to people with disabilities.

Regional and Social Equity

Expansion of rail service can expand opportunity and strengthen ties to our Gateway Cities. Regional Rail holds special promise for the wide variety of lower-income communities across the Boston region, which are often rich in underutilized rail infrastructure, a legacy of their industrial past. Unfortunately, as Commuter Rail has come to emphasize fast suburb-to-core commutes at the expense of all other trips, many stations in dense, walkable areas have been abandoned or moved to inaccessible "park and ride" locations. Regional Rail would move stations back to town centers, walkable to working-class residents—precisely the sort of strategy that grows ridership and improves access to jobs. A complete Regional Rail vision and system will one day include intercity rail to Springfield, enhancing regional equity and enabling another route to New York City.

Lower-income urban neighborhoods are underserved as well, and residents must endure long commutes by bus.[8] Regional Rail can bring new stations to underserved areas. The ongoing project to add infill stops on the Fairmount Line is a good model. TransitMatters' vision of Regional Rail includes additional stops in walkable locations, many of which are located in low (or lower) income communities. With EMUs and level boarding, a future Regional Rail system could make these extra stops without losing time.

Regional Rail would connect Gateway Cities to Boston, Providence, and each other with frequent, reliable service.

Benefits of Regional Rail:

From Everywhere to Anywhere, at Any Time

People who live in the inner core neighborhoods of Boston and Cambridge can ride the subway anywhere, 19 hours a day. Regional Rail can bring the same high frequency of service as the subway to the entire region, at a grander scale.

Who benefits from higher frequency?

Everyone.

Many people ride to work, not just in Downtown Boston, but also in other job centers. They ride not just for work, but to meet friends and family, to go to school, to run errands, to travel to healthcare appointments, sports events, museums, and other cultural venues. And they don't just ride at rush hour, but also fill trains in the off-hours and on weekends, even at midnight. A successful public transportation system will respond to the needs, complexities, and preferences of all riders regardless of time of day, purpose of trip, or destination.

Those who commute outside rush hour would benefit from higher frequency. As would people who reverse-commute, for example from Boston to Providence, and people who commute between two outlying points. All-day frequency will also benefit traditional rush hour commuters. For example, office workers coming to Downtown Boston at 9 a.m. might today choose to drive, fearing they might need to stay late to meet a deadline, or leave early to care for a child or elderly parent. These commuters require a large measure of flexibility in their travel times, and only Regional Rail with its frequent all-day schedules provides that as an alternative to driving. Anyone who has missed an evening rush hour train, resulting in a long wait for the next train, understands this basic tenet of mobility convenience. Transforming intercity rail with Regional Rail's all-day frequencies should be one important element of the MBTA's stated objective to increase ridership.

> Regional Rail can bring the same high quality of service as the subway to the entire region, at grander scale.

Regional Rail that includes the NSRL tunnel also enables people to live on one side of the region and work in another. In northern suburbs, people would get easy access to the Financial District, Back Bay and the Longwood Medical Area. In southern suburbs, they would benefit from access to Government Center and MGH. People could work in suburbs on the opposite side of the region they live in, providing the kind of transit connectivity and work/life flexibility that could be powerfully useful for two-income families, and for people choosing more affordable places to live outside the urban core.

Like the subway, Regional Rail is not just about work trips. It would facilitate occasional trips, which are concentrated on weekends and in the off-hours, and which are essential to the economy and to quality of life. Students and academics could visit Brandeis, Wellesley, or UMass Lowell or Worcester for a seminar. Patients could access medical care at the world-class institutions that are clustered in the Longwood Medical Area and at Massachusetts General Hospital. Families could visit museums near stations, including the Aquarium, the Museum of Science, Museum of Fine Arts, and Salem's Peabody Essex Museum. Sports fans could come from the entire region to the Bruins and Celtics games at the Garden directly over North Station, or watch the Red Sox play at Fenway Park.

> Regional Rail holds the promise of breaking the longstanding city vs. suburb dichotomy...

The Benefits of Electrification:

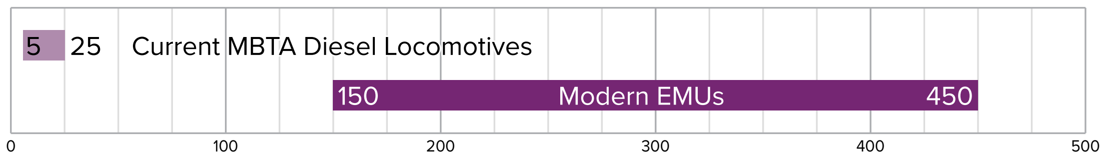
Better Performance

The better performance specifications of EMUs make them smart investments on their own, as they solve the chronic issue of routine train breakdowns that propagate delays across the system. New EMUs would replace old diesel trains: locomotives that were based on freight locomotive designs. Today's MBTA commuter rail locomotives fail about once every 5,000 to 6,000 miles[12], whereas high-quality EMUs are in the 150,000 to 200,000 mile range, and those EMU performance measures are improving.[13] Put simply, EMUs are ~30 times more reliable than the current legacy fleet, and ~6 times more reliable than the newest diesel locomotives. This is why systemwide electrification is such a crucial component of Regional Rail.

Environmentally Friendly

Electric trains emit no local pollution, and are much quieter than diesel locomotives. People living near the tracks, who should be the greatest proponents of more convenient train service, would no longer suffer from the noise of diesel engines. There would also be a positive impact on the elevated rates of blood lead levels[14] and asthma[15] in many urban neighborhoods. Rail electrification would reduce pollution levels first by making trains

Mean Distance Between Failures (MDBF, in thousands of miles)



Modern EMUs can achieve reliability up to 30 times than that of the current MBTA diesel locomotive fleet. [10 11]

cleaner, and then by enticing passengers to take the train instead of driving, reducing car pollution. There is, of course, the potential to use DMUs (diesel multiple units) rather than EMUs, but DMUs as a permanent solution fail the test of environmental sustainability, and do not provide the same increased performance as EMUs. Moreover, the world is moving away from diesel in all transportation sectors, as was dramatically demonstrated recently by Volkswagen's declaration that German tax incentives for diesel be ended.[16]

DMUs vs. EMUs

There is an ongoing debate regarding whether EMUs or DMUs make the most sense for the MBTA rail system. For a number of reasons, EMUs are the clear choice. The strongest argument for deployment of DMUs is that it doesn't require electrification of the system, and therefore can be more quickly implemented. There are benefits that come with a speedier rollout, but they pale in comparison to the downsides of embarking on a DMU strategy. Investments of this importance and scale should be made in the most cost-effective and environmentally friendly manner possible. The performance of DMUs over time is simply not on par with EMUs, and unlike EMUs, DMUs require intensive, costly maintenance. Adoption of DMUs as a permanent strategy takes us in the opposite direction of other developed countries and commits us to more costly, bespoke procurements for the duration of the MBTA's commitment to DMU technology. Leasing DMUs in the short term as a way to immediately improve service on a few designated lines prior to their electrification (like the Fairmount Line or the Worcester line if and when Allston Landing construction temporarily reduces track capacity) may be worth considering. A lease is the only procurement strategy that makes sense because DMUs can't easily be sold on the secondary market (we know of no agency outside North America that needs American DMUs, and no agency inside North America is making a large DMU order). Such potential short-term uses aside, the most cost-efficient, durable and sustainable investment will be the procurement of EMUs and the electrification of the system. And as we have pointed out elsewhere in this report, EMUs can be up and running almost immediately on the Providence Line.

> Rail electrification would reduce pollution levels first by making trains cleaner, and then by enticing passengers to take the train instead of driving, reducing car pollution.

Faster Rides

EMUs accelerate and decelerate much faster than trains pulled by locomotives, especially diesel locomotives. The difference is more than a minute per station when the top speed is 60 mph. *Together with speed benefits coming from higher reliability and level boarding, Regional Rail would offer higher average speeds.* Future all-local trains would be faster than today's express trains, averaging 30 mph on the Fairmount Line, 43 mph on the Worcester and Franklin Lines, and 50-55 mph on the remaining lines.[17] Faster trip times allow the same number of trains to run more trips in a day. In addition to the added capacity of additional trips, this leads to greater utilization rates for capital assets and investment. When combined with higher ridership, the cost per passenger savings of regional rail will be substantial.

A significant component of trip time is dwell time, or the time spent sitting at each station. Dwell time is decreased by level boarding from high platforms and by better passenger flow within the train cars. EMUs are designed to maximize passenger ingress and egress (i.e. more and wider doors like a subway car) and as such are almost always specified as single level cars rather than the bi-levels now common on the MBTA Commuter Rail network. Any passenger capacity decreases arising from the use of single level EMUs will be easily offset by the increased frequency made possible by the inherent efficiencies of the modern regional rail network.

Regional Rail is a mode for both central cities and suburbs. It holds the promise of strengthening town centers with improved connections to other parts of the region. Because EMUs enable all-local service to still be fast, improvements to Boston's mainline rail system can and will benefit both urban and suburban users. Investments made in the Fairmount and Providence Lines, for example, would give residents of Dorchester, Mattapan, and Hyde Park access to jobs in suburban towns like Dedham and Norwood, with trains running through to the Franklin Line.

Transformational Change

Regional Rail transforms the underutilized, underinvested, and niche-oriented "commuter" rail network into something of value to a much broader swath of citizens. We don't think of our highway system as simply available for peak hour commuting travel. Instead, our roads offer vehicular mobility at all times, not just for 9 to 5 commuters. Similarly, a Regional Rail system provides inbound and outbound rail service to people at convenient times throughout the day.

