A BETTER CITY

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POSITIVE SIGNALS:

A FRAMEWORK FOR ADVANCED SIGNALS & CONTROL FOR THE MBTA RED & ORANGE LINES

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A Better City represents a multi-sector group of nearly 130 business leaders united around a common goal: to enhance the Greater Boston region's economic health, competitiveness, equitable growth, sustainability, and quality of life for all communities. By amplifying the voice of the business community through collaboration and consensus-building, A Better City develops solutions and influences policy in three critical areas: 1. transportation and infrastructure, 2. land use and development, and 3. energy and the environment. A Better City is committed to building an equitable and inclusive future for the region that benefits and uplifts residents, workers, and businesses in Greater Boston.

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EXECUTIVE SUMMARY

MBTA RED & ORANGE LINE TRANSFORMATION

The Massachusetts Bay Transportation Authority (MBTA) is undertaking a multi-billion-dollar overhaul of the Red and Orange Lines, the two most heavily used parts of Boston's regional transit system, with substantial investments in new vehicles and associated infrastructure. Pre-COVID-19, the Red and Orange Lines carried a combined ridership of nearly 450,000 trips, or 38 percent of the 1.2 million trips the T delivers systemwide on a normal weekday.[1] With nearly four out of every ten riders (pre-pandemic) who take mass transit in the Boston region using them, the Red and Orange Lines are the workhorses of the MBTA system. Like much of the transit system, these two key subways suffer from decades of underinvestment, as capital maintenance and worthwhile upgrades were deferred.

However, thanks to the leadership of the MBTA's Fiscal Management and Control Board (FMCB), MBTA executives, and other public officials, transit investment is now heading in the right direction, as the T is midway through a $10 billion capital investment plan to modernize and upgrade major parts of the transit system, with $2.1 billion allocated to help transform the Red and Orange Lines. Under a contract originally executed in 2015 to buy replacement vehicles for the Red and Orange Lines, 404 new cars are scheduled to enter service by 2024 at a projected cost of about $1 billion dollars. These new cars will entirely replace the existing fleets. They will also expand the number of active Red Line vehicles from 218 to 252 and the number of active Orange Line vehicles from 114 to 152. With 16 percent more Red Line and 33 percent more Orange Line vehicles available each day, the MBTA can run more trains per hour which will reduce the headway between trains and shorten the time that riders need to wait on platforms. With more trains arriving more often at each station, the MBTA promises to deliver expanded capacity and faster, more comfortable, more frequent, more reliable, and less crowded subway trips.

To accommodate and complement the new vehicles, the MBTA is investing $1.1 billion on various infrastructure upgrades, including improvements to maintenance facilities and yards, test tracks, power systems, and signals. The signals work includes $267 million to replace some of the most worn cabling and componentry attached to the tracks and upgrade much of the existing analog equipment housed beside the tracks (in relay rooms) with the latest generation of microprocessor-based digital modules. While the trains used to transport riders will unquestionably be more current, this report will explore if the same will be true on one crucial and fundamental part of the subway's more hidden infrastructure—its signals.

FIXED-BLOCK VERSUS COMMUNICATIONS-BASED TRAIN CONTROL SIGNALS

To begin, this report looks at the historical development of signals and describes how much of the fundamental techniques invented over 150 years ago are still in widespread usage today. The report examines the two types of signals systems currently offered by the two companies that control the marketplace in North America.

1. "Normal" meaning excluding the influences of a global pandemic; The author believes transit ridership will rebound to pre-pandemic levels sooner than most prognosticators and this report and its recommendations should be read in that context. Ridership source: MBTA Data Portal.

Fixed-Block signals, based on inventions and patents that date back to the 1870s, divide subway tracks into “blocks” that form an electric circuit. When a train is in a block, it triggers a track circuit that indicates to the signal system that the block is occupied, thereby preventing another train from entering that occupied block. Each block typically averages 1,000 feet, a length that cannot readily change due to the large amount of fixed componentry. With Fixed-Blocks, the maximum speed of each train will in part depend on how many blocks are unoccupied, or open, in front of it. However, the signals do not register the trains’ speed, nor do they understand where each train is located within each block. The inexactness of Fixed-Block signals therefore limits a system’s ability to run more trains at higher frequency.

To address the operational inefficiencies of Fixed-Blocks, a newer signals approach referred to as Moving Block or Communications-Based Train Control (CBTC) signals was invented in the 1980s. Using sophisticated computer software to calculate the required amount of separation between trains in real-time, CBCT effectively creates blocks that can move or change in length. By constantly tracking each train on the line using a complex system of two-way radio communications and other technologies, CBTC signals can more precisely track the status of adjacent trains and expand or shrink the safe gap needed between them. As such, CBTC signals generally promise to increase the number and frequency of trains and enhance overall capacity. CBTC can also enable trains to run in either semi-automatic mode or in full autonomous mode, which can help to further increase capacity as well as provide for additional passenger conveniences such as platform screen doors.

ASSESSING SIGNAL UPGRADE OPTIONS

While most newly constructed subway lines, such as London’s Crossrail project approved in 2007, have adopted CBTC signal technology, the decision about whether to switch an existing system—like the MBTA’s Red and Orange Lines—from Fixed-Block signals to CBTC signals is less clear cut. Complexities range from incompatibility with pre-existing signals to limited contractor access windows typically result in challenging procurement processes and costly construction schedules. With respect to implementing CBTC signals onto an existing fixed-block system, CBTC systems typically overlay all sorts of extremely sophisticated and very expensive equipment onto a legacy system. These legacy systems usually have an existing array of complicated track circuits that form each fixed-block. Such track circuits provide important advance notice of any failure or breakage in the running rails or tracks, and that legacy signals componentry is typically also retained and kept operational as part of the upgrade to CBTC. Although CBTC signals can and do offer many benefits over fixed-block signals, any operational, maintenance, or repair savings are realized over a lengthy payback period on a life-cycle cost basis.

As a comparative case study, this report will discuss the decision of the New York City Metropolitan Transportation Authority (MTA) to switch from Fixed-Block signals to CBTC signals and the MBTA’s decision to upgrade but retain its Fixed-Blocks signals system on the Red and Orange Lines. This study assesses the signal upgrade options available to the MBTA for the ongoing Red and Orange Line signals upgrades, and it explains why the MBTA’s decision to stay with Fixed-Block signals was the right choice for the near future, given the limited and imperfect options available in today’s signals marketplace: to either switch over to CBTC and face the prospect of a decade of construction and about $1 billion in additional cost per line, or to retain and upgrade the existing Fixed-Block system until the design and construction process to install

CBTC signals becomes considerably easier. Or, alternatively and preferably, until a new third or next-generation signals system emerges.

RECOMMENDATIONS

This report reviews some key aspects of the MBTA's Red Line and Orange Line signals upgrade project and considers the imperative for the system to adapt to the now certain impacts of climate change, including sea-level rise, by adopting a more resilient, next-generation signal system. Moving forward, A Better City recommends that the MBTA consider the following three recommendations with respect to signals on the MBTA's Red and Orange Lines:

1. **SEMI-AUTOMATIC CAPABILITY:** A Better City recommends that the MBTA amend existing contracts for new vehicles and signals upgrades to incorporate modest amounts of semi-automatic capability in routine train operations at a cost of approximately $70 million. A Better City has conducted extensive research demonstrating the feasibility of achieving some of the semi-autonomous operational benefits ordinarily found only in CBTC signals into the planned Fixed-Block system upgrades. Specifically, A Better City believes that existing MBTA contracts can be amended to incorporate the ability to automate train acceleration/deceleration between stations, as well as the station berthing process.

2. **PLATFORM SCREEN DOORS PILOT:** A Better City recommends that the MBTA undertake a new Platform Screen Doors Pilot Project at several key Red Line and Orange Line stations in the downtown Boston core at a cost of approximately $25 million. Platform Screen Doors are used in many world-class cities to enhance track safety by preventing fires caused by trash and debris falling into the track pits, improve passenger safety by preventing accidental and other falls from the platform, improve the flow of passengers exiting and entering vehicles and reduce dwell times, and to enable the installation of air conditioning to help enhance the transit experience, a benefit customers may increasingly expect as temperatures continue to increase due to climate change. If the MBTA can achieve the semi-automatic berthing capability (i.e., automated station stopping with precision), then the system should pilot the installation of Platform Screen Doors along the length of several key station platforms.

3. **NATIONAL ADVANCED TECHNOLOGY CENTER FOR NEXT-GENERATION SUBWAY SIGNALS:** A Better City recommends that the MBTA together with federal transportation officials and industry leaders collaborate on the development of a federally funded National Advanced Technology Center for Next-Generation Subway Signals based in Boston. This recommendation includes the suggestion that $1 million be allocated to help fast-track collaborative efforts to develop a proposal to seek and obtain federal funds for this new center. A Better City's research suggests a national need to help develop new next-generation signals that use contemporary artificial intelligence and digitized machine-vision techniques to determine location and speeds in a completely movable block approach that reduces or eliminates the need for any equipment to be located within the track, which is increasingly vulnerable to the impacts of climate change, including sea-level rise and saltwater intrusion. Government, academic, and business leaders in Greater Boston are uniquely positioned to form a leading consortium to seek federal funding.

