POSITIVE TRAIN CONTROL: GETTING ON THE RIGHT TRACK

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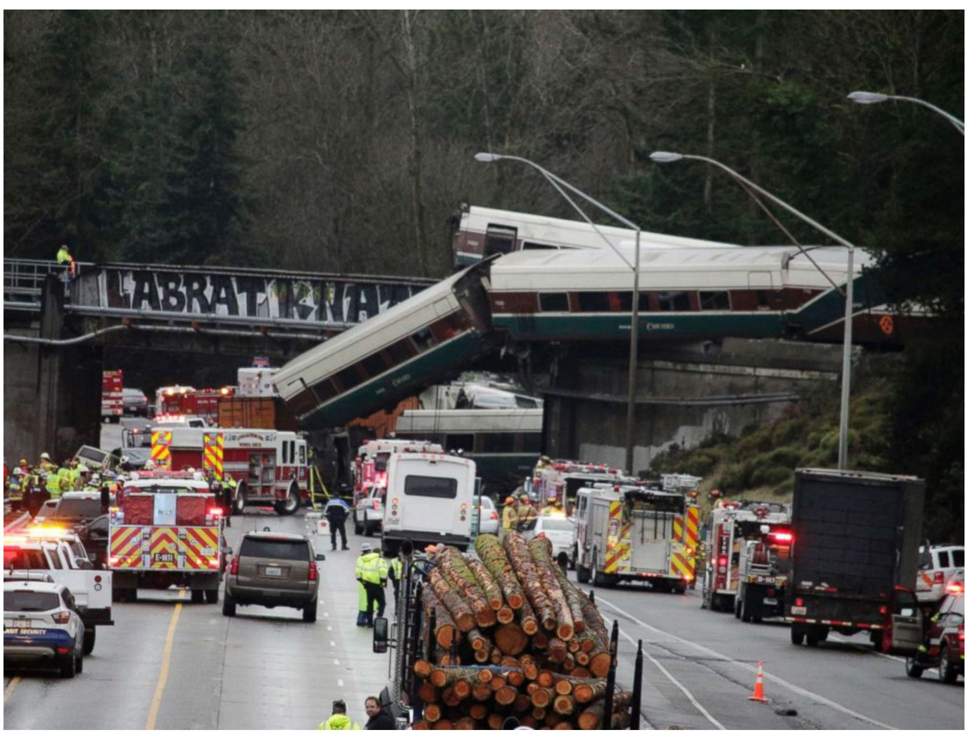

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0 Executive Summary

On May 12, 2015, an Amtrak passenger train in Philadelphia entered a 50 mph curve at 108 mph. The train derailed, leaving eight people dead and nearly two hundred injured. Safety reports determined that an existing technology known as Positive Train Control (PTC) could have prevented this incident.

Because of the vital role trains have played in American life for two centuries, train safety is a paramount concern. Either on short trips to work or long trips across the country, a vast number of people ride on trains everyday: Amtrak alone estimated their passengers as numbering 31.3 million in 2016. The National Transportation Safety Board (NTSB) and the United States Federal Railroad Administration (FRA) are two of the most important government bodies for the purpose of train safety.

In recent years, many fatal crashes have placed a more immediate emphasis on train safety. Various crashes in Massachusetts, New York, Washington D.C., Philadelphia, and California brought attention to an important new technology: PTC. PTC is a backup system designed to apply the brakes in the case of driver error. All of the train crashes mentioned were caused by human error; the engineers driving the locomotives were distracted, tired, or simply unprepared. Upon review by the NTSB and other agencies, it was determined that PTC could have prevented each of these accidents from happening.

PTC is an automated software-based system. The primary design premise is that trains should be able to recognize unsafe driving behavior and correct it by applying the brakes. There are many things for the software to consider in determining this unsafe behavior. One of them is determining if a collision will take place. For example, if a train is approaching a stretch of track already occupied by another train, the control system can notify the engineer of the problem. If the issue is not corrected in time, the control system can remotely apply the brakes to the approaching train to prevent the collision. PTC can also reduce a train's speed if it is approaching a length of track at an unsafe speed. In the Philadelphia crash mentioned above, the NTSB safety report concluded that PTC could have prevented this accident from happening. Numerous other recent crashes have underscored the need for active PTC as soon as possible.

PTC technology utilizes several different systems to make its decisions. Global Positioning System (GPS) devices onboard each train, as well as other fixed-block devices such as track circuits and axle counters, pinpoint the exact location of each train moment by moment. Onboard technology can determine a train's speed and send this information to the central control system. PTC software then generates signals; these can be either permissive (suggested) or absolute (required) for the train engineer to carry out. The system can intervene by applying the brakes if this is not done hastily enough. Cab signaling systems transmit signals to train engineers automatically, reducing the possibility that wayside signals (such as signs on the side of the tracks) will be missed. Redundant systems throughout the entire PTC system further decrease accident probability. PTC thus helps to eliminate accidents due to train-to-train collisions, overspeeding, improperly aligned switches, and incursion into work zones without proper authorization.

The FRA has been attempting to institute widespread PTC since 1990. However, it was not until 2008 that Congress passed an act mandating its implementation. The Railroad Safety Improvement Act (RSIA) of 2008 placed a 2015 deadline for railway companies to have operational PTC on all tracks. However, when railway companies complained that PTC implementation was too expensive, Congress granted them an extension until the end of 2018 with the possibility of another extension through 2020. Most companies are now making significant progress, but some are still lagging behind schedule. The economic costs of PTC are extremely high, so Congress has set aside $6.6 million each year to help railway companies with implementation. This is far from enough to seriously expedite the process, and most railway companies will need the additional deadline extension through 2020.