To envision the Regional Rail system at work, think about the transportation system as if it were the human anatomy.[18] Your body is constantly circulating blood from your muscles (the region) to your heart and lungs (the urban core) and back. When you exercise (rush hour) it picks up the pace, but it doesn't bring all your blood into the core and wait until the next time you exercise to send it out again. A healthy body responds appropriately to differing conditions and supports a variety of activities. A healthy transportation system provides the same kind of adaptability, responding to and supporting a variety of mobility needs throughout the day. Regional Rail will be the centerpiece of such a healthy system, a transformational way to extend sustainable, inclusive and egalitarian transit mobility to the entire Metro Boston area.

Regional Rail will draw the region closer together. It will provide better job access for people living in working-class suburbs, such as Lynn, Haverhill, and (once South Coast Rail is constructed) New Bedford and Fall River. And it will do so without burdening the air quality in central neighborhoods such as Roxbury and Dorchester. In short, Regional Rail holds the promise of breaking the longstanding city vs. suburb dichotomy in transportation planning and resource allocation.

Achieving Regional Rail

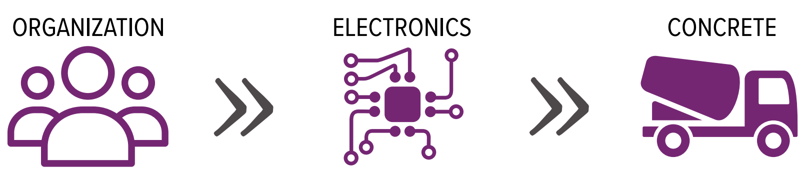
A Path to Achieve a 21st Century System

Transitioning to Regional Rail will take time and investment, but it can be planned and introduced incrementally and affordably in parallel with other important regional and statewide mobility initiatives. Achieving this vision and moving toward a new business model will require the coordination of decisions related to equipment procurement, schedule setting, and infrastructure improvement. These decisions must be connected by a clear vision and business model and cannot be considered in a vacuum. In other words, the Regional Rail vision should inform every action the MBTA and its partners take with regard to the current Commuter Rail network. Every design should be future-proof and accommodate the necessary elements of a Regional Rail plan. This is the only effective way to put an end to the current outdated system that costs "way too much for way too little ridership."

A Guiding Principle

The overall design and framework for a Regional Rail system will follow a number of best practice approaches to service delivery. The guiding principle, borrowed from Switzerland, is: *organization before electronics before concrete.* In other words, before adding expensive tunnels and viaducts, the MBTA should first invest in electrification and system improvements. And before investing in anything, the MBTA should immediately improve schedule and fare coordination by moving all Commuter Rail stations within subway-range to Zone 1A and implementing free transfers with subways, MBTA buses, and other regional buses (such as in Worcester and Lowell).

Following this guiding principle, Regional Rail illuminates not only which capital investment projects are priorities, but which ones are not. *Anything that Regional Rail makes redundant should be canceled.* A prime example of this point: the MBTA should never again buy diesel-powered trains or unpowered cars; all future procurement should be EMUs. This one initiative will improve service and reduce costs over time. Similarly, the T should not build stations in unwalkable areas, but instead keep them in walkable neighborhoods, and build new urban stations where appropriate. These strategies are geared toward improving ridership and service in a cost-prudent fashion.



The overall design and framework for the Regional Rail system should follow a number of best practices informed by the guiding principle of organization before electronics before concrete.

The International Best Practices outlined in Appendix A also illustrate components of a successful Regional Rail strategy: it's important to treat Commuter Rail as longer-range rapid transit, with the frequency, electrification, stop spacing, and connections to match, and it's worthwhile to build city center tunnels to unlock regionwide mobility. While none of these examples provide perfect analogues to Metro Boston, there are sufficient similarities to warrant a closer look to understand what other systems have done and are doing, and what can be gleaned from those experiences to the benefit of Metro Boston riders. For example, Paris didn't build its regional rail network (the "RER") for faster travel within the city—that was just a nice byproduct. *It built it for faster travel between the suburbs and city neighborhoods and between the suburbs and other suburbs.*

Targeted, Strategic Infrastructure Investments

Improved Regional Rail schedules should aim for timed meets to reduce infrastructure requirements, but some additional construction is unavoidable (for example, double-tracking certain single-track segments that would be problematic in the future). All infrastructure investments must be limited, targeted, and strategically based on a future high-frequency timetable. For example, official plans to increase service on the Old Colony Lines (via South Coast Rail) include a tunnel, but they don't need to: the Red Line has four tracks in that area that can be reduced to two to make room for more Commuter Rail tracks.[19]

Providence Line: Affordable Electrification in the Short Term

The electrification of the Providence Line, which is entirely electrified except for a small number of yard tracks and sidings, will provide an early and affordable way to significantly improve service from the rider perspective and air quality in adjacent communities. Electrification of the remaining components of this line should be completed as a priority. Installation of high platforms at all Providence Line stations will transform the Line into service that responds more effectively to all users.[20] *For more detail see Appendix C1.*

Municipal Collaboration

Municipalities in the region should be encouraged to lay the foundation for transit-oriented development around existing and future Regional Rail stations. They should be encouraged to add housing, retail, and office space around train stations. Such an approach would support ridership on the future network and provide the maximum utility to future users of the system.

High-Level Platforms

Metro North enables barrier-free universal access for riders with high-level platforms at all stations. This allows the use of modern EMUs with wide doors to speed boarding and reduce dwell time.

Infrastructure modifications to enhance accessibility and speed the boarding process are essential to fulfilling this vision and improving service for all riders. The wide doors on modern trains cannot serve low platforms, thus requiring high level platforms at all stations. Most MBTA stations do not have such platforms and because of a recent rules change, any modification to a current station requires a full-length, high-level platform. Based on several recent projects procured by the MBTA, an 800-foot, high-level platform costs between $1.5 and $2 million, with additional spending for associated costs. These costs vary: at stations where vertical circulation is already in place (along the Providence Line, for instance) there would be minimal costs beyond the platforms themselves. In these cases, the total cost to build the high level station would be in the $4 to $5 million range.[21] At other stations, ramps and elevators would be required, increasing costs while providing full accessibility for passengers. In still other locations, freight railroad clearances require track and platform modifications, resulting in higher costs. A rough estimate would put the average cost of high-level platforms at stations that do not currently have them in the $8 to $10 million range. The cost of designing and building high-level platforms can be contained by utilizing standardized designs for these platforms. Each station does not require an expensive bespoke design. Use of standard design specifications (which may require modest modification in appropriate circumstances) and creative use of materials can make a meaningful difference in keeping the cost of this important equity and service improvement in reasonable and affordable territory.

Replace the Needham Line

TransitMatters' Regional Rail plan recommends that the Needham Line be integrated into the Inner Core subway and light rail systems by offering riders a combination of Orange Line and Green Line service. There are two reasons for this. First, the Needham Line has a flat junction with the Providence Line trunk at Forest Hills, and grade-separating the junction to prevent a bottleneck would be difficult and costly. Second, running so many trains (the Providence, Stoughton, Franklin, and Needham Lines) on one trunk line causes significant scheduling difficulties. As a better alternative for Needham Line riders, we recommend that along with preparing the other Commuter Rail lines for Regional Rail, *the MBTA should replace the Needham Line with a combination of Orange Line and Green Line service.* An extension of the Orange Line to West Roxbury would require little new infrastructure, and the same is true of a Green Line route branching off the D Line to Needham, which the city of Newton has already proposed.[22]

Cancel South Station Expansion

Most importantly, the state should cancel the plans for South Station Expansion, a $2 billion project of practically no transportation value that will cement, perhaps irretrievably, outdated approaches to providing intercity rail service in the Commonwealth. Our opposition to the current South Station expansion proposal has nothing to do with our support for NSRL; it is based on what we consider an imprudent expenditure of scarce resources that solidifies the outdated status quo approach to providing intercity rail service. South Station expansion doesn't pave the way for a better rail future; it enables continuation of the failing status quo business model.

In the short run, the MBTA can create new capacity at South Station by simply turning the trains around faster, so they don't occupy station platforms for as long as they currently do. Today, most outbound trains terminating at Framingham and Worcester turn around and run inbound in 13 to 20 minutes. [23] The current average platform occupancy time at South Station is 35 minutes. We know of no barrier (particularly given South Station's high level platforms) that would prevent the MBTA or its contractor from achieving 20-minute turn around times at South Station. *Doing this would nearly double current capacity at South Station.* This is exactly the kind of high-impact, low-cost approach to managing the system that TransitMatters advocates, and that is consistent with the approach to governance being taken by the FMCB. Since this can be done now, at virtually no net new cost to the T, why would the Commonwealth spend $2 billion to expand South Station?

> We know of no barrier that would prevent the MBTA or its contractor from achieving 20-minute turn around times at South Station. Doing this would nearly double current capacity at South Station.

Rolling Out Regional Rail

Realizing a Modern Intercity Rail Network

We estimate the cost range of systemwide electrification, high platforms to enable level boarding, and strategic capacity improvements at bottlenecks to be about $2 to 3 billion. This estimate excludes the cost of EMUs for two reasons: the MBTA needs to procure new trains in any case, and a Dutch benchmarking study from 2006 finds that the *lifecycle costs of electric trains are half those of diesel*, so EMUs will actually save money in the long term.[24] EMUs also save money in another way: they can climb steeper grades than heavy locomotives, which means that NSRL tunnel construction can be shorter and therefore cheaper. A shift to EMUs will require appropriate maintenance and layover facilities. Given the age and condition of today's facilities, we view this as a necessary and inescapable expenditure regardless of the type of equipment purchased, and therefore not a net additional cost to the MBTA. The NSRL would come with its own costs, which are currently in the process of estimation by the state and third parties.

