CBTC: An Overview

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Abstract

The New York City Subway, while an iconic part of the city, is an antiquated one that has technology dating back to the early 20th Century, and has riders frustrated with the sordid condition of the system, and with the city as a whole. Central to the problem is with the Subway's signalling system; the Subway uses an old type of signalling called a "fixed-block system" (or block signalling system), where sensors under train tracks dictate the movements of trains. However, because of difficult maintenance and overall inefficiency, a new, advanced form of train communication/signalling is coalescing: Communications-Based Train Control (CBTC). CBTC's moving-block system brings many advantages, such as increased trains per hour, more passenger service, and better flexibility. Even so, there are a few flaws, such as operators' general inexperience with CBTC. Hence, we propose a solution that that combines the old and the new: a combination of fixed-block signalling and CBTC. The benefits of CBTC can be maximized while minimizing potential malfunctions associated with relatively new technologies.

Introduction

The New York City Subway is one of the largest and most complicated subways in the world, is more than a century old, and continues to modernize and advance to this day. But one particular facet of the Subway the MTA (**Metropolitan Transportation Authority**: the managing company of the Subway) has difficulty in modernizing is the system's signalling system. In one form or another, the system's signalling system-- from the control tower to the track signal-- has not been upgraded since its initial installment when the Subway first opened. While built to be safe and reliable, the signal system's continual safety and reliability is becoming questionable, as signal problems, train delays, and rider dissatisfaction increase. Following several tragic accidents on the Subway (e.g. the 1991 Union Square train derailment), the MTA has resolved to invest in modernizing its signal system, by embracing a new design called **Communications-Based Train Control** (CBTC). While the MTA has done much to try to maintain/increase efficiency, there are many misconceptions about the new agenda that leave riders frustrated both with the Subway and the MTA. Hence, this paper aims to answer many of these misconceptions by explaining, in depth, what CBTC is and how it works, how it's been implemented on other subway systems and how it's been implemented on the NYC Subway, and by proposing an additional initiative to further increase reliability.

Pre-Cursors to CBTC

Before CBTC is explored, it's essential to understand predecessor signalling systems. This makes for greater understanding of CBTC's true value. CBTC's most notable predecessor is called **Block Signalling**, the principal signalling system used on the New York City Subway. ("CBTC: Communications-Based Train Control.") Under Block Signalling, tracks are physically "divided" into segments by way of insulator, and an electrical current is ran through the rails. When there are no trains in the vicinity, the electricity current runs undisturbed, indicating to a *supervisory tower* (a central managing point for all the signals of a certain track line) that there are no trains in the area. This constitutes a **green block**. However, when a train enters the track-line, its wheels disrupt the track current, indicating to a supervisory tower that there *is* a train in the area. This constitutes a **red block**, and trains are not allowed to enter this section, under penalty of automatic emergency brake. (Hartong 8) To ensure timely operation of trains, a set of **buffer blocks** are inserted between trains that keep trains a safe distance apart. (See Figure 1.1) Trains that get too close to another train will be slowed down or stopped by special signals called **timers**, which are specifically made to spread out trains evenly, and safely. (Hartong 9)