CONCLUSION

The pandemic has interfered with the pace of the MBTA's Red and Orange Line Transformation project, impacting both schedule and cost. The MBTA has broken the program into two phases. Phase 1 will include all previously committed design and construction work consisting of new vehicles and infrastructure upgrades, exhausting the available $2.1 billion and running through the end of FY23. The MBTA still aims to meet the headway targets by 2024 but has delayed the reliability targets until 2029. Based on the January 2021 FMCB presentation, the new Phase 2 work, which includes additional and necessary investments in track and power system repairs and upgrades needed to meet the reliability targets, will require approximately $700 million in newly identified but currently unfunded dollars.[2]

At this critical juncture, A Better City recommends that the MBTA adopt the above-mentioned recommendations to advance signals and train controls. This relatively modest increase of $100 million will leverage the revised $2.8 billion total for Phase 1 and Phase 2 and allow the Red and Orange Lines to better serve the economic development and environmental needs of the Commonwealth and Boston region for decades to come.

2. Source: FMCB meeting, staff presentation, Red Line/Orange Line Improvement Program Update, January 25, 2021

INTRODUCTION

The Red and Orange Lines are among the oldest and most established parts of the MBTA system, having opened for initial service in 1912 and 1901, respectively. Like much of the transit system, they suffer from decades of underinvestment, as capital maintenance and worthwhile upgrades were deferred. New vehicles were last added to the Red Line fleet over 30 years ago; the Orange Line runs trains that were built between 1979 and 1981, over 40 years ago. Each of these two vehicle fleets journey over one million miles every month and have now traveled down the rails a total distance of nearly one billion miles.

Fortunately, the MBTA is undertaking a multi-billion-dollar overhaul of the Red and Orange Lines to replace vehicles and upgrade infrastructure, including signals. As the new vehicles enter service and the old cars are scheduled to be retired by 2024, for the first time in two generations these two lines will have the look and feel of a more modern subway system. While the trains used to carry riders will unquestionably be more current, this report will explore if the same will be true on one crucial and fundamental part of the subway's more hidden infrastructure—its signals.

The primary function of any signals system is to maintain train and passenger safety. Above and beyond that primary function that trains operate safely in normal operations, many modern subways seek a wide range of additional or secondary functions from their signals. These range from a need to run more trains at the same time to increase capacity to a desire to offer more modern passenger conveniences like the ability to cool subway stations with air conditioning, a benefit that can only be implemented if the signals can support semi-automatic berthing with precision stopping at stations. Many, newer signals are designed to overlay the secondary functions for enhanced passenger conveniences on top of the fundamental need for safety. All subway signals are designed to ensure that the primary function of train and passenger safety is omnipresent. Signals must not fail, and if they do they must be designed to bring each train into a default mode that maintains safe operation.

This report is intended to illuminate how subway signals work. The report will review how signals operate on the Red and Orange Lines today. It will cover how those signals will change and what will stay the same because of planned construction work now underway. And it will suggest how the development of a new, next-generation signals approach could help Boston and other coastal cities better plan for some of the mass transit and environmental challenges posed by climate change.

Chapter 3 reviews the MBTA's Red and Orange Line Transformation program and its substantial investments in new vehicles and associated infrastructure, including signals. It also describes the MBTA's recent decision to break its Red and Orange Line Transformation project into two phases and recent estimate that $700 million in newly identified but currently unfunded dollars will be needed to complete necessary track and power system repairs and upgrades. Chapter 4 explains how our signals work today and demonstrates that many fundamental techniques invented over 150 years ago are still in widespread usage today. Chapter 5 assesses the signal upgrade options now offered by the two companies that control the marketplace in North America and why both options have limitations that restrict the ability of transit agencies to modernize their signals systems and subway operations more fully. Finally, Chapter 6 presents the report's three recommendations, which together form a framework for advanced signals and train control for the MBTA Red and Orange Lines going forward.

MBTA RED & ORANGE LINE TRANSFORMATION

The Red and Orange Lines carry many people at relatively high speeds within the central business districts of Boston and Cambridge and to and from outlying areas. As of January 2020, the patronage on a typical weekday is over 239,000 people on the Red Line and over 206,000 people on the Orange Line. They carry a combined ridership of nearly 450,000 trips, or 38 percent of the 1.2 million trips the T delivers systemwide on a normal weekday.[3] With nearly four out of every ten riders who take mass transit in the Boston region using them, the Red and Orange Lines are among the most heavily used parts of the MBTA system.

The MBTA procured new Red Line and Orange Line vehicles in 2015. Under this key contract to buy replacement vehicles for the Red and Orange Lines, 404 new cars are scheduled to enter passenger or revenue service by 2024 at a projected cost of about $1 billion dollars. These new cars will entirely replace the existing fleets. They will also expand the number of active vehicles from 218 to 252 on the Red Line and from 114 to 152 on the Orange Line. With 16 percent more Red Line and 33 percent more Orange Line vehicles available each day, the MBTA can run more trains per hour, which will reduce the headway between trains and shorten the time that riders need to wait on platforms. With more trains arriving more often at each station, the MBTA promises to deliver expanded capacity and faster, more comfortable, more frequent, and more reliable trips.[4]

To accommodate and complement the new vehicles, another $1.1 billion is being spent on an integrated and complex array of necessary infrastructure upgrades, including improvements to maintenance facilities and yards, test tracks, power systems, and signals. Under the leadership of the MBTA's FMCB, the MBTA created a new organizational structure to oversee the massive $2.1 billion investment in new vehicles and infrastructure upgrades, dubbed the Red/Orange Line Transformation program.

BUDGET BREAKDOWN BY ELEMENT & BY LINE

The approximately $1 billion new vehicles budget appears to include $630 million for the new Red Line fleet and $380 million for the new Orange Line fleet. With respect to the $1.1 billion budgeted for various infrastructure upgrades, it appears $505 million and $423 million is allocated to the Red and Orange Lines, respectively. When the total investments in vehicles and infrastructure are combined, it appears $1.1 billion (or 59 percent) is programmed for the Red Line with $0.8 billion (41 percent) allotted to the Orange Line. For more details, see Figure 1, Red/Orange Line Transformation: By the Numbers.

Of the $505 million budget for infrastructure upgrades to the Red Line, it appears $125 million, or 25 percent will fund signals upgrades. For the Orange Line, it appears the budget for signal upgrades is some $118 million or some 28 percent of the total infrastructure budget of $423 million. Figure 1, Red/Orange Line Transformation: By the Numbers includes a detailed breakdown of the various infrastructure elements, including track work, maintenance facility and yard improvements, test tracks, and signals.

3. "Normal" meaning excluding the influences of a global pandemic; The author believes transit ridership will rebound to pre-pandemic levels sooner than most prognosticators and this report and its recommendations should be read in that context. Ridership source: MBTA Data Portal
4. Source: MBTA staff presentation to FMCB, Red/Orange Line Vehicle Procurement Project Update, January 8, 2018

HEADWAY & RELIABILITY TARGETS

The multi-billion-dollar Red/Orange Transformation promises to help modernize these two key parts of Boston's regional transit system and its goals and objectives include much more than the quantity of dollars involved or number of new vehicles procured. As stated by former Chair Joe Aiello at the MBTA FMCB meeting on August 13, 2018:

> "We're not spending money to buy cars, we're not spending money to build infrastructure, we're spending money to deliver a particular promised service of a specific headway outcome that has been outlined to us by a certain date that should then last a very, very long time."[5]

The MBTA's commitment for the Red/Orange Transformation has been widely publicized and specific; that by 2024: the Red Line would operate with 95 percent reliability at 3-minute headways, with the Orange Line at 96 percent reliability at 4.5-minute headways.[6] As calculated by A Better City, these headways represent a 33 percent and 25 percent improvement over the 4.5-minute and 6.0-minute headway targets that existed on the Red and Orange Lines, respectively, in 2019.

5. Statement made at FMCB meeting during staff presentation, Red and Orange Future Reliability, 2019 – 2029, August 13, 2018
6. Source: FMCB meeting, staff presentation, Red and Orange Future Reliability, 2019 – 2029, August 13, 2018

FIGURE 1: Red/Orange Transformation: By the Numbers: Budget by Element and Line

ELEMENT	RED LINE	ORANGE LINE	NOTES
TRANSFORMATION: PROGRAM BUDGET ($ in dollars) (Per 1/25/21 FMCB presentation, unless noted)			Funded CIP projects only; Current and future requests not included
NEW VEHICLES PROCUREMENT	**$629,919,894**	**$379,951,664**	a. $1,009,871,671 (total both fleets) b. Assumes price fleet parity at $2,499,682/vehicle
INFRASTRUCTURE PROGRAM			Per 12/7/20 FMCB except where noted
TRACK			
RED LINE FLOATING SLABS - ALEWIFE TO HARVARD	**$8,800,000**		Per 1/25/21 FMCB
ALEWIFE CROSSING IMPROVEMENTS	**$21,664,914**		Per 1/25/21 FMCB
KENDALL CROSSOVER IMPROVEMENTS	**TBD**		Item listed with no budget $
YARDS & FACILITIES			
CABOT YARD & MAINTENANCE FACILITY IMPROVEMENTS	**$258,892,395**		
CODMAN YARD EXPANSION & IMPROVEMENTS	**$63,554,385**		
WELLINGTON YARD & MAINTENANCE FACILITY IMPROVEMENTS		**$240,977,671**	
RED LINE TEST TRACK	**$26,240,010**		
ORANGE LINE TEST TRACK		**$7,649,569**	
POWER			
ORANGE LINE TRACTION POWER UPGRADE		**$56,800,000**	**$243,347,926**
SIGNALS UPGRADES	**$125,449,798**	**$117,898,128**	$267,600,000 (total for both); per 1/25/21 FMCB; TBD: $24,252,074 difference (not included at left)
INFRASTRUCTURE PROGRAM SUBTOTAL	**$504,601,502**	**$423,325,368**	Incomplete
TOTAL (PHASE I: 2016–2023)	**$1,134,521,366**	**$803,277,032**	Incomplete: $162,201,602 needs to be added in

SOURCE: MBTA staff presentations to FMCB, Red Line/Orange Line Improvement Program Update, various dates including November 4, 2019, and January 25, 2021

PANDEMIC IMPACTS TO SCHEDULE: HEADWAY & RELIABILITY TARGETS

Prior to the COVID-19 pandemic, the MBTA targeted 2024 as the design year to reach the headway and reliability targets. At a FMCB meeting in January 2021, a presentation that provided a Transformation update appears to suggest that the pandemic has interfered with the pace of the Transformation program.[7] First, the MBTA has broken the previous single program into a Phase 1 and Phase 2. Phase 1 will include all previously committed design and construction work consisting of new vehicles and infrastructure upgrades, exhausting the available $2.1 billion and running through the end of FY23. The MBTA still aims to meet the headway targets by 2024. However, the reliability targets need more effort and more time and will be achieved in 2029 and have been moved over into a new, second phase of the Transformation that will cover the years 2024 through 2029.