> Every intermediate step should provide immediate benefit to riders, or provide meaningful cost savings to the MBTA.

This cost estimate is based on our understanding of the prevailing costs of designing and building standardized high level platforms (and associated station work) and electrification of the system (design and installation of catenary) and the cost of the NSRL. Cost estimates for NSRL, undertaken by MassDOT consultants and independent third parties, significantly vary in range. These variances often are attributable to consultants not comparing like-to-like, or using different methodologies. The reality is that actual costs can vary greatly depending on the quality and complexity of project designs, labor costs, and many other factors. Massachusetts has learned valuable lessons in cost containment through its recent Green Line Extension experience, and we would expect the same rigorous approach to providing maximum value for reasonable cost to apply here as well.

Funding

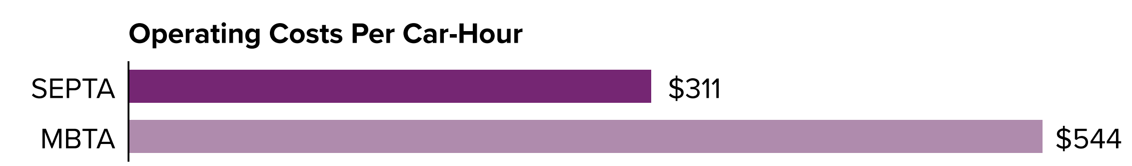
Federal funding for this transformative initiative remains elusive at the time of this report, as Congress and the Trump Administration have yet to develop a consensus for a national infrastructure bill. TransitMatters believes there should be federal funding available for mobility benefits like this, particularly if a bipartisan approach to funding takes root. Regardless, the benefits to the Massachusetts economy and quality of life are so high that the Commonwealth should begin with 100% state funding if necessary. State funding could come, at least in part, from bonding against expected cost savings from lower operating costs. Philadelphia's SEPTA runs the closest service in the United States to Regional Rail; its operating costs per car-hour are $311.00,[25] whereas the MBTA's are $544.00. The Commonwealth ought to pay the infrastructure costs to implement Regional Rail because this initiative—providing quality, low-carbon mobility to the vast majority of residents of Massachusetts—is and should be a state obligation.

Incremental Approach

Delaying electrification until the NSRL tunnel opens is unlikely to save money—it would delay the purchase of EMUs by a few years, during which the existing diesel-powered fleet would continue to deteriorate. Building the tunnel is likely to take 10 to 20 years. In the meantime, *Regional Rail can advance through a number of important intermediate steps that provide immediate benefit to riders and meaningful cost savings to the MBTA.*

The Commonwealth should electrify the MBTA Commuter Rail network. The best way to do this is line by line, so that the MBTA can replace the diesel equipment on each line with new EMUs. The MBTA can thus move diesel trains to the remaining lines and retire the worst-performing rolling stock. Given that Connecticut and other jurisdictions use EMUs today, there may be an opportunity for Massachusetts to "piggy-back" on EMU procurements by others, securing competitive pricing and earlier delivery of equipment. Electrification should be implemented at the same time as high platforms so the MBTA can procure EMUs without the current equipment's steps, which require manual operation, delay passenger boarding and alighting, and make the schedule less reliable.

The Providence Line is already electrified for the use of Amtrak's services. Only short MBTA siding and yard segments are unelectrified. Thus the first priority is to complete electrification on this line, as well as on the Stoughton Line, which consists of just four miles of branch route and enters Boston via the inner Providence Line. The bulk of the work on the Providence and Stoughton Lines requires upgrading stations with high level platforms. Improving these lines would reduce the speed difference between the MBTA and Amtrak by about two thirds, simplifying the schedule (where today fast Amtrak trains share track with slower Commuter Rail trains). We anticipate funding participation coming from both Amtrak and Rhode Island as these initiatives benefit riders using Amtrak and living or working in Rhode Island.[26] Signal systems do not pose a barrier to electrification of the line, *as explained further in the Technical Information Appendix B.*



The MBTA Commuter Rail's operating costs per car-hour are currently out of step with Regional Rail providers.

The next priority should be the Fairmount Line. All but two of the line's stations (Readville and Fairmount) have high platforms, and the line is short, with closely-spaced stations, making the high acceleration rates of EMUs especially useful. Moreover, the line could use the Providence Line's electrical substations, reducing costs. *See Appendix C2 for more detail on the Fairmount Line.*

The MBTA should lease DMUs, if possible, to immediately improve service on the Fairmount Line until electrification can be completed; this is appropriate given the long history of social justice issues tied to the corridor, whose residents have not received equitable and reliable mobility. The use of leased DMUs might also serve as mitigation on the Worcester line during the anticipated temporary track constraints related to construction activities associated with West Station and the larger Allston Landing development. Use of leased DMUs as a short term measure in these special circumstances should not obscure the reality that the facts and data point to the procurement of EMUs as the best approach to improving intercity rail service. Any short-term adoption of DMU technology for these limited duration purposes should be paired with an unambiguous promise and clear timeline for the switchover to EMUs.

Electrification of the Providence, Stoughton, and Fairmount Lines should begin as soon as possible, ideally in this decade. The other lines should follow. We encourage the MBTA to select metrics that reflect the importance and efficiency of electrifying each line and follow a data-driven process in selecting the subsequent order of electrification.

As each line is electrified, the MBTA must commit to running frequent local service on it. Trains should come at least every 15 minutes at rush hour and every 30 minutes off-peak on each branch. Urban lines, such as Fairmount, and the inner ends of some other lines could provide supplemental service, such as every 10 minutes at peak and every 15 minutes off-peak. The terminals at North and South Stations are set up in a way that permits lines to enter and depart the stations without interfering with the other lines. Thus, frequent EMU service on the Providence, Stoughton, and Fairmount can coexist with less frequent diesel service on other lines.

Implementing Regional Rail best practices has a transformative effect as seen in the comparison below:

Wellesley Hills, MA
MBTA Commuter Rail

Stamford, CT
Metro North

Whatever the order, within about ten years, the entire system should be electrified. There are plans for further extensions of the MBTA network, to Fall River and New Bedford (South Coast Rail), Hyannis, Nashua and Manchester, Springfield, and Kingston and Westerly. The states of Massachusetts, Rhode Island, and New Hampshire can pursue these extensions before, during, or after Regional Rail is installed. The Regional Rail timetables can accommodate all of these extensions easily.

A few more minor expansions would work especially well with Regional Rail. These are short and add branches to lines just outside a major station, where the frequency boost would be especially useful. They include restorations of the Peabody Branch and the Woburn Branch. These have little value without Regional Rail, but would become more useful if trains ran more frequently and served the entire region.

Conclusion

The economy of the Commonwealth of Massachusetts has historically depended upon, and been concentrated within, the communities that, for the most part, comprise the MBTA service area. The Metro Boston region depends in a significant way on transit mobility to provide people with access to jobs, affordable housing choices, and a host of other amenities that improve quality of life. While the urban core benefits from a well-established subway and bus network, it is intercity rail—what we call "Commuter Rail"—that provides access and opportunity to thousands of people who do not live or work in that urban core. *A high-functioning intercity rail system has many benefits: it helps keep Gateway Cities connected and competitive, it reduces traffic congestion and carbon emissions by offering important modal choices, and it empowers people by offering them quality personal time during their journey, a precious commodity in an increasingly time-constrained world.*

> What's at stake is nothing less than the durability of our economic future.

Massachusetts is doing itself, its economy, and its residents a disservice by continuing to operate and plan for its intercity rail system in the same ways it did during the 1970s and 1980s. What we know as "Commuter Rail" must become a modern Regional Rail system that responds to the realities of today's world—the realities of an economy that is no longer exclusively or primarily oriented to a 9 AM to 5 PM jobs framework; of a housing crisis that is forcing people to seek more affordable choices outside the urban core; of a critical need to reduce traffic congestion by encouraging modal shift on a large scale, the kind of shift that can only come from offering quantifiably better rail service. Commuter Rail does not respond to these existing realities, and it will not respond to tomorrow's needs and expectations. Transitioning the current system to Regional Rail is an achievable goal that will modernize the system, increase ridership and opportunity, and significantly reduce costs over time.

If Massachusetts fails to move toward Regional Rail, it will be limiting how much its economy can grow and the geographic diversity and equity of that growth. At a time when the focus and objective of the Commonwealth and the MBTA should be on adopting new approaches to service delivery that are cost-effective, regionally and socially equitable, and designed to support changing demographics and business models, the adoption of a clear and unambiguous Regional Rail policy should be a first-level priority. What's at stake is nothing less than the durability of our economic future.

Appendices

Regional Rail for Metropolitan Boston

Visit RegionalRail.net for additional and revised appendices.

Appendix A

Lessons Learned from International Best Practices

The following examples of regional rail systems across the globe provide important lessons that inform our thinking. While there is no precisely exact analogue to Metro Boston, these examples demonstrate the effectiveness and importance of electrification, high-level platforms and connecting stub-end terminals as approaches to providing riders with a rail service that serves their mobility needs.

Note: All dollar figures cited are in US dollars, adjusted for exchange rates and inflation.

Paris: A Best Practices Model

With a combined 1.1 billion riders a year, Paris's RER ("Réseau Express Régional" or Regional Express Network) and Transilien regional rail networks carry more passengers than nearly any other city in the world. The only busier systems are in Japan and South Korea, where there is little technological distinction between Commuter Rail and the subway, and in India, where the Mumbai Suburban Railway substitutes for a subway and is infamously dangerous and overcrowded. As the busiest proper regional rail system running alongside a separate metro system, the RER is a useful case study for Boston.