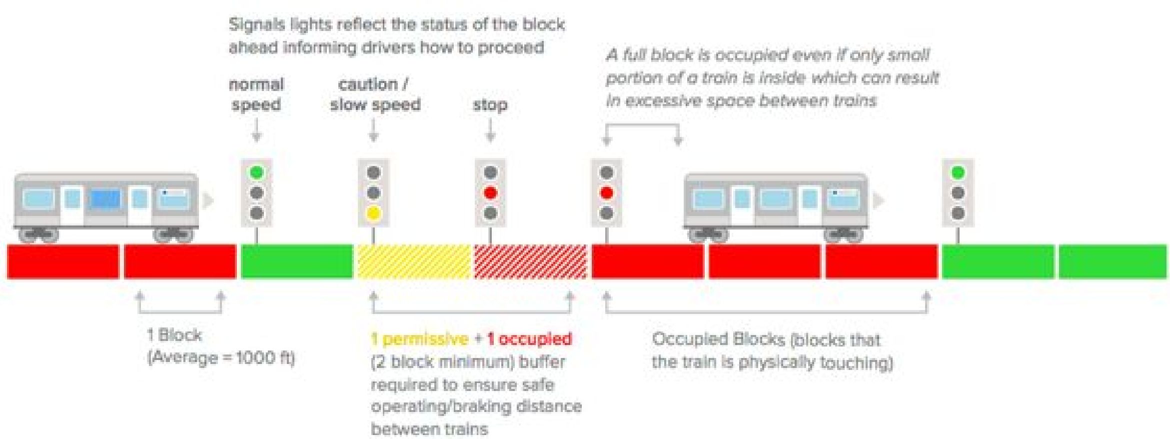

Figure 1.1 (Source: Somers, James. Fixed-Block Signalling. Digital image. *Why New York Subway Lines Are Missing Countdown Clocks*. The Atlantic, 13 Nov. 2015. Web.)

Signal systems like these are typically extremely complex, hard to maintain, and in the NYC Subway's case, old. Take, for instance, the MTA's *West 4th St. Supervisory Tower* ("CBTC: Communications-Based Train Control."), which has equipment dating back to the 1930s', when the station was constructed. Its systems have not not been upgraded since they were first installed, and currently are *self-sufficient*, meaning that the equipment is not supported by the railroad industry. Even the cabling dates backwards eighty years, presenting risks of communication if a fire were to erupt. ("CBTC: Communications-Based Train Control.") This system has quite a number of limitations. First, operators do not know the exact location of trains, and cannot adjust speed to account for passenger demand. This means that trains must maintain unwieldy buffer zones for optima passenger safety. ("CBTC: Communications-Based Train Control.") This sets a strict limitation on the number of trains. Second, this system is very resource demanding, requiring massive amounts of equipment to operate properly. Its inefficiency creates additional maintenance issues, causing even minor complications to result in major catastrophes.

Other Signalling Systems

The North American railway system used a system called Timetable operation until the 1980s. In essence, it enforced the use of personal scheduling train "appointments" for train usage ("The Geography of Transport Systems" 1). It presented obvious disadvantages, such as the inflexibility to accommodate for additional trains and its inability to directly locate trains, causing for longer delays to ensure safety. Even as the availability of telegraphs increased efficiency in terms of direct communication, manual block systems became the prominent communication system. This system is the of appointments in order for a train to occupy a "block", which are labeled with fixed signs. Occupation of a block is controlled by a dispatcher with the use of radio communications. The Long Island Rail Road still uses the manual block system today, proving its effectiveness ("LIRR Railroad Signal System").

CBTC

Communications-Based Train Control (CBTC) is a railway signaling system which makes use of the communications between the train equipment (called **onboard equipment**) and track equipment (called **wayside equipment**) in order to manage traffic. Because of CBTC systems, trains could move in a more efficient and safe way to manage the railway traffic. CBTC makes it possible to shorten the space between trains without increasing risk. CBTC systems are more reliable and less prone to failure than older train control systems. CBTC systems normally have less equipment and their tools have been improved, which makes them easier to implement and, more importantly, easier to maintain. This is in opposition to block signalling, which has fixed blocks.CBTC is akin to *moving* blocks, as the "blocks" in question are the trains themselves.

CBTC Architecture

Within CBTC, there are several levels of association. First is on the "supervisory" level (e.g. the previously mentioned West 4th Street Supervisory Tower), akin to what's called **Automatic Train Supervision**. Some would call this level the "control center" of CBTC, and they would be correct. As part of ATS, the location and speed of trains are monitored, and signals and track switches are manipulated to safely move trains in and out of stations. (*Secure Communications Based Train Control (CBTC) Operations*) Central to this is a kind of controller called the **Movement Authority Controller**, which ensures that all of the previously mentioned roles are carried out successfully. (*Secure Communications Based Train Control (CBTC) Operations*) The next level of CBTC is at the track level, typically called the *wayside* level, and is similarly akin to what's called **Wayside Automatic Train Protection**. This section of CBTC serves as a relay between the MAC and rolling stock equipment (e.g. transmitting location and speed of trains), has control over wayside equipment (e.g. signals and track switches), and prepares information about trains to be sent to ATS. (*Secure Communications Based Train Control (CBTC) Operations*) The third and final level is associated with equipment on the rolling stock (the train itself), and is called **Automatic Train Operation**. This level takes up quite a number of functions: first, it assumes primary control of the train, and accounts for typical operation of the train, as well as any emergency stops necessary. In addition, it monitors the speed and location of trains and sends this information to wayside systems. It also provides information to the cab driver if s/he must make any necessary judgements regarding the operation of the train. (*Secure Communications Based Train Control (CBTC) Operations*)