NEWLY IDENTIFIED FUNDING NEEDS: HEADWAY & RELIABILITY TARGETS

As mentioned, the Transformation program is now divided into a Phase 1 and Phase 2, with the goal of having the transformed Red Line operate at 95 percent reliability and the Orange Line at 96 percent reliability now transferred from Phase 1 to Phase 2.

The FMCB's resolution in August 2018 to not only run more trains to decrease headways and increase capacity but also to simultaneously improve reliability- of subway service was a very ambitious commitment. It arguably represents the most audacious declaration of service goals and delivery in the history of the MBTA.

MBTA leadership created a new internal Task Force that was put in charge of making sure the system would be able to deliver on these headway and reliability targets. Started in early 2019, the Task Force increased collaboration within the organization and worked to increase coordination on a very complex, difficult, and interrelated set of design, engineering, and construction issues.

The outcome of the Task Force's work was presented to the FMCB on December 16, 2019, and on January 25, 2021. It appears that the Task Force, building upon a robust asset management review, identified additional investment needs for track and power through the years 2024 and 2029 that will be needed to sufficiently sustain the headway targets so that the reliability targets can be met.

Some of the new investment needs identified by the Task Force that are needed into order to meet the reliability targets include: 1) 220,000 feet (or 42 miles) of track will require renewal or deep maintenance, and 2) extensive power system renewals to take place at same time as the track work. The Task Force also identified and decided on the scope of several specific new Red Line and Orange Line projects that need to be added to the Transformation program for it to meet the reliability goals by 2029 in a sustainable way are shown in Figure 2[8] and Figure 3[9].

When presented to the FMCB in December 2019, the additional work in Track, Power, and Signals that was needed during 2024–2029 to sustainably achieve the reliability targets by 2029 was estimated to cost $878 million dollars. In the more recent update presented to the FMCB in January 2021, the corresponding additional funding needs for Track, Power, and Signals was

7. Source: FMCB meeting, staff presentation, Red Line/Orange Line Improvement Program Update, January 25, 2021
8. Staff presentation to FMCB, Red/Orange Line Headway Attainment & Maintenance Plan, December 16, 2019, Slide #17
9. Same as immediately above, Slide #18

estimated at $615 million dollars. The details of these additional funding needs for Transformation Phase 2 are shown in Figure 4. Based on the both the December 2019 and January 2021 FMCB presentations, the new Phase 2—which includes additional and necessary investments in track, power system, and signals repairs and upgrades—will likely require approximately $700 million (not based on detailed design) in newly identified but currently unfunded dollars.

FIGURE 2: MBTA Task Force Identification of New Red Line Projects Needed for Phase 2

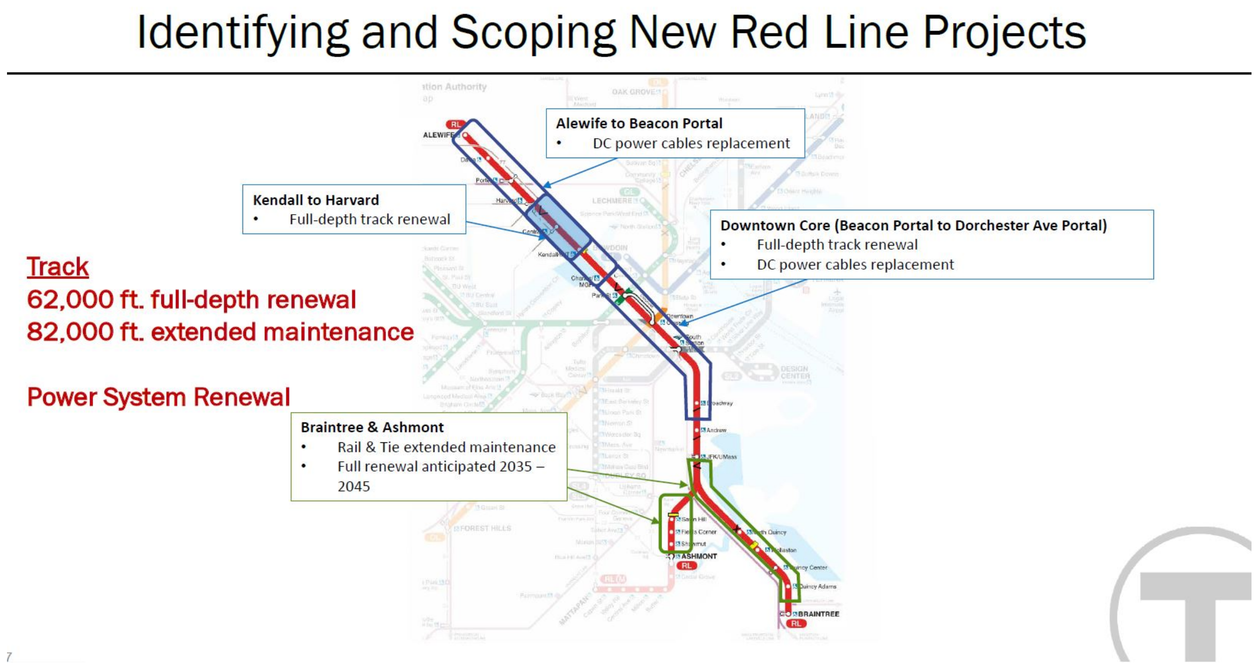


FIGURE 3: MBTA Task Force Identification of New Orange Line Projects Needed for Phase 2

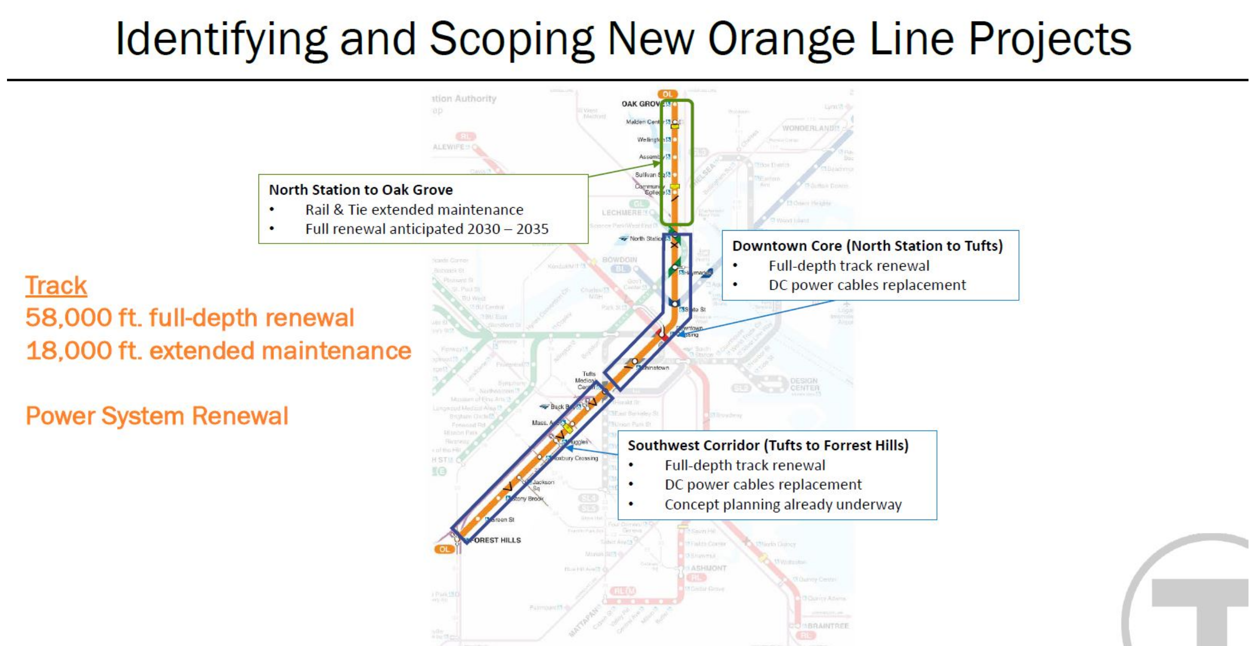


FIGURE 4: Red/Orange Transformation Phase 2: Estimated Additional Investment Needs (2024-2029)

DATE OF PRESENTATION TO BOARD	DECEMBER 2019	JANUARY 2021
TRANSFORMATION: PROGRAM BUDGET ($ in millions of dollars)		
INFRASTRUCTURE PROGRAM		
TRACK & DRAINAGE	$470	$528
POWER	$398	$87
SIGNALS UPGRADES	$10	$0
TOTAL (PHASE 2: 2024–2029)	**$878**	**$615**

FIXED-BLOCK VERSUS COMMUNICATIONS-BASED TRAIN CONTROL SIGNALS

The intent of this chapter is to demystify how the Red Line and Orange Line signals work and show that many fundamental techniques invented over 150 years ago are still in widespread usage today. This section will describe a newer, alternative signals approach that has increasingly become the signals option of choice at peer agencies in North America. Finally, this chapter will discuss the challenges and opportunities associated with these two signals options and include a review of the limitations that exist today in the North American signal's marketplace.