Paris historically had six intercity rail terminals and three smaller terminals used only by commuter lines. It had some frequent service starting in the 1920s, but no real regional integration. In 1937-8, Metro operator RATP bought one isolated commuter line, the Ligne de Sceaux, and electrified it and began running frequent service, treating it as a regional Metro line. The diagrams to the right show the evolution of the Paris RER network.

Paris' model has been copied worldwide with Commuter Rail transformations in Toronto (RER) and Brussels (RER). In the last two decades, London has also invested in two RER-like projects, both of which run through central London: Thameslink connecting the Brighton Main Line and the Midland Main Line with an unused short rail link, and Crossrail which connects the Great Western Main Line to the Great Eastern Main Line and the North London Line with 13 mi of deep bore tunnels.

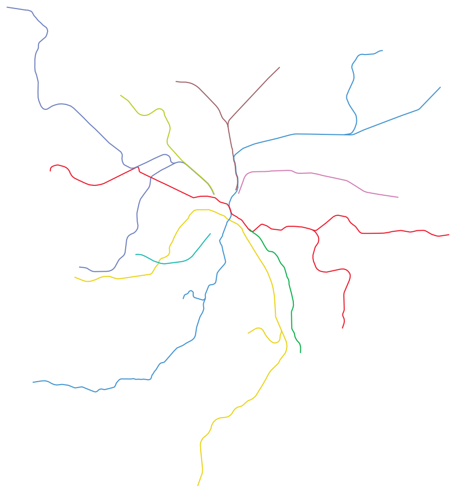
Predating Paris's transformation, Philadelphia connected its two legacy Commuter Rail networks, the Reading and Pennsylvania Railroads. Similar to our preferred version of the NSRL, the connecting tunnel is short and includes 4 tracks. Unfortunately, SEPTA did not complete relatively inexpensive complementary capital projects to support more efficient use. The only through-running American rail doesn't come close to its full potential. They have also begun terminating many trains downtown. Thus, our plan for regional rail and the NSRL would make Boston a pioneer among American transit agencies.

Frequent commuter rail in Paris, 1970:

In the postwar era, the lack of through-service and the distance of most rail terminals from the emerging central business district became serious enough problems that RATP and national rail operator SNCF began planning for multiple rail links.

The Ligne de Sceaux is in blue pointing southwest. The southeast-pointing red line is the Ligne de Vincennes, bought by RATP in the 1960s and electrified in 1969, connecting to a new terminal in Paris, Nation, a major Metro transfer station.

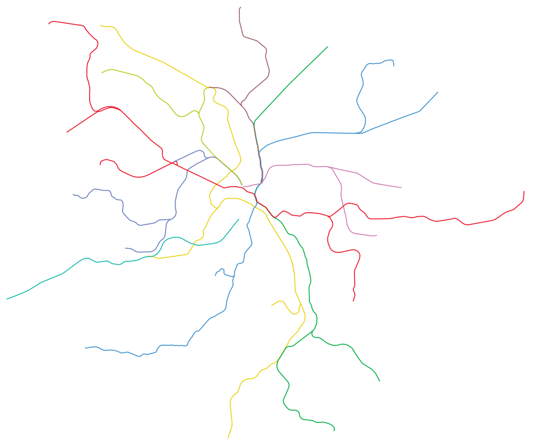
Frequent regional rail in Paris, 1985:



RATP and SNCF cooperated in planning. RATP would route its new tunnels to serve intercity rail stations, and there would be through-service between RATP- and SNCF-owned lines.

The RER A, run by RATP, is in red; the east branch is new construction. The RER B is in blue; the Ligne de Sceaux is operated by RATP whereas the northern side, with a new branch going north to the airport, is operated by SNCF. The RER C is in yellow, operated by SNCF. Other lines, still stub-ending at the terminals, are called Transilien.

Frequent regional rail in Paris, today:



The RER A has a long tunnel going west, serving La Defense, a suburban high-rise business district. Unlike Paris, Boston's office density in the South Station area enables similar functionality with a shorter tunnel.

The green line is RER D, and the magenta RER E, both run by SNCF. The RER E is being extended to the east, taking over some additional Transilien lines and relieving the overburdened RER A. On the RER A, the new east branch now serves suburban jobs in Marne-la-Vallée and Disneyland Paris; a new west branch serves jobs in Cergy.

Munich: Connecting Two Stub-End Train Terminals

Like Boston, Munich historically had two main stub-end train terminals: Hauptbahnhof (Main Station) and Ostbahnhof (East Station). Passengers transferring between these stations had to use the city's overcrowded streetcar network.

Since 1930 the German term for regional rail, including high frequency and through-running, has been S-Bahn, where S stands for Stadtschnell (city-fast). But whereas Berlin and Hamburg had such systems for decades, Munich would have to wait. There were recurrent plans for underground rail tunnels; a plan for an S-Bahn network from the Nazi era began construction in 1938, with an east-west and north-south tunnel, but the works were suspended in the war and little had been built. After the war, West Germany recovered quickly, and Munich grew especially fast, but infrastructure was inadequate. Plans for both a municipal subway and an S-Bahn run by national railway DB resumed, reducing the S-Bahn to just one east-west tunnel connecting Hauptbahnhof and Ostbahnhof.

Both the subway and the S-Bahn began construction in 1965. In the next year, Munich was chosen as the host city for the 1972 Summer Olympics, forcing both projects to accelerate. In the next six years, not only did the region build the east-west tunnel and the first subway line, but also it electrified the commuter lines that hadn't yet been wired, and lengthened and raised the platforms to allow for long trains, comparable to 8.5-car American trains.

To reduce costs, the S-Bahn was not built to the same standards on the outer branches as in the city. Some branches are single-track, and some require S-Bahn trains to share track with intercity passenger and freight trains. Since the system's initial opening there has been additional construction, but these design compromises still impose constraints on the system's timetable. To resolve them, Munich invented the clockface schedule, in which timetables repeat regularly all day on a prescribed interval, such as every 20 minutes.

Riders began crowding the system. Daily ridership had crept up from 114,000 in 1961 to 160,000 when the system opened, but then reached 250,000 by the end of 1972, 430,000 at the end of the 1970s, and 640,000 in 1987. Today there are 840,000 passengers per day.[27] Some lines today run every 10 minutes, combining to a peak frequency of a train every 2 minutes in the central tunnel.

Munich rail network trains are very crowded, and as a result, there have been plans to build a second east-west tunnel to add capacity. However, with more underground infrastructure in Munich today than there was in the 1960s, construction has run into schedule and budget overruns. The second tunnel, under construction since last year, is now projected to open in 2026 and cost $1.1 billion per underground mile, the second highest figure outside the English-speaking world (the RER A, at $1.2 billion, is first). At this cost, the NSRL tunnel could be built for $6 billion.

Boston had 80 years of head start on Munich in building underground urban rail. It has an opportunity to use NSRL to catch up. Munich's innovations in scheduling show the MBTA how to run a fast, reliable schedule even with grade crossings and single-track segments on some branches. Conversely, Munich's one failure, the mounting costs of the second S-Bahn tunnel, presents a strong argument for building a four-track NSRL from the start. It might look cheaper to start with two tracks and then expand to four later, but the lifetime costs would be much higher.

Philadelphia: A Tunnel Needs Trains

Like Boston and Munich, Philadelphia historically had two separate stub-end train terminals: Suburban Station and Reading Terminal. Suburban Station was built by the Pennsylvania Railroad; intercity trains stopped just outside Center City, at 30th Street Station, which offered through-service from New York to Washington. Reading Terminal served the trains of the Reading Railroad as well as other railroads that competed with the Pennsylvania, such as the Baltimore and Ohio. Each station was about a quarter mile from City Hall, where the city's two main subway lines intersect, but connecting between the two stations required walking the half mile.

In the 1970s, with both the Pennsylvania and Reading bankrupt, SEPTA took over both of their commuter rail networks, and began to plan to unify them. Both networks were already electrified, having been wired between the 1910s and 1930s. SEPTA designed the Center City Commuter Connection, a 1.8-mile tunnel connecting the two networks, extending four tracks of the already-underground Suburban Station to the east, with a new Market East station replacing the above-ground Reading Terminal. In today's money it cost $1.24 billion; if the North-South Rail Link could built at the same cost per mile, it would cost $2 billion.

The effect was not as transformational as hoped. The through-service patterns originally proposed were based on European best industry practices, with high frequency on every branch, going up to a train every ten minutes. Unfortunately SEPTA ran trains infrequently off-peak, and fares were set at a premium over bus and subway fare even within the city. This is especially harmful to in-city ridership: several SEPTA Regional Rail branches run entirely within Philadelphia's city limits, and all have weak ridership, even ones running parallel to overcrowded bus lines. This pattern of stronger ridership in the suburbs than in the city should not surprise Boston-based readers, since the Fairmount Line has relatively low ridership, and had the lowest ridership per mile when it charged premium fares.