Several technical challenges arise in PTC implementation. It's possible, and even probable, that PTC will negatively affect performance. By restricting motion by applying the breaks, railway capacity will decrease. Component degradation, which is unavoidable, must be graceful so that the system can be repaired easily and relatively cheaply. Finally, in order to be fully robust, PTC systems must be interoperable; with a plethora of railway companies in the country, it is vital that they are eventually able to function together effectively.

In addition to the technical challenges of PTC, there are also some ethical and societal considerations to draw from in analyzing PTC. The most important hindrance of timely PTC implementation is the insufficiency of funding for its research and development. The funding that the federal government provides to local authorities is in the scale of tens of millions of dollars, whereas ungenerous budget estimates of PTC implementation is in the scale of billions of dollars. Therefore there is a need for a significant source of funding.

The main reason for PTC's high price tag is the cost of researching and developing the technology. Given that Union Pacific has a successful implementation of PTC in 98% of its infrastructure, we recommend that Union Pacific open-source its PTC technology for the use of other railways. We derive from duty ethics in analyzing this ethical dilemma.

Another concern is the safety and reliability issues associated with making a PTC system that delivers the desired protection from fatal crashes. Experts observing the PTC development practices have identified security vulnerabilities that can be used to disrupt and hijack the PTC system, potentially causing worse crashes than the ones that we intended to prevent. Our recommendation in this case is to err on the side of caution, leaning towards a slower but secure development of PTC than develop it posthaste. We derive from utilitarianism in the making of this decision.

We will also address concerns related to labor displacement. There is a misconception that PTC will automate all types of train motion and render the engineer obsolete. However, PTC is merely an automatic braking system: it identifies a potential for derailment or crash and applies the brakes if the brakes are not applied by the engineer in a timely manner. In fact, development efforts of PTC results in adding more jobs to the labor economy. Union Pacific has invested over $2 billion and hired about a thousand engineers to work on the development of PTC (Union Pacific, 2018). Therefore a discussion on the negative impact on labor economy is unfounded.

Finally, we discuss the legislative issues with PTC, namely, Congress' stance in the legal enforcement in PTC. Deadline extensions for railway companies to implement PTC have totaled to 5 years and are expected to increase. Rights ethics is summoned to analyze the actions of the Congress and its responsibility to U.S. citizens. Essentially, the people's rights to life and safety are put at risk, therefore Congress needs to be steadfast in its enforcement of deadlines.

This analysis shows that implementation of PTC is a multifaceted process with difficulties in both technological and societal viewpoints. Our use of various ethical frameworks helps bring structural meaning to decision-making processes and advocate for the decisions that uphold ethical values we all can stand for.

1 Introduction

In preparing this report we initially divided our research between broad aspects of our topic. John and Michael decided to research the technological aspects of PTC, Doruk researched the economics behind PTC, Austin researched the laws regarding PTC, and Christian examined train crashes that could have prevented by PTC. After compiling sufficient information, we wrote short descriptions of our research individually. At this point, we had not yet received the course survival guide, and had no idea what the actual objective of our report was. In week eight of the quarter, we received the survival guide and drafted an outline for our report. We attempted to integrate our research into our technology and society sections of our outline. Then we brainstormed major ethical issues that were relevant to our topic and assigned writing sections for each group member.

We decided to include the train derailment cases that Christian researched in the background, John and Michael's technical research in the technological issues section, and Austin and Doruk's economic and legislative research in the ethical and societal issues section. For each ethical issue, we applied ethical frameworks to justify our reasoning about which course of action should be taken. Each member of our group discussed our ethical analysis with each other. We tried to separate our ethical analyses so that the person who researched an ethical issue the most provided analysis for that issue. Afterwards, we drew conclusions based on our ethical analysis and wrote recommendations for action.

Our editing process was done in person, and we met for a period of about six to seven hours as a group to finalize this report. During this time period, we integrated our work, wrote additional sections required for the final report such as the summary, introduction and conclusion, and worked to improve the flow between sections. After completing the bulk of our writing, we added images and diagrams to help expand on our topic, some of which we drew ourselves. We also compiled a glossary and table of contents.

Shown below is our contribution matrix, where X indicates primary contribution.

Table 1: Responsibility Assignment Matrix

	Doruk	John	Christian	Michael	Austin
Formatting	X	X		X	
Executive Summary	X				X
Introduction				X	
Background			X		X
Technological Issues		X		X	
Ethical and Societal Issues	X	X	X	X	X
Recommendations			X		X
Conclusion	X			X	

2 Background

Train accidents are devastating for the victims and their families: in the past decade there have been 20 railroad incidents across the United States, causing 147 fatalities in the past decade alone (U.S. Dept. of Defense, 2017). Many of these accidents were collisions or derailments caused by human operator error and could have been prevented with technology known as PTC. PTC is a system which uses sensors on trains and on tracks to automatically stop a train when a potentially dangerous situation is present. The system is designed to prevent speeding derailments, train-to-train collisions, and work-zone incursions. Over the past decade, it “could have prevented at least 23 deaths and 300 injuries” according to NTSB chairman, Robert Sumwalt (Dooley, 2018). By implementing PTC across the country, people will have more faith in our infrastructure and lives will be saved. Most of these crashes could have been prevented because human error was the root source of the catastrophic crashes.

2.1 Case Studies

By analyzing the deadliest train incidents of the past decade, it becomes apparent that many of these collisions are very similar and that human negligence and failure or outdated technology is the root of most collisions. The six incidents with the worst casualties are listed below.