To begin to understand signals, first consider the instantaneous access to location and speed data available today to every person who owns a smartphone. Think about how easily Google Maps can tell people where they are with high-precision and exactly at what speed they are moving. Think about how well the Find my Device or Find my iPhone apps work to locate an Android or Apple phone. Or consider the many automobiles sold today that use onboard cameras and other sensory componentry to offer a modernized cruise control that automatically adjusts speed to maintain safe separation with the vehicle ahead and, increasingly, also combines those cameras with artificial intelligence integrated into a compact onboard computer to perform driver assist functions, including the ability to automatically steer the vehicle so that it stays in the center of the travel lane.

Now, forget about all of that. Pretend that global position satellites (GPS) do not exist, so that there is no ability for a smartphone to lock into three satellites and via computerized triangulation instantly obtain highly precise location and travel speed data. Pretend that today's robust competition in the automotive business space to develop vehicle autonomy does not exist, or that no car manufacturer has yet to embed tiny, digitized cameras and other sensors in the exoskeleton of vehicles to provide driver-assist functionality such as traffic-aware cruise control as a standard convenience found in many modern automobiles available for sale today.

The MBTA needs to design, build, and operate a complex and integrated system of new vehicles and infrastructure upgrades to successfully transform the Red and Orange Lines. Signals have a big part to play in that transformation. But to understand the challenges associated with that important role, one needs to first suspend any knowledge of smartphones or semi-autonomous vehicles. The need to ignore these modern, highly intelligent technologies is simple: that's what both subway signals options available today do—they pretend as though the calendar is stuck somewhere in either the early 1870s or 1980s. Given all that we do know about digital GPS and digitized cameras tied to machine-vision and artificial intelligence techniques today, who would want to ignore their existence and rely on techniques that are either 40-years old or 150-years old? The answer is hardly no one, of course. Except that's what transit executives must do, because of the limited product offerings available by the two vendors that dominate the market in North America today.

At best, as they consider signals upgrades, transit agency executives and their consultants are forced to pretend they are back in the early 1980s, as that is when the second or "newer" signals option, known as CBTC was invented. Invented over 40 years ago, CBTC is based on the relatively rudimentary (as compared to today) computer hardware and software systems that existed back then. However, in order to best understand CBTC signals, and the opportunities and limitations, it is important to have some understanding of the signals option that existed before. This first signals option, referred to as Fixed-Block signals, entered the train equipment marketplace in the early 1870s. While it may have been invented over 150 years ago, it remains in widespread usage today.

A SHORT HISTORY OF SIGNALS & TRAIN CONTROLS

In the very early days of trains, say the early-1800s, people were employed to stand at intervals or "blocks" along the line with a stopwatch and use hand signals to inform train drivers that a train had passed more or less than a certain number of minutes previously. If a train had passed very recently, the following train was expected to slow down to allow more space to develop.

The watchperson had no way of knowing whether a train had cleared the line ahead, so if a proceeding train stopped for any reason, the crew of a following train would have no way of knowing unless it was clearly visible. As a result, accidents were common in the early days of railways. The invention of the electric telegraph and its widespread use in the 1840s did make it possible for the signalperson to confirm that a train ahead had passed and that a specific block was clear. In the 1860s, the hand-signals that had been used by the signalperson to communicate to train crews had been replaced by a newer technique: fixed mechanical signs, each connected to a different lever, were located at the start of each block. When a train passed into a block, the signalperson would protect that block by setting its changeable sign from "all clear" to "danger."

These initial efforts to do railway signals were manually operated by individual observers, who were either signal tenders or station agents. When to give the signal to each train operator that it is safe to move ahead was basically left to the judgment of these human observers. Human error or inattentiveness occasionally resulted in improper signaling and train collisions. Railroad accidents received widespread attention both in the United Kingdom and United States, and in 1867, William Robinson, a recent college graduate, took it upon himself to craft some sort of automatic signal system that could help prevent railroad accidents.[10]

10. Primary source for discussion of William Robinson: The Invention of the Track Circuit, American Railway Association, Signal Section, 1922

ROBINSON'S INVENTION OF FIXED-BLOCK SIGNALS IN 1872

At first, Robinson went to work on a track on the Philadelphia & Erie Railroad that rounded its way through a mountain in Pennsylvania. Working with the best technology available to him, Robinson used simple batteries and the fact that the two train rails and train axels could conduct a small electric current to invent a rudimentary track rail circuit signal system, which was a simple electrical device that was used to detect the absence or presence of a train on a block of tracks. Robinson continued to tinker, and in 1872, he submitted a patent application with the United States government for an electric track circuit that would be placed at each separate block of track. Robinson's 1872 patent was granted and his invention, known as fixed-block track circuits or "Fixed-Blocks."

As compared to the previous signals approach that relied entirely on human observation, Robinson's electro-mechanical Fixed-Blocks signals was a great technological advance. See Figures 5 and 6 for a photo and sketch of Robinson's experiments on the Philadelphia & Erie Railroad that took place between 1867 and 1872.[11]

FIGURE 5: Robinson's Closed Rail Circuit System. Philadelphia & Erie Railroad, 1872

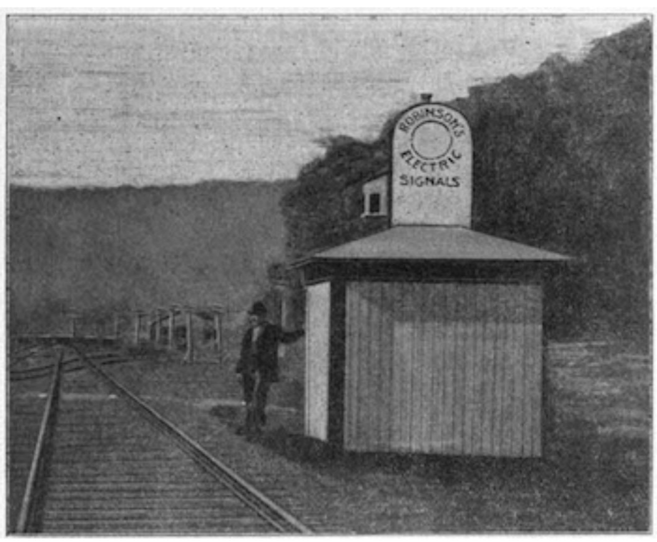
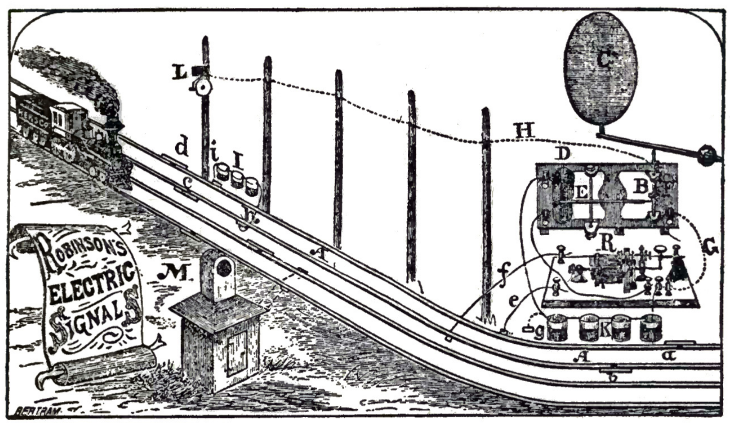


FIGURE 6: Sketch of Robinson's Closed Rail Circuit System. Philadelphia & Erie Railroad, 1872

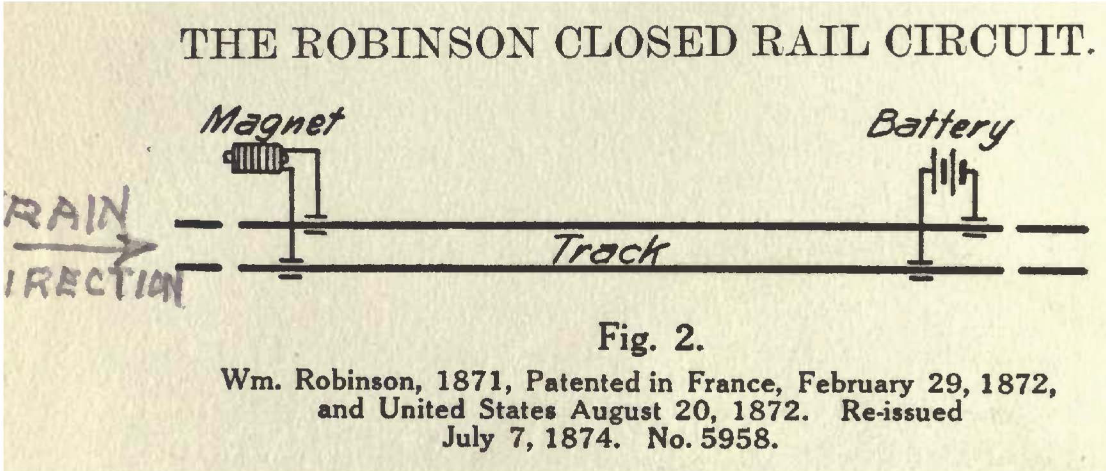


A PRIMER ON ROBINSON'S FIXED-BLOCK SIGNALS

From their start in the 1870s, Fixed-Blocks have been the most trustworthy method of block occupancy detection. See Figure 7 for the simplified illustration of Robinson's Fixed-Block signals design that was contained in his 1871 patent application as granted by the United States government in 1874.[12] Robinson's Fixed-Blocks signals are so trustworthy and safe, in fact, that even now, some 150 years later, they are in nearly universal use in signals that run subway systems throughout North America and across the globe, including today's MBTA Red and Orange Lines.