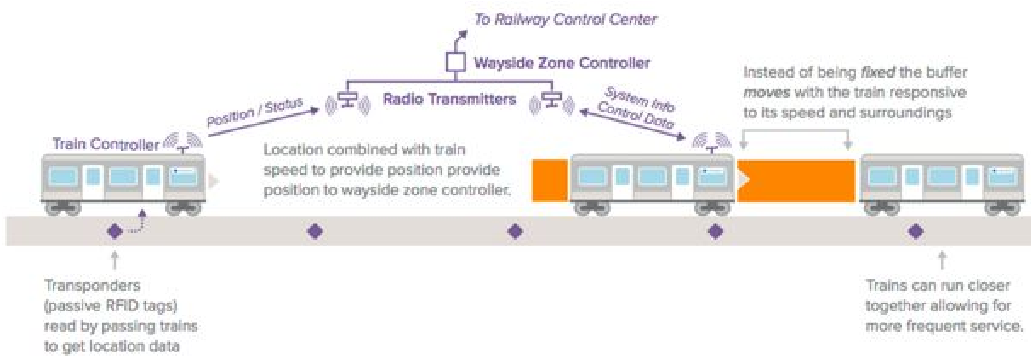

Figure 1.2 (Source: Somers, James. Fixed-Block Signalling. Digital image. *Why New York Subway Lines Are Missing Countdown Clocks*. The Atlantic, 13 Nov. 2015. Web.)

CBTC has several operating levels, for flexibility. The first mode, *Semi-Automatic Train Operation* (STO), relegates cab drivers to door control, and other secondary train operations. (*Secure Communications Based Train Control (CBTC) Operations*) The second mode, *Driverless Train Operation* (DTO), relegates the train attendant to secondary train operations. (*Secure Communications Based Train Control (CBTC) Operations*) The third and highest mode, *Unattended Train Operation*, does not require any driver on the train, and can automatically operate itself. (*Secure Communications Based Train Control (CBTC) Operations*)

There are various levels of CBTC that allows for it to function. Firstly, the Central Office Equipment is responsible for authorizing the movement of all the trains. It dictates the train's speed, station destinations, and where they should be. The Movement Authority Controller also controls switches and signals to dictate their movement. Many trains use Automatic Train Supervision (ATS), which monitors the movement of trains while responding with specific controls to minimize train delays and traffic. They are associated in both individual stations and in control areas around multiple stations. (*Secure Communications Based Train Control (CBTC) Operations*)

Trackside Equipment also helps facilitate train transportation. Similar to Wayside ATP, it relays communication between the Movement Authority Center and In-Car Equipment. Its functionality differs from different CBTC systems, but many account for the In-Car Equipment's physical location or by radio. (*Secure Communications Based Train Control (CBTC) Operations*)

The In-Car Equipment is another level of CBTC that controls speed and within their specific limits and parameters. Information is given to the cab driver in order to make adjustments in accordance to the train's status. It furthers the ability for the Automatic Train Operation to control the train. In addition, both primary and secondary controls are used, with secondary control used for emergency purposes. Lastly, the Onboard Automatic Train Protection (ATP) System computes train speed and location, working hand-in-hand with the carborne equipment to monitor its movement. (*Secure Communications Based Train Control (CBTC) Operations*)