1. - **Where**: May 28, 2008 in Newton, Massachusetts.
   - **Casualties**: 1 killed; 6 injured.
   - **What**: The accident occurred between two westbound Massachusetts Bay Transport Authority trains, since the operator of one train, Train 3667, failed to stop at a red signal and accelerated to a maximum authorized speed of 38 mph and collided with an already stopped train, train 3681. The operator of of train 3667 died from blunt force trauma and was the only fatality while six others were injured. The total damage was estimated to be $8.6 million dollars.
   - **Why**: According to the NTSB's report on the incident, the operator failed to recognize the stopping signal. This was most likely due a loss of awareness from micro-sleep, a brief episode of sleep lasting between a fraction of a second and 30 seconds that can occur in anyone suffering from “fatigue or inadequate sleep”.
   - **Preventable**: Yes, according to the NTSB report, “This accident in Newton, Massachusetts, is another in a long series of accidents that could have been prevented the

territory been equipped with a positive train control system" (NTSB Newton, 2009).

2. - **Where**: September 12, 2008 in Chatsworth, California.
   - **Casualties**: 25 killed, 102 injured.
   - **What**: A Southern California Regional Rail Authority (Metrolink) passenger train collided head-on with a Union Pacific Railroad freight train. The Metrolink's locomotive and one of the three passenger cars derailed while two of the freight's locomotives derailed and 10 of its 17 cars derailed (Hanna and Criss, 2018). Damages were in excess of $12 million.
   - **Why**: The cause of the accident was the failure of the Metrolink engineer to appropriately respond to a red signal which led to the head on collision with the Union Pacific Railroad train. The engineer failed to respond accordingly because of use of a wireless device. During the time periods that the engineer was responsible for operating the train, he sent 21 messages and received 20 while also making 4 outgoing telephone calls. This is a violation of The General Code of Operating Rules.
   - **Preventable**: Yes, the final investigation report that the use of PTC would have prevented the crash (NTSB Chatsworth, 2010).

3. - **Where**: June 26, 2009 in Washington D.C.
   - **Casualties**: 9 killed; 52 injured.
   - **What**: Washington Metropolitan Area Transit Authority (WMATA) train 112 collided into the back of train 214, which was stopped on the tracks. The back car of train 214 telescoped about 63 feet into the lead car of train 112. Damage to train equipment exceeded $12 million.
   - **Why**: A track circuit component meant to detect trains failed where train 214 was stopped. Train 214 was essentially invisible to train 112 and train 112 was commanded to continue going into the back of train 214.
   - **Preventable**: Yes, WMATA was using an outdated system of a train control system known as the automatic block system which implements on track circuits to record where trains are located so that only one train can occupy a block at a time. PTC would have prevented this accident since it relies on GPS and wireless communication.

4. - **Where**: December 1, 2013 in Bronx, New York.

- **Casualties**: 6 killed; 61 injured.
- **What**: The Metro-North Railroad passenger train derailed at a left-hand curve. Damages exceeded $9 million.
- **Why**: The train derailed because the train was moving 82 mph, significantly faster than the imposed maximum speed of 30 mph. The operator responsible had recently complained about fatigue due to his shift schedule which likely caused his lack of awareness when changing the speed of the train to make the turn.
- **Preventable**: Yes, The NTSB report states that the implementation of PTC could have prevented this incident (NTSB Metro North, 2014).

5.
- **Where**: May 12, 2015 in Philadelphia, Pennsylvania
- **Casualties**: 8 killed; 185 injured.
- **What**: Amtrak passenger train 188 derailed going 106 mph around a curve that was restricted to 50 mph. Damages exceeded that of $31 million.
- **Why**:The accident was likely due to the operators loss of situational awareness since he likely do not intend to accelerate the train to 106 mph. While operating the train, the operator, who was found to have a regular and healthy sleep schedule and never found to use his phone, was distracted by a conversation about an emergency on another nearby train where the window of a Septa train shattered which sent glass into the eye of that engineer. This conversation occurred between 9:13 and 9:19 PM and the derailment occurred at 9:21 PM. The operator admitted in an interview three days after the incident that he was distracted by the conversation and was worrying about his own safety since he was travelling in a nearby area.
- **Preventable**: Yes, contributing to the cause was the "lack of positive train control system" (NTSB Philidelphia, 2016).

6.
- **Where**: December 18, 2017 in DuPont, Washington.
- **Casualties**: 3 killed; over 100 injured.
- **What**: An Amtrak passenger train derailed on its inaugural journey, sending 13 of its 14 cars off an overpass and onto rush hour traffic below.
- **Why**: The train was travelling 80 mph in a 30 mph zone. The train engineer told NTSB reporters that he mistook a signal and only braked moments before the crash.

- **Preventable**: Most likely, this incident is still being investigated by the NTSB (Hanna and Criss, 2018).