11. Source: The Invention of the Track Circuit, American Railway Association, pp. 8, Signal Section, 1922
12. Source: The Invention of the Track Circuit, pp. 10, American Railway Association, Signal Section, 1922

FIGURE 7: Sketch of Robinson's Fixed-Block Signals: Patent Application, 1872 & 1874



Under Robinson's Fixed-Block signals system, the subway tracks are divided into "blocks." Each block is created to form an electric circuit. These blocks typically average between 250 and 1,000 feet long, a length that cannot readily change due to the large amount of componentry affixed to the tracks that is coupled with equipment housed alongside the tracks. When a train is in a block, it triggers a track circuit that indicates to the signal system that that block is occupied.

The basic principle behind a Fixed-Block track circuit lies in the fact that the two parallel metal rails can serve as two built-in conductors to help transmit a lower power electric current (the method Robinson first used in the 1870s) or transmit a high-pitched audio frequency wave (the method now used in Fixed-Block signals today). Part of Robinson's genius was that his invention is based on a third built-in conductor that can tie the two rails at one end of the fixed circuit: the metal wheels and axle of the rolling stock. So, with the two metal rails tied together electrically by the wheels and axel of the vehicle, a fourth conductor was needed at the other end of the block to tie the two rails together at that point and form a four-side closed circuit. That fourth conductor consists of a device known in the transit signals industry as a Wee-Z Bond, an amazingly ingenious invention but outside the primary scope of this report, except to say that, for example, each Fixed-Block signals system in use today employs a Wee-Z Bond that is affixed to the track bed at the interface between every two adjacent blocks.

FIXED-BLOCK SIGNALS ON TODAY'S RED LINE & ORANGE LINE

The signals that help run the Red and Orange Lines today are functionally similar to Robinson's original Fixed-Block invention, though key aspects of the componentry used to generate the track circuit signal used for track detection and occupancy has improved over time. A Better City created a new diagrammatic sketch of the Fixed-Block signals that run today's Red and Orange Lines, as shown in Figure 8[13]. Compare Figure 8 with the simple Fixed-Block signals techniques of Robinson's 1874 patent as depicted in Figure 7 and see how little has changed with respect to the fundamentals of Fixed-Block signals over the last 150 years.

13. Note: the diagram in Figure 8 is intended to provide a general illustration of the fixed-block track circuit signals utilized on the Red and Orange Lines. It is a significant simplification of the complex and varied conditions found in the track wayside associated with these two subway lines. For example, track circuits within switches/turnouts and interlockings (control points) are different as are other areas where loop circuits are used.

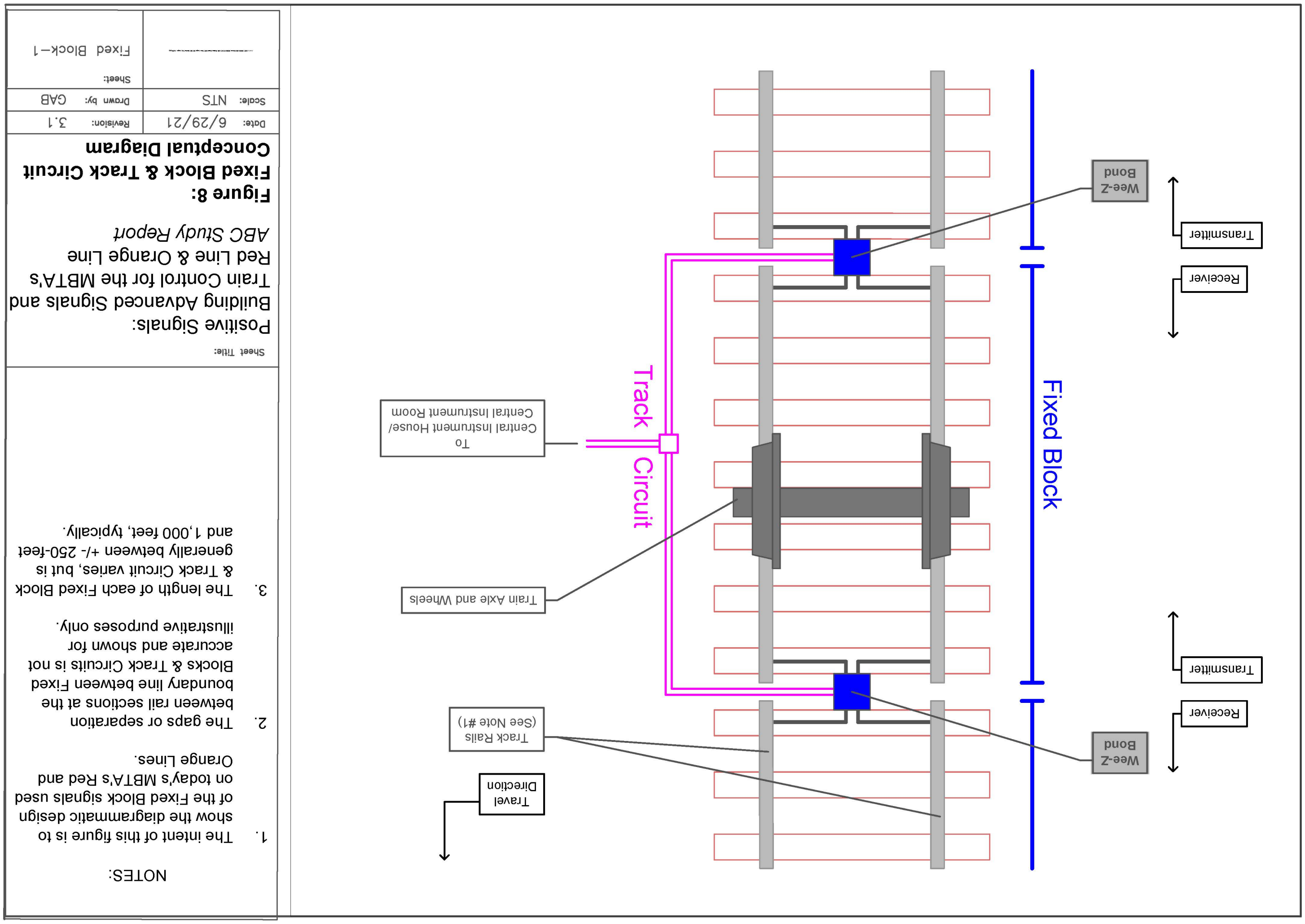
A Better City's research suggests that the Red Line's 54 miles of track are today divided into about 400 Fixed-Blocks, which calculates to an average block length of 713 feet; and that the Orange Line has 23 miles of track and some 271 Fixed-Blocks that average to about 448 feet in length.[14] A Better City has reached out to the MBTA to help confirm these quantities and average lengths, and has determined that with a total length of 395 feet, just a single new Orange Line train can fit into the average Orange Line block length of 448 feet. Similarly, just a single new Red Line train at 420 feet in total can fit into the average block length of 713 feet on the Red Line.

With Fixed-Blocks, the maximum speed of each train will depend on how many blocks are unoccupied, or open, in front of it. To perform that analysis, modern Fixed-Block signals must have some means to compare the fixed track circuit signal of train occupancy or vacancy from one block the same signal that is generated at several abutting blocks. Like individual tree branches that gather back to a main tree trunk, the indications of occupancy from each block's track circuit are collected back at one of the centralized equipment rooms. Equipment housed in vertical racks in these rooms reads the indication of occupancy from each block and compares it to the occupancy of adjacent blocks located downstream. The equipment then looks to see where each train is occupying a block and compares how far apart the train ahead is to the one that follows. It then indicates to each following train when and at what speed it can move forward to avoid colliding with the one ahead.

As MBTA staff presented to the FMCB on October 1, 2018, the Red Line has about 13 centralized equipment rooms that span the length its 54 miles of track. Each of the Red Line's 400 Fixed-Blocks are hard-wired back to one of the equipment rooms. A Better City's research suggests that today each room is responsible to manage the signals associated with an average of 31 discrete fixed-blocks of trackage. Based on the same research, the Orange Line has 11 centralized equipment rooms spaced along its 23 miles of track that contains 271 Fixed-Blocks, with each room responsible today to manage the signals associated with an average of 25 fixed-blocks of trackage. Each fixed-block track circuit requires its own unique cable run back to its designated centralized equipment room, which adds up to several hundred miles of cabling affixed to each track wayside to connect the fixed-blocks with the centralized rooms. For example, A Better City's research suggests that about 339 miles of signals cables exist out on the Red Line's 54 miles of track wayside to connect its 400 Fixed-Blocks to their associated 13 centralized equipment rooms.