Advantages and Disadvantages

Communications-Based Train Control (CBTC) offers various advantages that demonstrate its superiority over the fixed-block system. Most importantly, it increases the available space for train operation, freeing up space for more trains to carry passengers. Consequently, CBTC allows more passengers to be transported. Efficiency is improved, and the safety of passengers is still maintained. Since the communication based system only requires wifi for operation, paid operators are optional for proper functionality. Overall, the maintenance cost is reduced, allowing for additional money to be relocated for further advancements.Some disadvantages of CBTC include the inflexibility of the block or "buffer" distance between trains. In essence, even though slower trains could be closer to one another and still be at a safe distance, CBTC accommodates for the fastest trains on the tracks, rather than adjusting individual buffers for each train. In this respect, the fixed-block system is more efficient because slower trains are not handicapped from a larger buffer zone.

CBTC Examples

Metropolitan Transportation Authority

The MTA is undergoing a major overhaul of its signal systems. This is a multibillion dollar project that is projected to take several years to fully accomplish. Unlike other CBTC projects, the MTA CBTC project is notable in that the process is heavily complicated by an extremely complex, outdated, and unpredictable system. We will be focusing on two lines central to the current CBTC effort: the BMT Canarsie Line, the L Train's trackline, and the IRT Flushing Line, which is the 7 Train's trackline. (MTA)

BMT Canarsie Line

This is a completed project; the upgrade was completed by Siemens, a railway company. The process was spearheaded by the new R143 cars, the second of a new generation of subway cars called *New Technology Trains*. (MTA) It encountered quite a few delays, but is servicing many more passengers than it would have if block signalling were in place.

The first major CBTC project was made along the BMT Canarsie Line (Somers 4). Desires to begin automating the subway were sparked after a tragic accident on the IRT Lexington Avenue Line (the 4, 5, and 6 trains)'s *14th Street-- Union Square* station, where a drunk motorman crashed a train into a track switch (at 5 times the speed limit), killing 5 people and injuring 200 (New York Times). Accidents like these inspired the MTA to begin pursuing automated train control options as early as 1997, and ultimately culminated with the selection of Siemens Transportation Systems to head a 5-year CBTC contract for the Canarsie Line. This line was selected because of its relative shortness (compared to other stations) and its isolation and single-line operation. (Chan 3)

Implementation of CBTC in the NYC Subway was difficult, particularly because a) the Subway is immensely complicated and old,b) flexibility was of paramount importance at all times, c) the L Train (the service that operates along the Canarsie Line) had to operate while construction was being done. (NYC Transit Powerpoint) The Canarsie line was signalled with two aims: 1) function as a CBTC "pilot program" for NYC Transit, to provide lessons to be used in later CBTC operations (e.g. the IRT Flushing Line, as will be discussed shortly); 2) ensure maximum interoperability between wayside systems and rolling stock, which will be made brand-new specifically for the line, and will integrate fully with the ATS System. (NYC Transit Powerpoint) Central to the system was implementation of *Automatic Train Supervision*, plus a new system of radio/doppler tracking. (NYC Transit Powerpoint) Both of these innovations enabled the L Train to receive *countdown clocks*, which determined, to the minute, when the next train would come.

Figure 1.3 (Source: Flegenheimer, Matt. "Upgrades for L Train, but Not More Praise." *The New York Times*. The New York Times, 23 Mar. 2014. Web. 25 Apr. 2016.)

The first signs of the new project viewable to riders appeared when the **R143** became part of the NYC Subway roster. The contract was awarded to Kawasaki Rail Car, Inc. (Chan), and carried over several useful innovations from the **R142A**, a slightly older train-model also created by Kawasaki. (Kawasaki) Notably, it was part of a larger class of subway trains, called **New Technology Trains**, which reflected the MTA's jump into the 21st Century with innovations like automated announcements, modernized strip maps that lets riders know *exactly* where they are, and revamped exteriors/interiors to make the subway look modernized, clean, and reliable ("MTA Press Releases.").