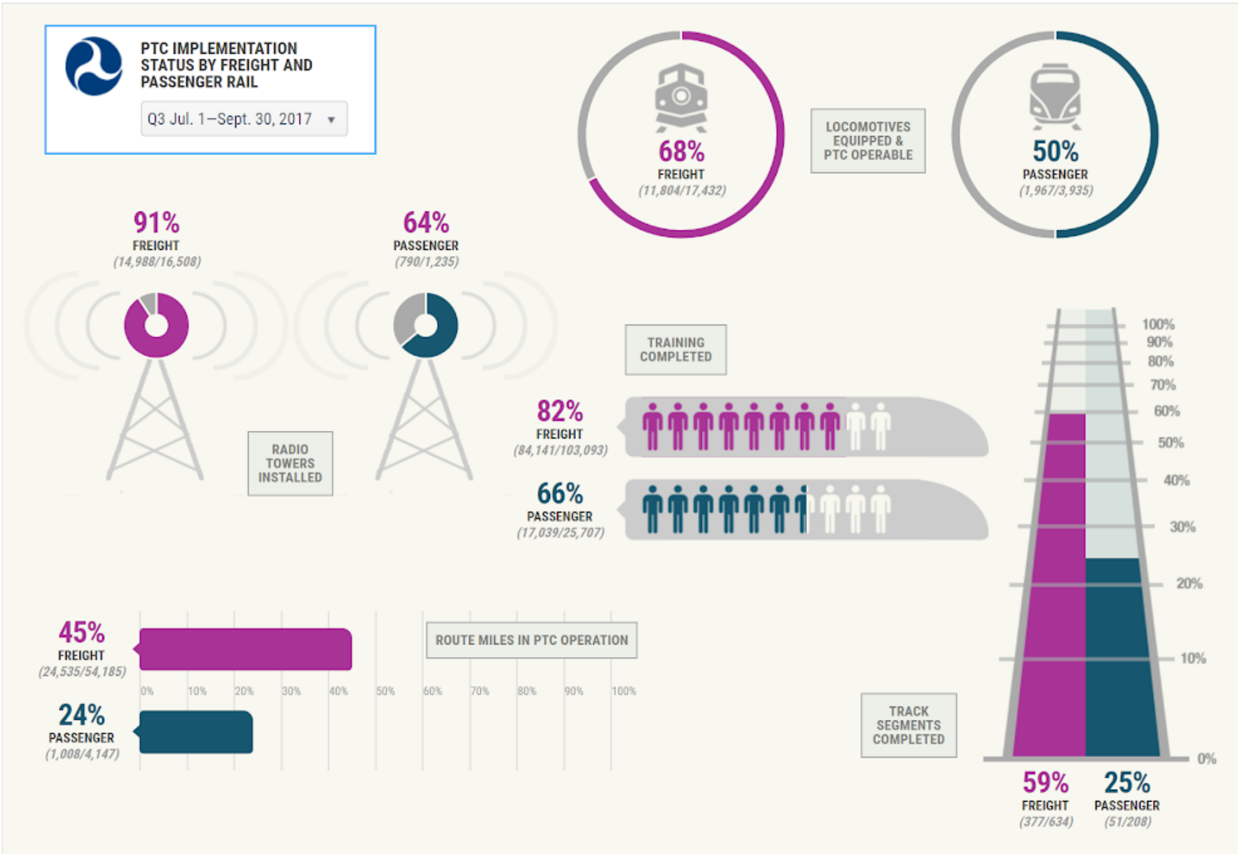

Figure 1: Total national PTC adoption progress as of September 30, 2017 (FRA PTC Implementation, 2017).

2.2 Current Adoption

With the implementation of PTC, these lives would have been saved. The lost lives cannot be brought back, but if PTC becomes universally implemented as soon as possible, then further casualties will be prevented. Unfortunately, however, most train companies have yet to fully install PTC, putting additional lives at risk. According to the FRA, as of September 30, 2017, only 64.4% of freight locomotives and only 43.8% of freight route miles in America are equipped with operable PTC; as for just passenger trains, only 50% of locomotives and 24% of route miles have PTC; see Figure 1 (FRA PTC Implementation, 2017).

2.3 Legal Coverage

Since train derailment due to driver error is such a common issue, laws have been passed to mandate the use of PTC. PTC had been listed in the "Most Wanted List of Transportation Safety Improvements" by the NTSB since 1990 (NTSB Most Wanted, 2007). However, no law was passed regarding it until 2008, nearly twenty years later. In October 2008, Congress passed Public Law 110-432: the RSIA. Many topics were addressed in this program, including railroad worker hours, standards for track inspection, and certification of locomotive conductors. However, the mandatory implementation of PTC was the most important part of this act. The RSIA required a plan of action from all railroads, provided technical assistance to accomplish PTC, demanded a 2012 progress report, and allowed Congress to penalize companies not complying with the laws. The RSIA also included provisions to provide economic and logistical assistance to railroads implementing PTC: a large loan, many grants, and a dedicated PTC task force to monitor and assist the rail companies (Congress, 2008). The governing body in charge of this process, the FRA, is a subdivision of the United States Department of Transportation (USDOT).

2.4 Deadline Extensions by Congress

Initially, the RSIA deadline for PTC implementation was December 31, 2015. When several major rail companies appeared to be behind schedule and asked for more time to install the necessary technology, Congress voted to move this deadline back to December 31, 2018. In the same extension, they included a possibility of a further extension through 2020 if railroad companies met certain requirements but needed still more time to finish PTC implementation.

The possible 2020 extension is based upon several criteria. Each railroad must give written notification that they have completed these steps to the FRA in order to be granted the extension and avoid daily FRA fines. By the end of 2018, railway companies must have installed all PTC hardware. They must have implemented PTC on a majority of territories and have made sufficient progress on employee training. Finally, the companies must submit a revised PTC Implementation Plan to the FRA to be fully PTC compliant by the end of 2020. As of September 30, 2017 (the most recent available data), many companies are making substantial progress toward these goals, yet they will likely need the additional deadline extension. Table 2 shows individual railway progress toward total PTC integration.

Table 2: Individual railroad progress toward PTC implementation as of September 30, 2017 (FRA Individual PTC Progress, 2017).