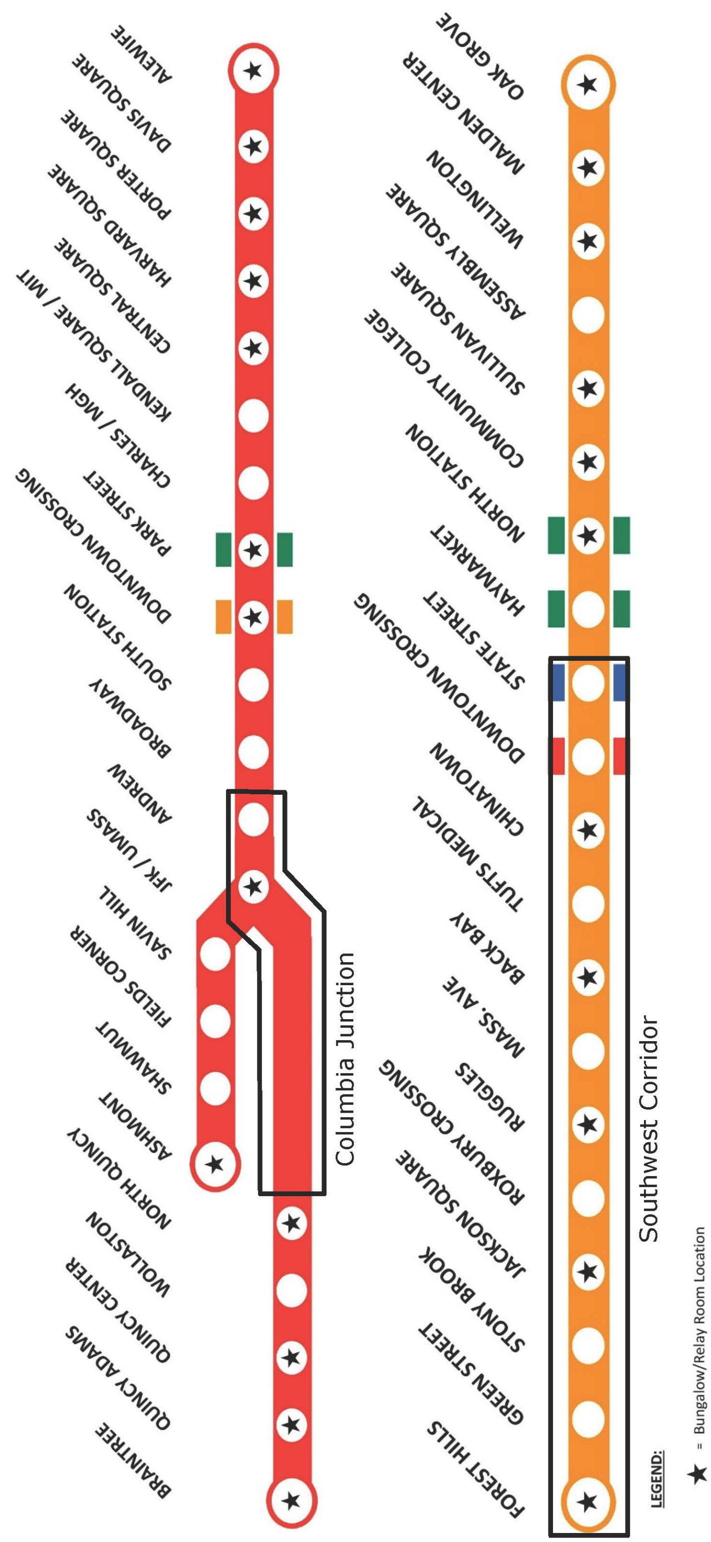
14. Note: A Better City is cognizant of some security concerns that the MBTA may have with specific identification of signals and other assets for the Red and Orange Lines. Any and all specific quantities and locations of equipment listed here and throughout this report were obtained from publicly available sources including the MBTA website and FMCB presentations.

FIGURE 8: Signals Study Track Circuit



See Figure 9 for a slide excerpt from the MBTA's October 2018 presentation for the generalized location and spacing of these signals equipment rooms that are each a key element of the Fixed-Block signals that help run these two subway lines.[15]

FIGURE 9: Red Line & Green Line Fixed-Block Signals: Generalized Location of Centralized Equipment Rooms



15. Source: FMCB meeting, staff presentation, MBTA Contract No. Q09CN01, Red Line and Orange Line Signals Systems Upgrades, slide #4, October 1, 2018

SIGNALS UPGRADE CONTRACT FOR THE RED LINE & ORANGE LINE

As part of the Transformation program, the MBTA awarded a design/build contract to upgrade and modernize the signal systems on the Red and Orange Lines. Once complete, the MBTA anticipates that the new signal systems on both lines are expected to substantially improve service reliability and improve peak hour headways. This $217 million dollar contract was awarded to Barletta Heavy Division, and when the contract was awarded in October 2018, the full signal system replacement along both lines was expected to reach substantial completion in mid-2022.

The scope of work for this contract comprises the following three components:

RED LINE & ORANGE LINE SIGNAL UPGRADES: The upgrades will include re-signaling the Red Line and Orange Line with next-generation Digital Audio Frequency Track Circuits. The track circuits will be designed with the capacity to add additional speed commands to take advantage of the improved vehicle performance technology of the new fleets.

COLUMBIA JUNCTION SIGNAL REPLACEMENT PHASE 2: Columbia Junction Phase 2 will replace the existing central instrument houses (CIH) with the latest generation of train control equipment to interface with the wayside equipment. The scope also includes the addition of a bungalow at Tenean Beach. Lastly, the existing electric lock crossover at Andrew Station will be converted to a remote-controlled crossover with a full complement of signaling equipment for powered switches.

SOUTHWEST CORRIDOR WAYSIDE SIGNAL REPLACEMENT (ORANGE LINE): The Southwest Corridor Equipment Replacement consists of the replacement-in-kind of all cabling, switch machines, and signals.

Several months after it was awarded the $217 million dollar contract, Barletta signed its own subcontract with Alstom Signaling, Inc. at a cost believed to be around $100 million to supply all signals equipment and related installation, testing, and commissioning services. Allstom is one of two alternative vendors that supply all signals equipment to the North American market.

Some observers believe that this Signals Upgrade contract will fully replace the existing analog signal systems on the Red and Orange Lines with new, digital infrastructure. A Better City's research on this topic suggests that understanding is partially accurate.

A Better City's research does confirm that existing analog signals equipment within each of the central equipment rooms will be replaced with digital technology. Under Barletta's contract with the MBTA, the existing analog signals equipment will be replaced with Alstom's latest generation of digital audio frequency technology and microprocessor-based train control logic. See Figure 10 for a photo of old analog signals equipment house in racks within one of the MBTA's signals equipment rooms. Specifically, Alstom will supply AFTC-5 track circuits, its latest generation of its digital signal technology. This switchover from analog to digital technology within the equipment rooms is a big upgrade, as this componentry is responsible for generating signals data at various frequencies.

FIGURE 10: Red Line & Orange Line Signals: Existing Centralized Equipment Room with Analog Equipment

SOURCE: MBTA

There is no AFTC-5 infrastructure included in any of the existing (legacy) signal system associated with the Red and Orange Lines. The decades-old analog components that are housed today in vertical racks within the equipment rooms generate signals that can sometimes get de-tuned (out of frequency) and require MBTA staff to head out into the field and access an equipment room that may be difficult to safely access while trains are in service to manually re-tune the specific circuitry located within a large rack array. That is but one of the many challenges associated with the existing old signals equipment. Unlike the old analog equipment that it will replace, the new digital equipment will be easily configurable, with various signals parameters, such as frequencies, code rates, transmit/receive levels, and IP addresses, and are software configurable, allowing identical track circuit hardware to be used. Key benefits of the new AFTC-5 upgraded signals equipment include:

SOFTWARE BASED CONFIGURABLE VARIABLES: The AFTC-5 can have multiple codes at once. This should allow for speed restrictions to be enforced remotely, adjust as needed to condition changes and provide greater flexibility. It should also be upgradeable with future software updates as needed if conditions were to change.

REMOTE MONITORING VIA ETHERNET: Each AFTC-5 should be able to have its values monitored at a central location. MBTA personnel should be able to check track levels, voltage/amperage readings, read fault codes and respond as needed.

GENERATION OF FAULT CODES: Fault codes should not require the use of an additional recorder. Each track circuit should be able to monitor and store fault codes which will help with troubleshooting and maintainability.

ABILITY TO AUTOMATICALLY ASSESS & ADJUST TO CHANGE IN SIGNAL STRENGTHS TO/FROM THE WAYSIDE: Each AFTC-5 unit should be "self-learning" and be able to adjust accordingly. For example, if the ballast resistance changes due to weather or condition, the circuit can adjust levels to maintain appropriate values by increasing voltage.

MODULARITY: The all-in-one styling of the AFTC-5 equipment should result in easy maintenance or equipment replacement if necessary.

The new AFTC-5 signals equipment that the MBTA is now installing on the Red and Orange Lines should provide the clear advantages of accurate frequency transmission and reception and improved stability due to its digital signal processing capabilities. See Figure 11 for a photo of a front rack view of Alstom's ATFC-5 digital signals componentry that will be installed in all central signals' equipment rooms on the Red and Orange Lines.

Understanding that all the generation and receipt of signals communications within the central equipment room will be upgraded from analog to digital equipment, however this is not the full story to the Fixed-Block track circuits that exist on today's Red and Orange Lines and that will remain in place after the signal's upgrades contract is complete.

FIGURE 11: Red Line & Orange Line Signals: Alstom's AFTC-5 Digital Equipment to be Installed in Centralized Equipment Rooms

SOURCE: Alstom Signaling, Inc.