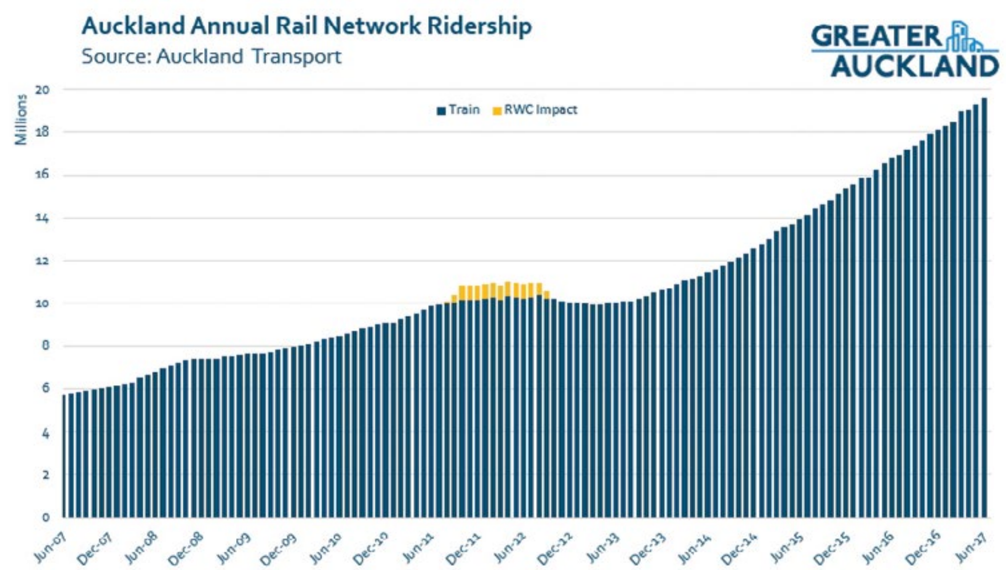
Thus Philadelphia completed the expensive part of regional rail - the tunnel and electrification - but has refrained from increasing service and integrating fares with city transit. Nonetheless, with through-running offering suburbanites access to several Center City stops, SEPTA Regional Rail has slightly higher ridership than the MBTA commuter rail network, on barely half the route-length. It also has the lowest operating costs of all major American commuter rail systems: $14 per car-mile and $310 per car-hour, compared with $18.5 and $540 respectively on the MBTA.[28]

In terms of size, historic urban form, and transit usage, Philadelphia and Boston are similar. That SEPTA's partial modernization (through-running and electrification, but no high frequency or fare integration) led to partial success (somewhat lower operating costs and ridership per route-mile) should make Boston more confident that full modernization of MBTA service would lead to full success.

Auckland: Electrify First

With 1.7 million people, Auckland is the largest metro area in New Zealand, and the fastest-growing. Provoked by increasing traffic and the unreliability of aging equipment and infrastructure, it has spent the last decade modernizing its formerly decrepit regional rail system, converting from a mixture of locomotive-hauled trains and secondhand DMUs to modern EMUs, with the full electrified system opening in 2015.[29] The region wired about 60 miles of track for NZ$80 million, about $60 million in 2018 US dollars; if the MBTA could electrify for the same per-mile cost, it would be able to wire the entire network for $400 million.

Along with electrification and modern rolling stock, Auckland introduced much more frequent service. Ridership has responded accordingly, rising from under 6 million per month in June 2011 to almost 20 million in June 2017 (the first electrified services began in April 2014), with no end in sight.[30]



At the same time that it modernized the regional rail system, Auckland also implemented a complete revision of the bus system. By using the added capacity to shift passengers onto the more efficient rail services, Auckland demonstrated a willingness to coordinate between modes that has often eluded Boston.

Even before the opening of electric service, discussions about building a downtown tunnel to turn Auckland's stub-end Britomart terminal into one stop on a through route had begun. Known as City Rail Link, that project is now underway.[31] Auckland's planners and advocates used the momentum generated by the activity around and success of rail modernization to build momentum for the tunnel, a much larger capital project. The tunnel project has begun to suffer from cost increases, and as of September 2016 its cost is estimated at $2.8-$3.4 billion NZ ($1.85-$2.25 billion US) for 2.2 miles of double-track tunnel.[32] Per track-mile, this is similar to the Harvard study's estimate of $4-6 billion for NSRL, a four-track tunnel.[33]

Auckland's experience offers three major takeaways for Boston: 1) Riders respond to provision of frequent, modern service even if there's no precedent for it, 2) integration of modes—such as Auckland's commitment to using buses and trains together—is crucial, and 3) The incremental strategy of building ridership through modernization and then immediately committing to the heavier infrastructure lift, the downtown tunnel, is viable; though it will not be ideal, or recommended, in every scenario. For those wishing to read more about Auckland's experience, the City Rail Link website provides an excellent breakdown and history.

Melbourne: Stub-terminals Become a Loop

Melbourne was at the forefront of railroad electrification, completing suburban electrification of its rail network in the 1920s. The city has never developed a typical subway network: the suburban rail network connected the early-1900s-era suburbs to the central business district (CBD), while an extensive tram network continues to provide the backbone of local transit. Ridership on the regional rail network stagnated in the 1950s and 1960s as the region suburbanized, although peak-direction CBD ridership remained relatively strong.

Two stations on the edge of the CBD provided rail service to the city with most trains terminating there and then turning back. There were four run-through tracks, but the unbalanced nature of the city's geography—with most service entering the city from the southwest—meant that simply running trains through would be sub-optimal. The rail line also followed the Yarra River and port, and most development had spread north and east of the river and the railroad, requiring last-mile trips by foot or on the crowded tram network.

The solution was to build the Melbourne Underground Rail Loop—now called the City Loop—with four tracks circling the CBD, adding three stations, reducing terminal bottlenecks and allowing suburban trains to better serve the downtown area. Built between 1970 and 1980, and opened in the early 1980s, the City Loop allows for significantly increased operations, and ridership responded. With recent improvements in frequency, other than the ends of the outermost branches most lines now operate at least every 20 minutes at off-peak times (and far more frequently at rush hour), with trunk routes operating more frequently and offering some local-express services. The system now carries more than 800,000 passengers per day.

The cost of the City Loop adjusted for inflation cost about $2 billion for 2.3 miles of four-track railroad and three new underground stations, as well as upgrades to the existing stations and two new elevated rail tracks. A new project is planned to relieve some of the capacity from the City Loop and is estimated to cost up to $8.5 billion for 5.6 miles of two-track tunnel and five new stations, with engineering and preliminary construction underway.

Toronto: Moving Beyond Rush Hour, Planning for the Future

Until 2012, Go Transit in Toronto was a rush hour operation. Only two lines provided any midday service, and the vast majority of service was geared towards peak ridership. In the past decade, the agency has shifted towards providing more comprehensive service. A new spur was built to the airport using DMUs, with plans to electrify this service and the busiest main lines, within the decade. The agency has bought 80 percent of the lines over which it operates in recent years and is planning upgrades to allow more bidirectional service on otherwise single-track lines, with the end goal of a Paris-style system with frequent service between Toronto, its inner suburbs, and regional cities further afield.

Trains in Toronto serve Union Station, which has run-through tracks, meaning that the city does not have the stub-terminal capacity issues which developed in many other cities and require tunneling projects. Most service today begins or ends at Union Station, but through-running service is possible without major infrastructure changes. The challenges for Toronto extend beyond Union Station: taking control of track, managing freight railroad interactions, and adding electrification to allow faster, more efficient service. The costs—$10.5 billion over 10 years—are high, but include electrification and significant new track construction to allow bidirectional operation, and Metrolinx, the regional government, makes the case that the service improvements, reduced operating costs and regional benefits will pay their way.

Appendix B
Technical Information

In constructing timetables, TransitMatters has relied on a combination of simulations, acceleration and deceleration information, and industry best practices from other countries, chiefly Switzerland.

Caltrain, the commuter rail system connecting San Francisco and San Jose, is currently in the process of electrifying its service. Local rail activist Clem Tillier ran simulations using public technical specifications and found that bilevel EMUs would connect San Francisco and San Jose 15 minutes faster than the current diesel locomotive-hauled trains. Electric locomotives would only save 1 to 2 minutes over diesel locomotives over the 19-stop local schedule. Our plan, with lighter single-level EMUs, saves more time per stop, especially since the MBTA has less powerful diesel locomotives than Caltrain.

The speed and acceleration data we use come from the FLIRT, a single-level Swiss-made EMU. The top speed can be up to 125 mph, but we use the more typical 100 mph. There are public videos of FLIRT acceleration to 100 mph[34] and deceleration from 60 mph.[35] These give enough information to compute the "stop penalty" at each top speed—that is, the time the train loses from decelerating to a stop and then accelerating back to line speed, excluding dwell time at the station:

Top Speed (MPH)	Stop Penalty (sec)
60	24
70	29
80	34
90	39
100	45

The dwell time at each station is 30 seconds. This is based on many observations of train performance in Paris and in Zurich. In Paris, the observed trains have level boarding and many doors. In Zurich, the trains are bilevel and have two door pairs per car, some with level boarding and some without; all trains have wide doors and open circulation, permitting short dwell times.

The only exceptions observed to the 30-second dwell time rule are the busiest city center stations. At Paris's Gare du Nord, rush hour trains on the RER B Line, with four pairs of doors per car, have about 500 passengers getting off and 500 getting on; the dwell time is about 60 seconds. Based on this, we believe Regional Rail should have 60-second dwell times at South Station, Central Station, and North Station, and 30-second dwell times everywhere else.

Finally, to allow trains to recover from delays, schedules must be slightly padded. In Switzerland, the padding factor is 7%, since the trains are reliable and dwell times are predictable. This is the value we use; in contrast, American commuter operations pad 15% or even more, especially on lines with complex express service patterns.

The North-South Rail Link has had a few different variants in official proposals. Some variants have one tunnel and two tracks, others have two tunnels and four tracks. We back the four-track option, for two reasons. First, the tunnel portals to the south of the South Station are complex and constrained, and it is not possible to connect all lines to just one tunnel; in engineering studies going back to the 1990s, one tunnel portal would always connect to Back Bay and the Providence and Worcester Lines, and the other to South Bay and the Fairmount and Old Colony Lines.