Railroad Name	Total Hardware Installed	Onboard Hardware Installed[2]	Wayside Hardware Installed	All Spectrum Acquired?	Sufficient RSD Initiated?	Employees Trained
Southeastern Pennsylvania Transportation Authority (SEPA)	100%	1,525/1,525	152/152	Yes	Yes	1,192/1,192
Sonoma-Marin Area Rail Transit (SMART)	100%	45/45	75/75	N/A	Yes	75/75
Regional Transportation District Commuter (RTDC) "Denver"	100%	264/264	228/228	Yes	Yes	120/120
Northstar Commuter Rail (NSCR)	100%	60/60	N/A	N/A	Yes	18/18
North County Transit District (SDNX)	100%	68/68	86/86	Yes	Yes	97/98
Portland & Western Railroad (PNWR) and TriMet (TMEV)	100%	68/68	20/20	N/A	No	30/32
Sounder Commuter Rail (SCR)	100%	128/128	24/24	Yes	No	2/4
Peninsula Corridor Joint Powers Board (PCMZ) "Caltrain"	100%	335/335	246/246	Yes	No	87/199
Terminal Railroad Association of St. Louis (TRRA)	100%	68/68	43/43	Yes	No	47/230
Denton County Transportation Authority (DCTA)	100%	44/44	121/121	N/A	No	0/50
Utah Transit Authority FrontRunner Commuter Rail (UFRC)	100%	120/120	96/96	N/A	No	0/200
Virginia Railway Express (VREX)	100%	164/164	N/A	N/A	To Be Determined	0/108
Southern California Regional Rail Authority (SCAX) "Metrolink"	99%	448/448	625/635	Yes	Yes	330/330
BNSF Railway (BNSF)	98%	19,396/20,000	13,627/13,735	Yes	Yes	21,877/21,877
Amtrak (ATK)	96%	1,968/1,968	591/689	No	Yes	9,817/10,985
CSX Transportation (CSX)	91%	8,000/8,000	5,019/6,248	Yes	No	18,711/19,234
Alaska Railroad (ARR)	90%	216/216	251/301	Yes	No	21/472
Union Pacific Railroad (UP)	86%	16,264/22,624	29,363/30,170	Yes	No	18,765/32,027
Kansas City Terminal Railway (KCT)	85%	8/16	48/50	No	No	0/14
Northeast Illinois Regional Corporation (NIRC) "Metra"	84%	1,727/2,112	721/789	Yes	No	545/1,801
Norfolk Southern Railway (NS)	83%	8,692/11,600	10,335/11,193	Yes	No	17,325/18,832
Canadian Pacific Railway (CP)	81%	1,630/2,020	2,219/2,732	Yes	No	1,564/2,775
Port Authority Trans-Hudson (PATH)	81%	1,095/1,150	1,625/2,210	N/A	No	910/910
Canadian National Railway (CN)	79%	2,651/2,930	3,928/5,378	Yes	No	4,150/4,603
Florida East Coast Railway (FECR)	72%	24/146	288/288	N/A	No	24/477
Kansas City Southern Railway (KCS)	69%	1,328/2,456	2,830/3,572	Yes	No	1,436/2,483
Belt Railway Company of Chicago (BRC)	63%	8/8	11/22	N/A	No	0/160
Metro-North Commuter Railroad Co. (MNCW)	62%	1,737/2,655	105/312	Yes	No	2,007/2,915
Long Island Rail Road (LIRR)	57%	1,571/2,900	210/210	Yes	No	1,207/3,194
Massachusetts Bay Transportation Authority (MBTA)	49%	730/985	128/760	Yes	No	215/932
Northern Indiana Commuter Transportation District (NICD)	41%	90/292	49/51	N/A	No	259/259
Central Florida Rail Corridor (CFRC) "SunRail"	39%	0/96	79/105	No	No	0/114
Consolidated Rail Corp. (CRSH)	31%	50/208	20/20	Yes	No	212/349
Maryland Area Regional Commuter (MACZ) "MARC"	29%	92/312	N/A	N/A	To Be Determined	0/100
New Mexico Rail Runner Express (NMRX) "Rio Metro"	9%	0/72	21/162	No	No	0/88
New Jersey Transit (NJTR)	7%	125/2,200	55/334	Yes	No	137/1,100
Altamont Corridor Express (ACEX)	7%	5/70	N/A	N/A	To Be Determined	0/16
South Florida Regional Transportation Authority (SFRV) "Tri-Rail"	4%	0/156	9/80	Yes	No	0/184
Capital Metropolitan Transportation Authority (CMTY)	0%	0/104	0/35	N/A	No	0/148
Nashville Regional Transportation Authority (NERR/NRTX) "Music City Star"	0%	0/70	0/147	Yes	No	0/15
Trinity Railway Express (TRE)	0%	0/68	0/89	Yes	No	0/80

2.5 Progress So Far

The RSIA requires many PTC components to be completed by all railroads: locomotive equipment, track segments, radio towers, employee training, and a PTC safety plan. These components must all be completed at the same location for a route mile to be considered "in PTC operation". The FRA has progress reports for all rail companies operating within the U.S. Amtrak, one of the most popular passenger railways in the country, has indeed made progress to complete implementation of PTC: 67% of its route miles are in operation, and more than 70% of locomotives equipment, radio towers, and training has been completed. In fact, the section of track where the deadly 2015 Philadelphia train crash occurred had the proper equipment installed. However, Amtrak had not conducted the tests needed to switch the system on. The accident was a result of human error and a lack of PTC, eight people were killed and an additional 185 were injured. Many other railroad companies are lagging behind Amtrak in PTC implementation, including multiple railways which have made no progress at all towards these goals.