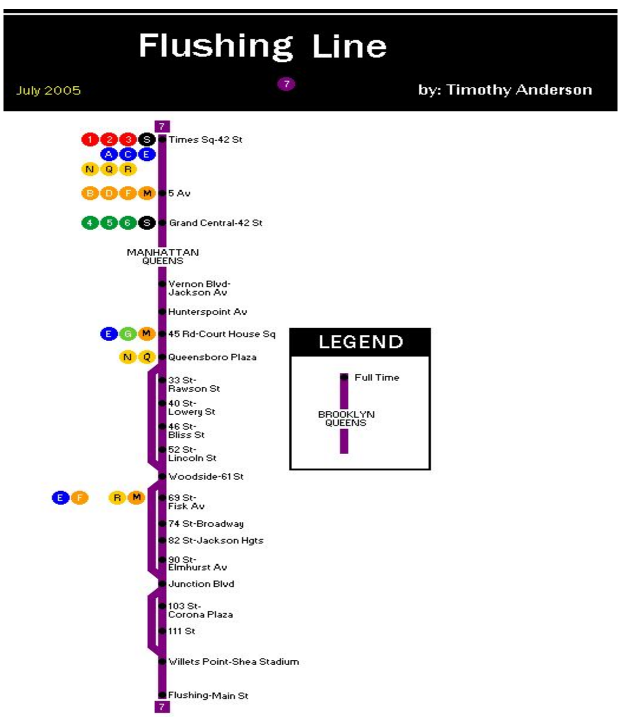

Figure 1.4 (Source: "Atlantic Avenue (L) - The SubwayNut." *Atlantic Avenue (L) - The SubwayNut*. N.p., n.d. Web. 25 Apr. 2016.)

Figure 1.5 (Source: Anderson, Timothy *Flushing Line.* 2005 MTA)

IRT Flushing Line

The IRT Flushing Line is currently undergoing upgrades to CBTC, and is being done by the railway company Thales. This is spearheaded by the introduction of the new R188 cars, the same technically as the R142A models, differentiating only by the introduction of CBTC. Additionally, this order is unique in that Kawasaki (manufacturer of the R188 order) is only making a part of the order from scratch-- the rest are converted R142As from various parts of the A Division. The project is expected to complete in **2017** (delays might say otherwise).

The second major line undergoing a CBTC upgrade, the **IRT Flushing Line**, is currently being upgraded by Thales, a similar company similar to Siemens. ("MTA Press Releases.") Lessons learned from the BMT Canarsie Line were carried carried over into this project. Like the Canarsie Line, the Flushing Line was chosen because it has only one major line of service (the 7 Train) and is generally isolated from the rest of the Subway, making the upgrade process easier. Additionally, it was spearheaded by the entrance of a new rolling stock, the **R188**. An identical clone of the older **R142A** ("MTA Tests New Subway Trains on Flushing Line."), the R188 has special antennas called **transponder interrogator antennas**, which enable the trainsets to operate with CBTC. ("CBTC: Communications-Based Train Control.")

Conclusion

CBTC will soon be significant throughout the world. Although many people are ignorant of its various technicalities that make up its design, our research paper shows how CBTC will be an advanced addition to our world. Firstly, many passengers will experience a faster ride when traveling to work on a daily basis, allowing for a city to flourish. Secondly, this advanced communication system fosters a safer environment, allowing for issues to be addressed and resolved immediately. In essence, by locating the exact location of trains through communication and moving sensors, surrounding trains can accommodate for sudden malfunctions, and aid can arrive quickly.

For many regular riders, the differences in time would be massive. The passengers will arrive at their destination faster, while also noticing an increase of arriving trains. By having more trains, more space is also available for riders to enjoy. In general, the mood of a busy city can be remedied by fostering a more convenient transportation environment.

In conclusion, our research has indicated what CBTC is and the clear advantages/disadvantages of CBTC. Although it is a clear step up from other methods, such as the fixed-block system, a trade off was necessary in order to highlight its benefits. As mentioned before, the inflexibility of the buffer zone shows that the system does not come without its disadvantages. Furthermore, this is the first time the world is implementing this highly complex and technical communication based system. For example, the Canarsie Project (L Train) has been operating with the fixed-block system for nearly a century. As a result, the inexperience of operators can hinder the performance of the train system, especially when a malfunction arises.