Second, there is not enough capacity with just two tracks. The maximum capacity on a two-track railroad is about 48 trains per hour—a train every 75 seconds—but only on driverless metro lines isolated from the national rail network. Commuter Rail lines top out at about 30 trains per hour in Paris, Tokyo, Berlin, and Munich—a train every two minutes. A more typical value, given the extent of branching expected on Regional Rail in Boston, is 24 trains per hour, a train every 2.5 minutes.

With ridership growth coming from better service, we expect peak travel demand to be well over 24 trains per hour across all lines entering Boston from the south. We estimate that peak Regional Rail traffic, across all lines feeding South Station today, would be 32-36 trains per hour. Calculating the same figure for the lines feeding North Station is more difficult, because Commuter Rail today has lower mode share on the north than on the south (most downtown jobs are closer to South than to North Station), and NSRL would change this, but total commute volume into Boston is about the same in the northern suburbs as in the southern ones.

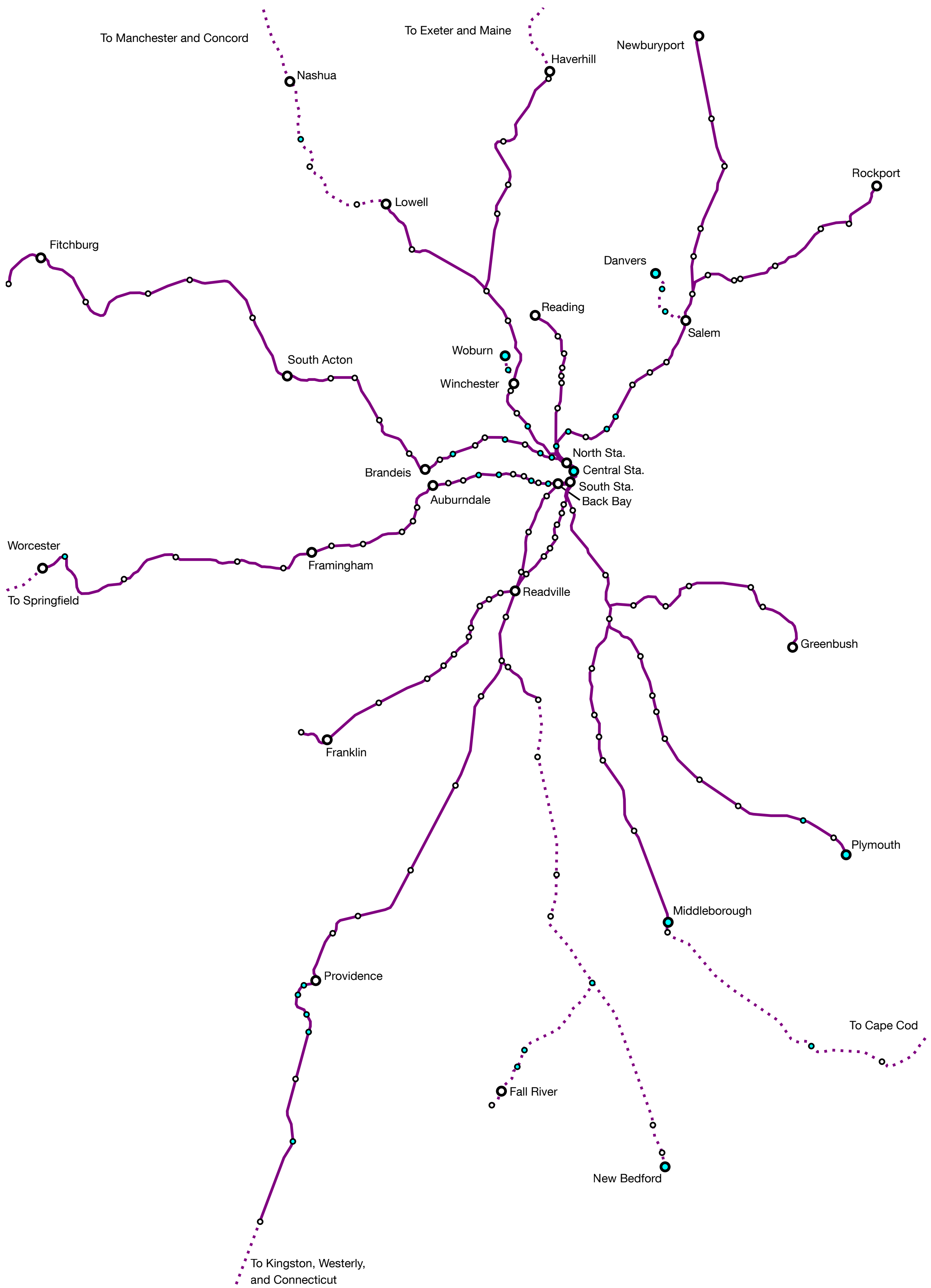
We do not expect any capacity constraints except on the immediate approaches to North and South Stations, and on some segments shared with other types of trains such as the Providence Line, where any future high-speed rail service would require facilities for timed overtakes with Regional Rail.

The state Secretary of Transportation suggested at a December FMCB meeting that electrification could be problematic because of constraints on the signal system governing the minimum spacing between trains. In fact, what we propose has the opposite effect: repeating clockface schedules, with all-local trains, ensures that on the branches, trains are always 15 or 30 minutes apart; even the ancient legacy signals, requiring a few miles of separation between trains, can easily accommodate that. The only problems come from freight trains—but the only significant volumes of freight on the entire MBTA network are on the outermost portions of the Fitchburg and Haverhill Lines; the former (beyond Littleton) could just run trains every 30 minutes even at the peak, and the latter (beyond Ballardvale) is so short and has such slow passenger trains that mixing the two train types should not cause problems.

The NSRL tunnel should be built with three stations: South Station, Central Station/Aquarium, and North Station. With large-diameter tunnels, it is possible to build stations entirely inside the tunnel, punching galleries between the two tunnels for cross-platform transfers. The NSRL project should set up these cross-platform transfers on the same model as in Hong Kong: Central Station should have same-direction cross-platform transfers, while North and South Stations should have opposite-direction ones. This means people from the Back Bay portal could transfer cross-platform to the South Bay portal at South Station, for example going from Braintree to Back Bay or from Brockton to Boston Landing. On the north, people could similarly transfer at North Station, for example going between Brandeis and Salem.

We include a technical appendix for each of the MBTA's commuter lines, explaining what needs to be done to upgrade it to Regional Rail standards, and what a future Regional Rail timetable would look like. The speed gains from electrification, top-line trains, level boarding, and the reduced padding coming from better reliability are very large: we estimate on average 40% speed gain, or 30% cut in travel time, even with the addition of some infill stops.

The MBTA is currently evaluating options for additional midday layover space, including land previously dedicated to West Station. With increased midday service frequency, the need to store trainsets close to downtown disappears, since overnight layover can be accommodated at yards near the ends of lines. The midday layover needs result from trains making only a single pair of trips—inbound in the morning peak and outbound in the PM—a service pattern that Regional Rail would eliminate in favor of all day equipment utilization.The MBTA should proceed with the understanding that, with increased midday service and a North-South Rail Link, additional investments in expensive core facilities are unnecessary. Boston Engine Terminal(BET), the primary maintenance facility for the commuter rail system, is unable to perform service on south-side trainsets without a long, slow trip through the non-revenue Grand Junction line. With the North-South Rail Link, trains could simply run through from the south side to BET.



The Regional Rail network Metropolitan Boston can achieve.

Appendix C1

Providence/Stoughton Line

This section analyzes the advantages of potential infrastructure and service improvements for the MBTA's Providence and Stoughton lines.

Providence/Stoughton line segments

- The shared Providence and Stoughton Line extends along the Northeast Corridor (NEC) from South Station to Canton Junction, a distance of 15 miles.
- The Providence line segment continues south from Canton Jct. along the NEC to Providence Station, and beyond, to Wickford Junction. This is 29 miles to Providence and another 19 miles to Wickford Jct.
- Stoughton Line segment extends from Canton Jct. to Stoughton, a distance of 4 miles.

The Providence line from South Station through Rhode Island is the only rail line in the MBTA system that has full electrified infrastructure available. Amtrak has expressed interest in the MBTA electrifying Commuter Rail service along the NEC in Massachusetts and Rhode Island.

Because the NEC is already electrified, the Providence Line offers the opportunity to almost immediately implement electrified rail service within the MBTA Commuter Rail system. Only short segments, used by the MBTA but not by Amtrak, are unelectrified.

Ridership

The Providence/Stoughton line is the busiest in the Commuter Rail system. The route has over 13,000 passenger trips in each direction every weekday. The current travel time for 43-mile route between Providence and South Station can typically take 70 minutes.

Line characteristics

Eight stations only have mini-high platforms, which are about two-thirds the length of a typical coach: Hyde Park, Canton Jct, Sharon, Mansfield, Attleboro, South Attleboro, Canton Center, Stoughton. Those stations have to be equipped with full-length high platforms; the other stations already have high platforms.

Between Boston and Providence, a distance of 43.6 miles, there are ten stops. But the potential time saving is substantial for how wide the stop spacing is, because the current MBTA rolling stock generally has a maximum speed of 79-mph, whereas much of the NEC rail line in Massachusetts and Rhode Island has speed limits of 100-150 mph.

Rhode Island is currently investing in an infill stop in Pawtucket. We believe that two more locations for infill stops are warranted: Readville, and Forest Hills. Both have stops on other lines branching off the NEC (Franklin and Needham, respectively), but would be useful on the Providence Line as well: Readville for transfers to the Fairmount Line, and Forest Hills for connections to the Orange Line.