3 Technological Issues

3.1 Basics of Railroading

The goal of train traffic control involves both *protection*, which ensures separation of trains and prevents conflicting movements that may lead to a collision, as well as providing additional control over the timing of movements in order to encourage *efficiency* (Bryan and McGonigal, 2006). As a mode of transportation, railroads are very different from cars or airplanes which gives them different kinds of safety issues:

1. *Excessive speed* can cause a train to lose control and derail. This is especially true on curved tracks, where the rails may not be able to handle the large centrifugal force of a turning train. Enforcing speed limits can solve this problem.

2. Because trains run on rails and cannot easily maneuver, train drivers can control the speed of a train but not its direction. Trains also tend to be heavier and have a much larger stopping distance. In many cases, it is already too late to stop a train when an obstacle comes into view. Because of this, *movement conflicts* are much more dangerous. Trains must be carefully scheduled to avoid head-on and rear-end collisions, as well as collisions at crossings.

3. In addition, railroad junctions are controlled by switches, which are mechanical devices that control the turning direction of a train. A switch must fully move into place in order for a train to proceed in either direction. A switch can be *misaligned* and cause a train to derail if it is not in any of these set positions. In addition, switching a train onto a wrong track can lead to collisions and overspeed conditions. We will refer to these two conditions collectively as *improperly aligned switches.*

4. *Mechanical failure* of the rail, car wheels, or brakes, as well as obstruction of the tracks, can lead to derailments and collisions. These failures can be caused by design defects as well as improper maintenance procedures.

Railroad companies must work to solve these problems before attempting to increase operational efficiency, or trying to safely schedule as many trains as possible. These two goals are often at odds. Scheduling trains more often can increase efficiency, but this leads to reduced spacing between trains and an increased chance of a collision. Because of this, train control often involves a comprehensive coordination between multiple operating segments, each responsible for different functions: *detection*, *processing*, *communication*, and *enforcement*. The first three together are often known simply as *signaling*. A typical division of labor looks like the following (Association of American Railroads, 2018):

1. *Wayside* and onboard segments, consisting of personnel and equipment that sense and controls train movement:
    (a) The wayside segment consists of track-side equipment and personnel, including equipment that monitors track conditions and occupancy, as well as switches that divert movement.
    (b) The onboard segment consists of the train crew, sensors that determine the status of a train, and enforcement devices.
2. The *central office* (a.k.a. *back office/dispatching*) segment makes use of the collected information to direct movement.

Operations on any of the above segments can take place at various levels of automation. They can range from being entirely dependent on manual operation, manually operated with an automated system as an emergency fallback, or even fully automatic.

Together, these segments perform the functions of detection, processing, communication and enforcement. Even though responsibility for controlling communication is typically distributed among segments, the most technically challenging aspect is the communication between ground stations and the moving train. We will focus on this aspect in the following discussion.

3.2 Signaling Technologies

3.2.1 Detection

Many methods exist to determine which train occupies which stretch of track. The earliest systems relied on verbal communication between train operators to establish occupancy of a block, as well as the location of individual trains (Bryan and McGonigal, 2006). Later, more automated detection systems came along. These systems are further divided into *wayside-centric* or *train-centric* systems.

In a wayside-centric system, devices installed along the tracks are responsible for detecting the presence of a train. These devices, such as track circuits and axle counters, can determine occupancy for fixed stretches of track. These sections of track are known as blocks, and wayside signals form the backbone of *fixed-block* signaling systems (Pascoe and Eichorn, 2009). Although track circuits do not directly identify individual trains, this data can be combined with information about when and where a particular train departs and arrives to infer its location.

By contrast, in train-centric detection, the train itself is responsible for collecting its location data. Automatic positioning of individual trains can be performed with the assistance of transponder systems installed along tracks. When a train passes over a transponder, the device is activated and sends its location to the train. Positioning can also happen via other means, such as by using GPS. Typically, the location signal is first received by onboard devices, which then transmit it to a dispatch center. In practice, these absolute positioning devices are only activated intermittently because they are supplemented by devices that collect relative location data such as speed or acceleration. Therefore with train-centric detection, a train's location can be known with more precision than by using fixed-block methods. This forms the basis of Communications Based Train Control (CBTC), which is a more modern form of train control (Pascoe and Eichorn, 2009).

Train control systems also use other types of data to ensure safety. Onboard train equipment can collect speed information that is used to enforce speed limits. Also, track-side devices can detect safety hazards on the tracks. For example, some track circuit systems can provide limited detection of broken track rails which disconnect the circuit. Similarly, slide fences—barriers which form electrical circuits that are easily broken or displaced—are used to detect falling rocks. Other types of devices detect overheating wheels and brake problems, which when untreated can cause a train to derail (Bryan and McGonigal, 2006).

3.2.2 Authority Generation

Given that trains move on predetermined tracks, more precise prediction of their positions over time is possible as opposed to a self-driving car on a free road where the next course of action is less deterministic. This paves the way for dispatching systems in which we coordinate multiple trains in the same railroad system.

The earliest form of train dispatching heavily relied upon timetables, which specified in advance where trains should be at key moments in time. These systems were not very flexible, and often had to be augmented by additional communication in order to cope with delays, breakdowns and other "unforeseen circumstances" (Bryan and McGonigal, 2006).