As shown in Figure 8, the central equipment rooms are connected by cabling to each track circuit that make up every fixed-block, and each track circuit is hardwired to a discrete section of track. The signals information that will get generated by the new digital componentry inside equipment rooms will be transmitted in analog—not digital—format over cabling that is attached to a device formally known as a Wee-Z Bond. To see where the Wee-Z Bond is typically affixed to the center between the tracks and is separately wired to each of the two adjacent rails, also see Figure 8. As also depicted in Figure 8, the Wee-Z Bond takes the analog—not digital—signal that comes out of the equipment room and feeds it into each of the steel rails. The rails then act as their own conduit to feed the analog signal down the rail to where a train may be located. A specialized antenna, known as a "coil," is located underneath the front of each train cab, and that coil accepts the analog signal that is being communicated via the rail. Once a signal is received from the coil, the analog information is onboarded to the vehicle and is transferred by cabling to signals equipment located near the dashboard that the cab operator interfaces with. According to the MBTA, this equipment near the dashboard on each of the new Red Line and Orange Line vehicles will be able to receive the analog signals onboarded from the rails and convert it into a digital signal to interface with the new dashboard electronics and related subsystems. See Figure 12 for a photo of the antenna or coil that acts as a wireless receiver of vital signals information as it gets communicated from the rails to signals equipment located onboard the vehicle.

To summarize, the existing signals upgrades contract will make significant improvements within each of the central equipment rooms. Within these equipment rooms, analog signals componentry will be fully replaced with digital microprocessor-based equipment. That new digital equipment will provide several important benefits to Red Line and Orange Line signals. Even with the installation of these important digital upgrades, all signals information will be communicated in analog—not digital—format between the equipment rooms and the tracks and between the tracks and the front cab of each train. Based on these understandings, the signals upgrade contract will replace a majority of the existing analog signal systems on the Red and Orange Lines with new, digital infrastructure.

FIGURE 12: Red Line & Orange Line Signals: Coil or Wireless Antenna Located Underneath Each Cab

SOURCE: A Better City

LIMITATIONS OF FIXED-BLOCK SIGNALS

Although the MBTA's ongoing signals upgrade contract for the Red and Orange Lines will remove all of the analog signals equipment located inside central equipment rooms and replace it with fully digital microprocessor-based componentry, nearly all of the signals apparatus located outside of those rooms, including the communications between the rooms and the tracks and between the tracks and the front operator cabs at the lead of each trainset, will not be upgraded to digital from analog. Further, the MBTA's signals upgrade contract is based on a decision to retain the existing Fixed-Block signals that have long been used on these two lines, in lieu of upgrading those fixed-blocks signals to the "newer" moving blocks signals technology.

A Better City acknowledges that, in large part, just two manufacturers compete in the North American signals marketplace. The signals hardware and software equipment offered by these two manufacturers appears to be incompatible with each other. In effect, the result is that once a transit system installs equipment from one manufacturer, that manufacturer has the strong lead on future purchases and upgrades.

The challenges associated with implementing signals upgrades are not simply limited to an unfortunate lack of robust competition in the signals marketplace. Most subways lines, including the Red and Orange Lines, have a long history of design and development. This results in unique geometry and other physical characteristics associated with stations and track wayside for each individual subway line. Due to these unique characteristics of each subway line, any signals system must be custom tailored for the particulars of station design, spacing between stations, and the important track waysides that typically involve both above ground and underground trackage. Given the important and variable physical characteristics associated with each line, there is no turnkey system that the MBTA can specify and procure off the shelf.

The need to custom-tailor signals upgrades for each specific line, the very complex technologies (Fixed-Block and CBTC) that dominate today, the lack of robust competition that also exists in the manufacturing marketplace, the inability to procure an off-the-shelf design, and the cardinal objective to put train and passenger safety first at all times by using equipment that has proven itself and been fully approved by federal regulators, combine to make it very challenging for any transit agency to swiftly implement signals modernization and upgrades programs.

Fixed-Block signals have a long-standing proven record of reliability to help ensure that subways operate safely. That proven record of safety is a huge reason why Fixed-Block signals remain in widespread usage, including serving to control operations of the MBTA's Red and Orange Lines. Yet Fixed-Blocks signals have some inherent drawbacks or limitations with respect to more modern needs to increase subway capacity and offer more passenger conveniences.

With Fixed-Blocks, the maximum speed of each train will depend on how many blocks are unoccupied, or open in front of it. Yet Fixed-Blocks signals do not register the trains' speed, nor do they understand where each train is located within each block. Because the fixed-blocks must be sized for the worst-case stopping distance to safeguard against running into the train ahead regardless of the actual speed and actual location of each train, Fixed-Block signals make the blocks longer and require trains to be spaced further apart than they would be ideal, thus decreasing the lines capacity.

While Fixed-Block signals could readily handle the passenger demands for much of the 21st century, the limitations of the fixed-block approach have throttled the ability of transit agencies to operate more trains during the peak commute to provide for increased passenger capacity to meet the transportation and environmental objectives of Boston and other contemporary cities.

THE "NEW" SIGNALS OPTION: COMMUNICATIONS-BASED TRAIN CONTROLS

To address the operational inefficiencies of Fixed-Blocks, a newer signals approach was invented in the 1980s by employing the then-new invention of distributed computer hardware and software systems to allow for blocks that can move or change in length. This new approach to signals featured moving—as opposed to fixed-blocks and is known as CBTC. By constantly tracking two-way communications among all trains operating on a given line and radio beacons and other specialized componetry installed in the track wayside, CBTC signals can more precisely track the status of each train. This unshackles the safe movement and separation of trains from fixed-blocks with the real-time status of train speed and location measured by complicated computer software to calculate the required amount of separation between trains. Unlike Fixed-Blocks, CBTC signals can expand or shrink the safe gap needed between two trains based on a computerized analysis in real-time.

Depending on the details of the specific subway line at issue, CBTC signals promise to run more trains on the rails at the same time and thus increase frequency. As trains arrive at each station more frequently, the capacity of each subway line can be increased. In addition, where Fixed-Block signals typically work with trains that run under full manual control of the cab operator located in the front of each train, CBTC offers the ability for trains to run in either semi-automatic mode or in full autonomous mode, which offers additional benefits as well.

The newer CBTC signals approach has begun to win over much of the subway signal marketplace for brand new subway lines. The choice between Fixed-Blocks and CBTC is made simpler or more complex depending on whether the subway itself is an existing, legacy system that is already in operation where Fixed Circuits signals are likely in use or if the line itself is a new construction project not presently in service. For several decades now, CBTC has won out over Fixed-Blocks for nearly every newly constructed subway line where no such passenger line had previously existed, such as London's Crossrail subway construction project underway mainly in central London. This subway line was approved in 2007, and construction began in 2009 with CBTC selected as its signal technology. London has recently begun to place portions of this new line into passenger revenue service.

ASSESSING SIGNAL UPGRADE OPTIONS

NYC MTA: MOVING FORWARD WITH THE SWITCH FROM FIXED-BLOCK TO CBTC SIGNALS

The decision of whether to switch an existing system from Fixed-Block signals to CBTC signals is very difficult. It involves many complexities that range from incompatibility with pre-existing signals to limited contractor access windows that usually result in very lengthy construction schedules. As compared to Fixed-Block signals, CBTC signals typically need massive increases in construction costs and schedule, with any annual operational or maintenance savings necessitating a lengthy payback period on a life-cycle cost basis.

The conversion of the New York City Metropolitan Transit Agency (MTA) subway system from Fixed-Block to CBTC signals is a prime example of the agonizingly slow-pace and astonishingly high cost of switching signals on an existing legacy system. In 1999, the MTA signed a contract to install CBTC on the Canarsie Line, as its first such transition away from Fixed-Block signals. While the supplier it had selected had successfully installed a similar system on Line 14 of the Paris Metro, which was a brand-new line, the existing and decrepit Canarsie (BMT or L) line presented a host of unexpected and costly challenges. Installation of the CBTC equipment on the Canarsie Line did not begin until 2003. Design and construction continued for another 6 years and was completed in 2009, a full decade after the original contract was executed.

The New York MTA waited some eleven years before executing its next contract to switch a second line—the Flushing (#7) Line—over to CBTC. In the interim, MTA leadership and consultants watched as CBTC installations increased around the world. On the belief that its second effort to install CBTC would be easier and faster, the MTA decided to move forward to install CBTC on the Flushing Line. In the 2008, the MBTA award a seven-year contract to convert the Flushing Line over to CBTC. After the numerous design and construction issues that followed, the CBTC system was activated in October 2017, nearly ten years after the original contract went into effect.

Despite taking about ten years in each case to fully implement the transition from Fixed-Block to CBTC signals on two of its 36 subway lines, in 2020 the MTA decided to re-signal another four of its lines—the A, C, E, and Culver (F)—from Fixed-Block to CBTC signals.

MBTA: STAYING WITH FIXED-BLOCK SIGNALS ON THE RED LINE & ORANGE LINE

In contrast to their colleagues in New York City, the MBTA decided in 2016 that it would not make the switch over to CBTC and instead retain but upgrade the Fixed-Block signals that have long been used to safely operate the Red and Orange Lines. To its credit, MBTA leadership asked staff to study the benefits and challenges associated with switching these two lines over to CBTC, and the results of that analysis were presented to the FMCB in September 2016.[15]

That effort included conducting an extensive independent system capacity simulation on Red Line and Orange Line, utilizing actual service data, visual observations, and actual signals and station designs, modeling vehicle performance, and studying other specific improvement initiatives. A detailed analysis assuming a moving block CBTC system on the Red Line was completed. The analysis found that a CBTC system would produce an improvement of just one train per hour beyond the improvement from the new cars and minor system changes. It found that major Red Line capacity improvements can be achieved without implementing very costly CBTC, and that long dwell times in the downtown area and close spacing of stations (such as Park Street and Downtown Crossing) limit CBTC as much as they limit fixed-block systems.