To transform the Providence/Stoughton line to high speed EMU rail service in the near-term, the MBTA should:

- Procure rolling stock,
- Electrify the Pawtucket service yard, which was designed for electrification,
- Build high-level platforms at the eight stations with mini-highs,
- Electrify short track segments not used by Amtrak:
  - The platform tracks at Attleboro, where the line has four tracks,
  - The Stoughton line,
  - The 11-mile FRIP track from Providence Station to Greenwood, Warwick, and
  - The Wickford Jct. siding.

Capital investment along the NEC south of Massachusetts would be the exclusive responsibility of Rhode Island. Within Rhode Island, there are unfunded long-term plans to extend the line even further south than Wickford Jct., into Kingston and Westerly at the border with Connecticut. The state's rail plans are compatible and complementary with Regional Rail.

MBTA subway and bus, and GATRA, BAT, and RIPTA bus service should have full fare integration with Regional Rail along the Providence/Stoughton lines. RIPTA should expand its current free transfer policy for MBTA pass holders to full fare integration for all Regional Rail fare products; a trip on a Regional Rail train within Rhode Island should cost the same as a RIPTA bus ride.

For more frequent Providence and Stoughton line service, trains should run equally at all times of day in both directions. Before NSRL opens, trains should use two captive tracks at South Station and shuttle back and forth, turning back within ten minutes to avoid congesting South Station tracks. With implementation of the NSRL there would be no need for extended dwell times at South Station as trains would potentially travel beyond to the north side of the MBTA system.

With either the current terminal service at South Station or with NSRL through train service, extended train layovers for the Providence and Stoughton line service should be at:

- Providence Station
- Stoughton
- Pawtucket service yard
- Wickford Jct.

When NSRL is established, end of the line locations for layovers on the north side should be selected.

Train scheduling:

- Generally, trains should operate between 5 am and 1 am, 7 days a week.
- Scheduling should be consistent with recurring clockface times.
- Frequency should be the same for both inbound and outbound trains.
- The top speed should be 100 mph or more, except where constrained by track geometry. Positive Train Control, which prevents overspeed incidents, is installed and active on the line.

Frequency:

Station Segment	Peak	Current	Off-Peak	Current
South Station - Canton Jct.	**7.5 min**	20 min	**15 min**	30 min
Canton Jct. - Stoughton	**15 min**	30 min	**30 min**	60 min
Canton Jct. - Providence	**15 min**	30 min	**30 min**	60 min
Providence - Wickford Jct.	**30 min**	60 min	**30 min**	90 min

Travel Times

At full rollout, with NSRL removing the slow terminal tracks into South Station, the following schedules are feasible:

PROVIDENCE		
Station	Time	Current
South Station	**0:00**	0:00
Back Bay	0:03	0:05
Ruggles	0:05	0:08
Forest Hills	0:08	-
Hyde Park	0:12	0:18
Readville	0:14	-
Route 128	0:17	0:23
Canton Junction	0:20	0:29
Sharon	0:23	0:35
Mansfield	0:29	0:43
Attleboro	0:35	0:51
South Attleboro	0:40	1:01
Pawtucket	0:43	-
Providence	**0:46**	1:11
T.F. Green Airport	0:55	1:27
Wickford Junction	**1:02**	1:43

STOUGHTON		
Station	Time	Current
South Station	**0:00**	0:00
Back Bay	0:03	0:05
Ruggles	0:05	0:08
Forest Hills	0:08	-
Hyde Park	0:12	0:18
Readville	0:14	-
Route 128	0:17	0:23
Canton Junction	0:20	0:29
Canton Center	0:22	0:32
Stoughton	**0:25**	0:40

An additional small time saving, no more than 20 seconds, could come from high-speed rail curve modification north of Providence. South of Providence there is an additional potential saving from curve modification, perhaps a full minute.

Appendix C2

Fairmount Line

This section analyzes the advantages of potential infrastructure and service improvements for the MBTA's Fairmount Line, proposing upgrades and changes along its corridor.

Current situation

The Fairmount Line runs just over 9 miles from South Station to Readville, primarily through the Dorchester, Mattapan, and Hyde Park neighborhoods of Boston, with seven urban stations open and an eighth under construction at Blue Hill Avenue/Cummins Highway. The Fairmount Line has already had considerable upgrades to its infrastructure, with many bridges replaced and high-level platforms installed at all stations other than Fairmount and Readville.

At both ends, the line connects to the Providence Line, which is already electrified. Thus, it does not need electrical substations; electrifying the line merely requires stringing wire and connecting it to the Providence Line's substations. Electrification is a priority, especially given high levels of air pollution in Dorchester from sources like the congested Southeast Expressway in addition to the current Commuter Rail diesel locomotives.

The southern end of the line is closely parallel to the 28 bus, which runs along Blue Hill Avenue. The 28 is in a near-tie for busiest bus route in Boston; it is crowded at rush hour, despite averaging only 8 mph. Faster trains would connect passengers in Mattapan to Downtown Boston four times as quickly as the 28 bus with a transfer to the Orange Line.

Ridership

Historically, ridership on the Fairmount Line was poor, but it has tripled since 2012, when the MBTA moved most stations into Zone 1A (charging subway fare), added infill stations, improved track/signals, and heavily marketed the line as an alternative in Dorchester.[36] An additional experiment with free fares for two weeks in 2017 showed more latent demand, increasing ridership by 25-44%, despite service only every 40 minutes at rush hour and 60 minutes midday.[37]

Line characteristics

The Fairmount Line is unique among MBTA Commuter Rail lines in how urban it is. It connects South Station with 7 other stations, with an eighth station under construction at Blue Hill Avenue. All stations on the line are in the City of Boston, and all except the outermost two, Fairmount and Readville, have full-length high platforms built in the last few years as part of the modernization plan.

Because the stations are so closely spaced, the Fairmount Line should be the top target for electrification, alongside the already-wired Providence Line. The difference in travel time between EMUs and trains pulled by diesel locomotives, about 60-90 seconds per station, is much more salient on a line with 8 stations in 9 miles than on a line with a station every 3 to 4 miles. Electrification and the use of EMUs will have many benefits for the Fairmount Line, including reducing emissions to zero, but the most important benefit will be the ability to have a high frequency service that truly behaves like a high functioning subway system.

The line's urban setting also means that high frequency is imperative. A train every 30 minutes could work in cities and suburbs like Providence or Worcester, where the trip time to Boston is an hour. In Dorchester, higher frequency is nonnegotiable.

Equally important are good subway and bus connections. One ticket should be valid on all trains and buses within Boston and inner core communities (such as Cambridge and Revere), allowing people to transfer from the Fairmount Line to the Red Line at South Station, the 28 bus at Blue Hill Avenue, or the 23 bus at Talbot Avenue without paying an additional fare.

To transform the Fairmount Line into useful regional rail, called the Indigo Line on some MBTA plans, the following capital and operations improvements would be required:

- Fare integration with the buses and subway (leveraging the imminent AFC 2.0),
- High frequency: a train at least every 15 minutes all day,
- Electrification: hooking into the substations at both ends in order to wire the line cheaply,
- High platforms at Fairmount and Readville to speed boarding as well as permit EMUs without trap doors.

The terminal at Readville, on a grade-separation over the Northeast Corridor, is single-track. It is possible to schedule trains every 15 minutes with a single-track terminus: in Vancouver the SkyTrain Canada Line has single-track ends at both of its outer branches, each having a train every 7 minutes at the peak. However, this imposes operational constraints elsewhere on the line, and so it may be desirable to double-track this terminal.

Potential Through-Service

The Fairmount Line opened together with the Franklin Line as part of the New York and New England Railroad. Today, the Franklin Line goes between Readville and South Station along the route of the Providence Line, which offers a faster trip. However, optionally, the Fairmount Line and the Franklin Line could be reconnected, to offer direct service between communities in Dorchester and Mattapan and retail job centers in Dedham and Norwood.

If there is through-service, then some additional work is needed. Most of it is on the Franklin Line, but some is on the Fairmount Line: the Readville track would need to be double-tracked. The additional travel demand coming from Dedham and points south is such that peak frequency should be a train every 7.5 minutes. A single-track station at Readville would then be impractical, because it would excessively constrain operations elsewhere on the line.

Travel Times

At full rollout, with NSRL removing the slow terminal tracks into South Station, a fast schedule is feasible, almost doubling speed from today. Trains would go at 60 mph from South Station to Blue Hill Avenue, and between Blue Hill Avenue and Readville they could even reach 80 mph. This sample schedule assumes no through-service with the Franklin Line.