More sophisticated dispatch operations are based on the dynamic generation of movement

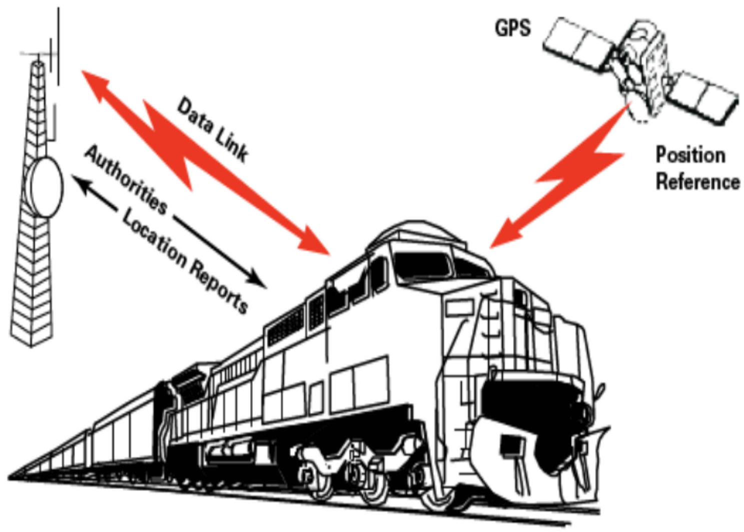

Figure 2: Implementation of GPS-based train-centric positioning (Badugu and Movva, 2013).

authorities. These authorities are permissions for a train to proceed through a block (Lindsey, 2009). For safety reasons, these blocks are made long enough so that trains have enough space to stop before reaching the end. The use of dynamic movement authorities allows for more flexible and efficient train control.

In addition, authority generation can be discrete or continuous (Pascoe and Eichorn, 2009). As the names suggest, the former is based on fixed section of railroad tracks while the latter works arbitrary sections of rail. These lead to two signaling systems known as fixed-block signaling and moving-block signaling, respectively. In these systems, only one train is allowed to occupy a block at a time. If a train attempts to move into a block that is already occupied, operators signal for the train to stop until the block becomes vacant again.

Signals that indicate authority can either be permissive or absolute. Permissive signals focus on protection, whereas absolute signals also focus on efficiency. The dispatch process can be fully manual, in which an operator would be physically responsible for pulling the levers that control the switches and signal indications. This process can be augmented by a mechanical or computer-assisted conflict checking device to protect against human error (Lindsey, 2009). It is typically done in a control center, but sometimes track-side equipment also generate permissive signals, which are used as a fallback (Bryan and McGonigal, 2006).

3.2.3 Delivery

Once the movement authorities are generated, they need to be communicated to the train crew and onboard equipment. Communication can be accomplished in a fully manual fashion, in which dispatchers would issue verbal instructions to the train crew in person or over radio. More mechanized systems such as wayside signaling are also commonly used. This method uses fixed track-side equipment that provides direct visual indication to the onboard crew. In addition to movement authorities, the train crew also need to know about speed restrictions, which can vary based on track maintenance conditions. Traditionally, this was accomplished using verbal communication and/or speed limit signs installed along the tracks (Pascoe and Eichorn, 2009).

Figure 3: A speed limit sign (Graf, 2013).

In contrast, *cab signaling* relies on electromagnetic means such as magnetic induction or radio to transmit signals and speed limit information, giving it numerous advantages over wayside signaling. Signals will be shown on an onboard display, which is convenient for train drivers as they no longer have to rely on spotting wayside signals. Additionally, they do not need to worry about accidentally missing a signal, as happened in the Dupont derailment (NTSB Washington State, 2018). Cab signals can be easily processed by other onboard equipment that performs automatic enforcement, providing more sophisticated protection against human error. In addition, this can help reduce costs for track-side equipment because the same transponder systems used for detection can be used for signaling as well. Cab signaling can either replace wayside signaling or function alongside it as an additional protective measure (Bryan and McGonigal, 2006).

3.3 Signaling Systems

We have examined the individual technologies required to perform some basic functions: detection, processing, communications, and enforcement. These technologies combine to form train control systems. We will now look at these systems, first from the perspective of signaling. Then we will consider how enforcement technologies interact with the rest of the system.

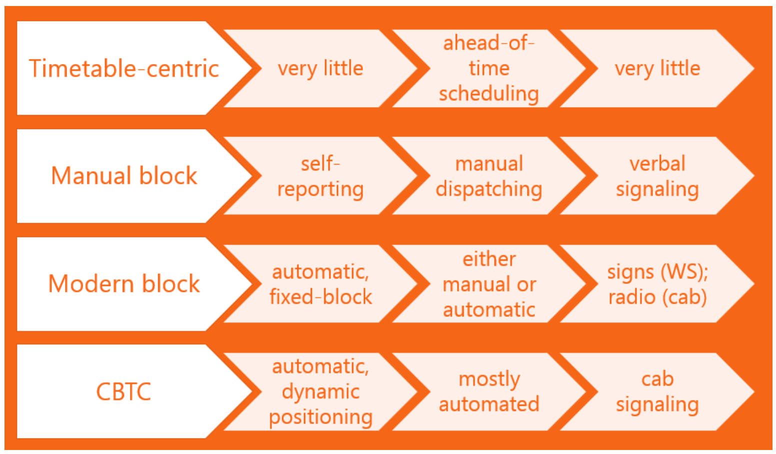

Figure 4: Overview of signaling technologies.

3.3.1 Manual Signaling

Early train traffic control systems were largely manual. Examples include the manual block system, in which human operators would set wayside signals. Another is the track warrant control system, where a train crew is responsible for reporting its location to a dispatcher. The dispatchers grant authority for movement over radio or phone. Although these systems could operate safely, they were also inefficient, prone to human error, and had limited hazard detection abilities. Today, they are typically used on railroads that do not see a lot of traffic.