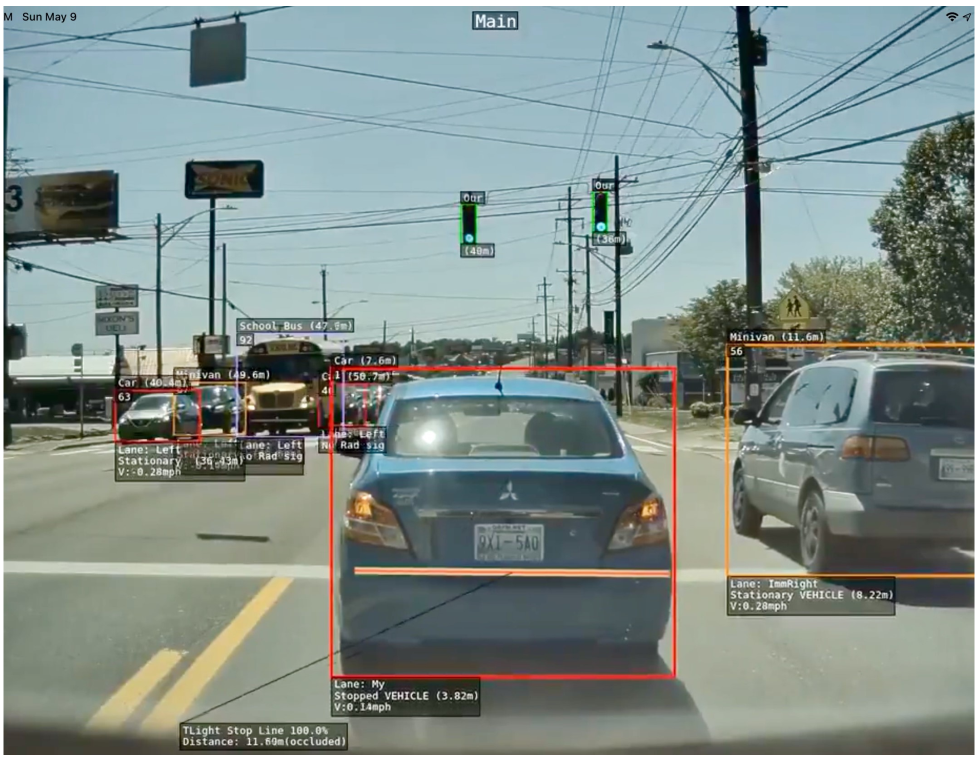
A Better City's research on the 2016 choice with respect to signals on the Red and Orange Lines suggests that the MBTA's decision to stay with Fixed-Block signals was the right choice for the near future, given the limited and imperfect options available in today's signals marketplace: to either switch over to CBTC and face the prospect of a decade of construction and about $1 billion in additional cost per line, or retain and upgrade the existing Fixed-Block system until the design and construction process to install CBTC signals becomes considerably easier or until a newer, third generation signals system emerges.

LEAPFROGGING CBTC: THE NEED TO DEVELOP A NEXT-GENERATION SIGNALS APPROACH

A Better City's research suggests the signals market today suffers from a lack of robust competition for business, as just two main suppliers exist in the North American market—Alstom Signaling, Inc. and Siemens—each of whom offers products that are not compatible with the other. This lack of competition and failure to provide for interoperability has real constraints. An instance of this might be when a transit operator chooses to install products provided by one of the two vendors, for all intents and purposes, it remains locked to that manufacturer for all future procurements. For example, signals products from what we will call vendor A were installed on the MBTA's Red Line in the 1960s. For well over a half-century now, all equipment needed to maintain and upgrade signals on the Red Line has essentially involved sole-source procurements from the same vendor or its progenitors.

A Better City's research suggests a national need to help develop a new next-generation signals system that uses contemporary artificial intelligence and digitized machine-vision techniques to determine location and speeds in a completely movable block approach that reduces or eliminates the need for any equipment to be located within the increasingly vulnerable track wayside. We believe this next-generation approach can be designed to address the climate change risks and other shortcomings associated with the limited choice between Fixed-Block and CBTC signals available in the marketplace today. Our research suggests a strong possibility that the development of next-generation signals should take root within the most modern highly sophisticated hardware and software techniques that are now being extensively researched and developed in the autonomous vehicles and trucks business space. By way of example, every Tesla automobile sold today comes standard with highly regarded driver-assist system, which utilizes a series of onboard cameras embedded in the vehicles exoskeleton together with a compact, integrated onboard computer hardware and software system that contains sophisticated artificial intelligence capabilities. The vehicle uses this highly digitized and integrated system to offer a modernized cruise control that automatically adjusts speed to maintain safe separation with the vehicle ahead and, in addition, offers artificial intelligence support to automatically steer the vehicle to stay in the center of the travel lane. Tesla's ability to undertake sophisticated machine-vision and object orientation to determine appropriate vehicle control to safely navigate ahead may have direct import to what the underpinning of a next-generation subway signals system may look like. Several other car manufacturers have started to offer driver-assist products like Tesla's, including Ford Motor Company, General Motors, Nissan, and Mercedes-Benz. See Figure 13 for an example of how Tesla's digitized machine-vision and artificial intelligence techniques are used today to provide for semi-autonomous vehicle operations with respect to traffic-aware cruise control and stay-in lane steering.

FIGURE 13: Example of Modern Machine-Vision Combined with Artificial Intelligence to Provide Semi-Autonomous Vehicle Operations



SOURCE: Tesla

RECOMMENDATIONS

This report reviewed key aspects of the MBTA's Red Line and Orange Line signals upgrade project and considered the imperative for the system to adapt to the now certain impacts of climate change, including sea-level rise, by adopting a more resilient, next-generation signal system. Moving forward, A Better City recommends that the MBTA consider the following recommendations with respect to signals on the MBTA's Red and Orange Lines:

SEMI-AUTOMATIC CAPABILITY: A Better City recommends that the MBTA amend existing contracts for new vehicles and signals upgrades to incorporate modest amounts of semi-automatic capability in routine train operations at a cost of approximately $70 million. A Better City has conducted extensive research demonstrating the feasibility of achieving some of the semi-autonomous operational benefits ordinarily found only in CBTC signals into the planned Fixed-Block system upgrades. Additionally, A Better City believes that existing MBTA contracts can be amended to incorporate the ability to automate train acceleration/deceleration between stations, as well as the station berthing process.

PLATFORM SCREEN DOORS PILOT: A Better City recommends that the MBTA undertake a new Platform Screen Doors Pilot Project at several key Red Line and Orange Line stations in the downtown Boston core at a cost of approximately $25 million. These doors are used in many world-class cities to enhance passenger safety (by preventing accidental and other falls into the track pits), to improve passenger flow and reduce dwell time, and to enable the installation of air conditioning to help enhance the transit experience, a benefit customers may increasingly expect as temperatures continue to increase due to climate change. If the MBTA can achieve semi-automatic berthing (i.e., station stopping not guided solely under human control), then the system should pilot the installation of Platform Screen Doors along the length of several station platforms.

NATIONAL ADVANCED TECHNOLOGY CENTER FOR NEXT-GENERATION SUBWAY SIGNALS: A Better City recommends that the MBTA together with federal transportation officials and industry leaders partner to fast-track the development of a federally funded National Advanced Technology Center for Next-Generation Subway Signals based in Boston. This recommendation includes the suggestion that $1 million be allocated to help fast-track collaborative efforts to develop a proposal to seek and obtain federal funds for this new center. The Red and Orange Lines face an increasing threat from salt-water flooding that can ruin critical infrastructure, including signals. In 2012, Hurricane Sandy showed that this threat should not be taken lightly, as salt-water flooded and destroyed vital Fixed-Block signals in the New York City Metropolitan Transit Authority's Cranberry Street subway tunnel, which carries the A and C trains between Manhattan and Brooklyn underneath the East River. A Better City's research suggests a national need to help develop new next-generation signals that use contemporary artificial intelligence and digitized machine-vision techniques to determine location and speeds in a completely movable block approach that reduces or eliminates the need for any equipment to be located within the track, which is increasingly vulnerable to the impacts of climate change, including sea-level rise and saltwater intrusion. Government, academic, and business leaders in Greater Boston are uniquely positioned to form a leading consortium to seek federal funding.

CONCLUSION

The MBTA's existing multi-billion-dollar overhaul of the Red and Orange Lines will be a much-welcomed improvement to these two workhorses of the Boston regional transit system. New cars will entirely replace the existing fleets. They will also expand the number of active Red Line vehicles to provide 16 percent more Red Line and 33 percent more Orange Line vehicles available each day for service. With new vehicles, expanded fleets, and various infrastructure upgrades, the MBTA can run more trains per hour, which will reduce the headway between trains and shorten the time that riders need to wait on platforms. By having more trains arriving more often at each station, the MBTA promises to deliver expanded capacity and faster, more comfortable, more frequent, and more reliable trips.

The pandemic has interfered with the pace of the MBTA's Red and Orange Line Transformation program, impacting both schedule and cost. The MBTA has broken the program into two phases. Phase 1 will include all previously committed design and construction work consisting of new vehicles and infrastructure (including signals upgrades), exhausting the available $2.1 billion and running through the end of FY23. The MBTA still aims to meet the headway targets by 2024, but has delayed the reliability targets until 2029. Based on the January 2021 FMCB presentation, the new Phase 2, which includes additional and necessary investments in track and power system repairs and upgrades, will require approximately $700 million in newly identified but currently unfunded dollars.

At this critical juncture, A Better City recommends that the MBTA adopt the above-mentioned recommendations to advance signals and train controls. This relatively modest increase of $100 million will leverage the revised $2.8 billion total for Phase 1 and Phase 2 and allow the Red and Orange Lines to better serve the economic development and environmental needs of the Commonwealth and Boston region for decades to come.

A BETTER CITY