FAIRMOUNT		
Station	**Time**	Current
South Station	**0:00**	0:00
Newmarket	0:03	0:09
Uphams Corner	0:05	0:12
Four Corners/Geneva	0:06	0:15
Talbot Avenue	0:08	0:18
Morton Street	0:10	0:21
Blue Hill Avenue*	0:12	-
Fairmount	0:15	0:25
Readville	**0:17**	0:30

Appendix D

Glossary of Technical Terms

ADA	Americans with Disabilities Act passed by Congress in 1990 ensuring egalitarian access to buildings, transit, and public services for people with disabilities
BAT	Brockton Area Transit Authority
Bottleneck	An infrastructure element that lowers the capacity of other elements- for instance, a section of single track in an otherwise double-tracked line
Capacity (service)	The theoretical number of users that a particular system can serve in a given span of time
Capital investment	Money spent on durable elements of a system, not on day-to-day operations
Clockface (scheduling)	Scheduling in which trains (or buses) repeat precisely every fixed interval. For example, if an inbound train leaves your station at 9:50 am under a 20-minute clockface schedule, then an inbound train will leave your station at :10, :30, and :50 every hour making the exact same stops.
Construction cost	The cost to build or implement new infrastructure
Corridor (rail)	Right-of-way in which a train operates
DMU	Diesel Multiple Unit, a train that runs using diesel engines to self-propel each individual railcar.
Double track	Having 2 tracks, enabling inbound and outbound service to use separate tracks; adding a second track means trains going one direction don't have to wait for trains going the other direction, which greatly constrains capacity and can often exacerbate delays
Dwell time	The amount of time a train spends at the station platform
Electrification	Building of electric power infrastructure along rail corridors
EMU	Electric Multiple Unit, a train that runs on electric power to self-propel each individual railcar
FMCB	Fiscal Management Control Board (of the MBTA)
FLIRT	A common model of EMU made by Stadler Rail
Frequency (of service)	How often service arrives
FRIP	Freight Rail Improvement Project
Full accessibility	Complete compliance with ADA and local guidelines enabling persons with a range of disabilities to have universal access to transit modes
Gateway Cities	"Mid-size urban centers that anchor regional economies around the state," facing "stubborn social and economic challenges," while retaining "many assets with unrealized potential" as defined by the Brookings Institution & MassINC
GATRA	Greater Attleboro Taunton Regional Transit Authority
High-level platform	Platform that is raised to meet the level of the entrance to a train, so as to enable level boarding
Infill stop	A new train stop that is built between two existing stops
Intercity rail	A rail network in which multiple cities are connected to each other with frequent rail service
Layover	Time spent by a train stationary at a terminal station or in a yard
Level boarding	Boarding a train at the same level as the platform with no barriers or steps, enabling full accessibility between the platform and the train; this can be installed as part of ADA accessibility, but is also a feature of some inaccessible stations (such as inaccessible subway stations)
Low-level platform	A platform which is at the same level as the tracks, requiring riders to walk up steps to enter a train. Low-level platforms are not ADA-compliant
MAPC	Metropolitan Area Planning Council
MBTA	Massachusetts Bay Transportation Authority
Metro(politan) Boston	Area roughly equivalent to the MBTA service area covered by existing Commuter Rail service, as defined by MAPC
Mini-high platform	A high-level platform, about two-thirds of a car long, that is constructed at a station with an existing low-level platform to enable level boarding for persons with disabilities
Mode share	The proportion of users in a corridor who travel by a given mode of transport
NEC	Northeast Corridor, the electrified rail corridor currently in use by the Providence Line on Commuter Rail as well as Amtrak service between Boston & Providence
NSRL	North-South Rail Link, a 2-mile tunnel connecting North & South Stations currently being studied by MassDOT
Operating cost	The cost to run rail service
Peak service	Service during "rush-hour" periods, roughly between 6-9 AM and 4-7 PM
RATP	Régie Autonome des Transports Parisiens, a state-owned public transport operator in France operating the Paris Metro and many other public transit services in the Paris region
RER	Réseau Express Régional, a hybrid suburban commuter/rapid transit system serving Paris, France and its suburbs
Right-of-way	The physical space dedicated to a railroad, highway, or other transportation corridor
RIPTA	Rhode Island Public Transit Authority
Rolling stock	Vehicles used on a railroad
SEPTA	Southeast Pennsylvania Transportation Authority
Single track	Having 1 track, meaning that inbound and outbound service have to share a single track, thus hindering service frequencies
SNCF	Société nationale des chemins de fer français, France's national state-owned railway company, which operates rail service throughout the country
South Station Expansion	A plan currently being considered by MassDOT which would expand the South Station stub-end terminal to 20 tracks, with an estimated cost of $2 billion dollars. If built, the expansion would hinder the potential to implement regional rail service.
Timed-	When two trains are scheduled precisely to be at a specific place for any of the following purposes: » **Meet** - When two trains in opposite directions on a mostly single-track line are timed to pass each other on a short double-track segment » **Overtake** - When a slow and a fast train in the same direction are timed so that the fast train will overtake the slow train on a segment with passing tracks (often four tracks on a double-track line) » **Transfer** - When two trains, in any direction, are timed to stop at a station at the same time, allowing passengers to connect between them, typically across the same platform
TOD	Transit-oriented development, a development centered around public transit, often featuring higher density and less parking than the surrounding community
Walkable neighborhood	A neighborhood in which everyday commercial and social trips can be achieved by walking, often in conjunction with public transit

Endnotes

1 Transcript at 1:58 p.m., FMCB Meeting, November 20, 2017; see also https://www.mbta.com/events/1158, 2:00:10 on video

2 https://ocw.mit.edu/courses/civil-and-environmental-engineering/1-201j-introduction-to-transportation-systems-fall-2006/lecture-notes/lect11.pdf&sa=D&ust=1511360427735000&usg=AFQjCNGN0RXyQkT4B2RpYKt2AlB-Cvr2iw

3 http://www.railwaygazette.com/news/single-view/view/benchmarking-identifies-good-practice-in-rolling-stock-maintenance-1.html

4 http://roslindale.wickedlocal.com/news/20160310/parkway-residents-voice-concerns-over-commuter-rail-fares&sa=D&ust=1511360427739000&usg=AFQjCNHIXeNKnXuHxNrROeknbI_1sApHSg

5 https://www.bostonglobe.com/metro/2017/04/26/fairmount/p9V0krkJUAQZidBAtUIl4K/story.html

6 http://amateurplanner.blogspot.com/2015/10/electrifying-fairmount-would-be-cheaper.html

7 https://docs.google.com/spreadsheets/d/1K4mKn14A4JEGwDD3Vx-rOOBY2inXtn5D-PXv-8bFfuk/edit#gid=256127059

8 https://www.bostonglobe.com/metro/massachusetts/2012/11/25/wide-racial-gap-exists-speed-boston-area-commutes/ut-DAVcJ9B6QUALUidI9DGL/story.html

9 https://www.youtube.com/watch?v=274vEkLOB_I

10 https://blog.mass.gov/transportation/mbta/wedgemere/

11 https://www.massdot.state.ma.us/main/tabid/1075/ctl/detail/mid/2937/itemid/315/MBTA-Officially-Re-opens-Wedgemere-Commuter-Rail-Station-as-Fully-Accessible.aspx

12 See Commuter Rail Power point presentation at FMCB Meeting, November 20, 2017; see also https://www.mbta.com/events/1158

13 http://www.mta.info/press-release/lirr/mta-long-island-rail-road-sets-new-goals-boost-time-performance-improve-fleet (modern LIRR fleet experiencing ~500k mean distance between delays "MDBF"), and https://www.lta.gov.sg/apps/news/page.aspx?c=2&id=dfde4510-8fb3-4f69-b992-a0c52a20a6f6

14 http://www.bostonindicators.org/indicators/environment-and-energy/5-3environmental-justice-and-equity/5-3-1public-health-stresses-on-children-boston-neighborhood

15 http://www.brighamandwomens.org/About_BWH/communityprograms/our-programs/CHNA-9-30-2013.pdf

16 https://www.nytimes.com/2017/12/10/business/volkswagen-diesel-subsidies.html

17 https://docs.google.com/spreadsheets/d/1K4mKn14A4JEGwDD3Vx-rOOBY2inXtn5D-PXv-8bFfuk

18 Cf. City Anatomy: A Framework to Support City Transformation, https://cpsociety.sharepoint.com/sites/cptf/CPTSC/Private%20Documents/Publications/CPA-I_001-v2_City_Anatomy.pdf?slrid=6575419e-4061-5000-02d1-b999b21aecb4

19 http://www.southcoasttoday.com/special/20160628/officials-reconsider-middleboro-route-as-south-coast-rail-cost-soars

20 https://commonwealthmagazine.org/opinion/dear-gov-raimondo-express-trains-wrong-ask/

21 In the Philadelphia suburbs, SEPTA recently built an infill station with a single- track high platform for $3.8 million.
See: http://planphilly.com/articles/2015/09/14/new-septa-station-in-lansdale-set-to-spur-transit-oriented-development

22 http://www.wabanareacouncil.com/sites/default/files/WabanHighlands2-29_1.pdf

23 https://framwormbta.weebly.com/turn-table.html

24 http://www.railwaygazette.com/news/single-view/view/benchmarking-identifies-good-practice-in-rolling-stock-maintenance-1.html

25 https://www.transit.dot.gov/sites/fta.dot.gov/files/docs/Transit%20Profiles%202015%20-%20Top%2050%20Agencies%20with%20Summary.pdf

26 https://commonwealthmagazine.org/opinion/dear-gov-raimondo-express-trains-wrong-ask/

27 http://www.s-bahn-muenchen.de/s_muenchen/view/wir/daten_fakten.shtml

28 https://www.transit.dot.gov/sites/fta.dot.gov/files/docs/Transit%20Profiles%202015%20-%20Top%2050%20Agencies%20with%20Summary.pdf

29 The outer end of one branch still runs DMUs, although electrification is actively under consideration (the other alternative being EMUs with an added battery system that can run off-wire).

30 https://www.greaterauckland.org.nz/2017/08/18/2017-rail-station-boardings/

31 https://www.cityraillink.co.nz/

32 https://www.nbr.co.nz/article/price-tag-auckland-rail-link-balloons-jw-p-194251

33 We recognize that NSRL faces unique potential cost pressures associated with the highway and transit tunnel infrastructure already in place along the route.

34 https://www.youtube.com/watch?v=tWD4MhX8cSc

35 https://www.youtube.com/watch?v=pMxrbEBzLbc

36 https://www.bostonglobe.com/metro/2017/04/26/fairmount/p9V0krkJUAQZidBAtUIl4K/story.html

37 https://www.mbta.com/news/2562

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