Hence, we propose that a combination of both CBTC and the fixed-block signalling would be an effective addition to the subway system. From one view, it allows developers to build upon current subway systems that are already operating with the fixed-block system. Also, it allows for more flexibility. When one of the systems fail, the other can be used as a back-up. For example, during Hurricane Sandy, many subway systems were forced into maintenance because of the disruption of the fixed-block system. If CBTC had been implemented beforehand, the issue would have been resolved immediately because of its communication, not based on the functionality of track sensors. Alternatively, if an unexpected malfunction occurs in a system where a train system relies on CBTC, the inexperience of operators can be covered for by switching to the fixed-block signalling. Overall, CBTC and block-signalling can help improve communication among the tracks and prevent maintenance issues from happening.

References

"$205.8M in Contracts Approved to Install Communications-Based Train Control System." *MTA*. Web. 20 Jul. 2015.

"Catastrophe Under Union Square; Crash on the Lexington IRT: Motorman's Run to Disaster." *The New York Times*. The New York Times, 1991. Web. 25 Apr. 2016.

Chan, Sewell. "Subways Run by Computers Start on L Line This Summer." *New York Times*. New York Times, 14 Jan. 2005. Web.

"Communications Based Train Control Projects Transportation Systems Design, Inc. Home Back." *CBTC Projects*. Web. 13 Apr. 2005.

Ferrari, Alessio, Giorgio O. Spangnolo, Giacomo Martelli, and Simone Menabeni. *Product Line Engineering Applied to CBTC Systems Development*. Pisa, Italy: n.p., n.d. PDF.

Ferrari, Alessio, Massimiliano L. Itria, Silvano Chiaradonna, and Giorgio O. Spangnolo. *Model-based Evaluation of the Availability of a CBTC System*. Pisa, Italy: n.p., n.d. PDF.

Hartong, Mark W. *Secure Communications Based Train Control (CBTC) Operations*. N.p.: Mason Archival Repository Service, n.d. PDF.

"Kawasakirc.com New York City Transit Authority R143." *Kawasakirc.com New York City Transit Authority R143*. Web. 25 Apr. 2016.

"LIRR Signal System." *LIRR Signal System*. Web. 25 Apr. 2016.

Liu, C., X. Sha, F. Yan, and T. Tang. *A Scenario-based Safety Argumentation for CBTC Safety Case Architecture*. Beijing, China: WIT Transactions on The Built Environment, 2010. PDF.

"Metro Business; Subway Job to Kawasaki." *The New York Times*. The New York Times, 1998. Web. 25 Apr. 2016.

Mtainfo. "CBTC: Communications-Based Train Control." *YouTube*. YouTube, 2015. Web. 25 Apr. 2016.

"MTA Press Releases." *MTA*. 22 Dec. 2008. Web. 25 Apr. 2016.

"MTA Tests New Subway Trains on Flushing Line." *WSJ*. 18 Nov. 2013. Web. 25 Apr. 2016.

New York City Transit. "NYCT CBTC Program." *MTA*. MTA, 5 Feb. 2004. Web.

Mohan, Shiv. *DUBAI METRO SIGNALLING & TRAIN CONTROL SYSTEM*. Dubai: Serco Dubai Metro, n.d. PDF.

"The Field-proven Moving Block CBTC Solution for Metro Transit Systems." *The Field-proven Moving Block CBTC Solution for Metro Transit Systems*(n.d.): n. pag. *Siemens Industry, Inc.* Siemens Industry, Inc., 2012. Web.

"The North American Intermodal Rail System." *The North American Intermodal Rail System*. Web. 25 Apr. 2016.

Somers, James. "Why New York Subway Lines Are Missing Countdown Clocks." *The Atlantic*. Atlantic Media Company, 13 Nov. 2015. Web. 25 Apr. 2016.

Yang, C. S., J. S. Lim, J. K. Um, H. M. Han, Y. Bang, H. H. Kim, Y. H. Yun, C. J. Kim, and Y. G. Cho. *Developing CBTC Software Using Model-Driven Development Approach*. Anyang, Korea: LS Industrial Systems, n.d. PDF.