In North America, significant areas rely on the aforementioned manual systems, as they do not have any modern signaling equipment or automatic detection systems installed. These sections of rail are known as dark territories. As of 2012, dark territories comprise approximately one-third of all railroad routes by length in the United States and Canada (Raymond, Lindsey, and Pachl, 2012). One source, a 2011 presentation by the Dark Territory Working Group of the Federal

Railroad Administration, estimates the amount of dark territory in the U.S. to be even higher at about 54% (FRA Dark Territory, 2011).

3.3.2 Modern Fixed-Block Signaling

Modern fixed-block signaling, also known as Automatic Block Signaling (ABS), originated in the early 20th century. Instead of relying on verbal communication, it uses detection devices such as track circuits to determine the presence of trains. These automatically operate signals that instruct trains to proceed, stop, or proceed with caution. The first generation of modern fixed-block signaling systems transmitted these signals as wayside signals. Later generations introduced the use of cab signals that could also send speed codes or profiles to the train (Morar, 2012).

The partial automation of train control provided by ABS allows for greater capacity of trains on a given track, which leads to increased efficiency. ABS can replace manual signaling entirely, or it might function as an additional protective layer on top of manual signaling. In this hybrid setup, the ABS signals create an additional level of redundancy which protects against operator error and equipment failure (Lindsey, 2009). This comes at the cost of increased operating and equipment expenses.

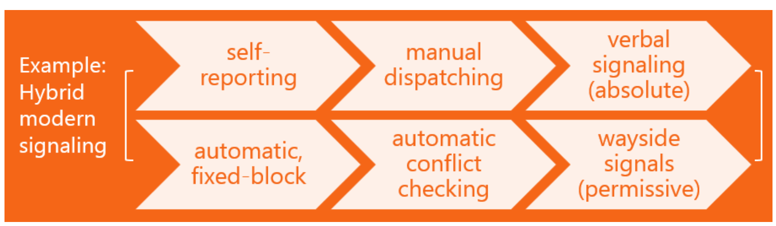

Figure 5: Hybrid fixed block signaling, with a manual system generating absolute signals and an automated system generating permissive signals.

3.3.3 Communications Based Train Control

The newest generation of signaling systems, known as CBTC, breaks from the tradition of fixed block systems. CBTC uses train-centric detection and dispatch technologies such as transponders or GPS. It also uses a wireless network for communication between the onboard, wayside, and office segments. This places more responsibility on the onboard segment for detection and communication functions, and reduces the responsibility of the wayside segment. In addition, dispatching can be performed by an electronic system known as the zone controller. This system can check for conflicting movements, automatically issue signals, and manipulate track switches.

CBTC allows for fine-grained monitoring and scheduling of trains, which can lead to better performance. In addition, the reduced dependence on fixed mechanical equipment can increase maintenance flexibility. However, CBTC can also increase the system complexity and introduce more potential safety concerns, especially if the wireless networks are inadequately secured. As with modern block signaling, CBTC can either replace an older fixed-block system or function alongside it.

Modern signaling systems are very common in North America. About half of all routes use full ABS, CBTC, or some combination of the two, and an additional one-sixth use the aforementioned hybrid manual-ABS setup. Almost all European railroads use modern signaling systems (Raymond, Lindsey, and Pachl, 2012).

3.4 Train Protection Systems and the Technology Behind PTC

3.4.1 Train Protection

Historically, human train operators have caused many deaths due to preventable mistakes. Automated mechanisms can provide additional protection against this human error. They can work to prevent accidents due to missed signals, movement violations, or improperly aligned switches. Some of these systems merely provide a warning to the train driver, while others can also perform an emergency stop (Connor and Schmid).

These form the basis of train protection systems, which are mainly intended to provide enforcement for train signals. One well-known protection system is based on the trip stop, a mechanical contraption installed along the tracks at a wayside signal. If a train passes the signal while it says to stop, the trip stop triggers the train's emergency brakes (Connor and Schmid). Other more sophisticated train protection systems can guard against both movement and speed violations by using information from the train itself.

3.4.2 Positive Train Control

PTC is the modern evolution of train protection systems. As required by federal regulations, the PTC system must determine and prevent the following types of safety issues:

1. Possible train-to-train collisions,

2. Overspeeding,

3. Improperly aligned switches,

4. Incursion into work zones without prior authorization, which can endanger maintenance workers as well as the train itself.

When PTC detects any of the above conditions, an emergency train stop will be initiated if the train crew does not quickly act to correct the issue. In addition, PTC will reduce speed in places where the railway infrastructure is considered unsafe (Government Publishing Office, 2018).

As with typical train control systems, conflict checking is done from a control center which monitors the locations of each train in the rail system. Communication between the control center and trains is achieved through wireless networks, allowing a control center to cover a large number of moving trains in a given system. The central authority issues movement authorizations for each train based on their relative locations. If a train begins to move outside its authorized movement zone, the control center will issue a warning to notify the train operator, who should correct the train's movement. If the engineer does not do so, the control center will give a signal for the train to automatically brake.

Onboard computers store speed limit profiles for the train tracks and information about the train's stopping capabilities to make these calculations (Badugu and Movva, 2013). Because this feature can be implemented onboard, constant communication with the central authority is not necessary to enforce speed limits. The central authority is only necessary to update stored speed limit profiles, which may be done intermittently.

The control center can also monitor track circuits, wayside signals, and switches on the tracks to prevent crashes. By doing so, the control center can detection more hazards on the tracks and stop trains in more cases. However, this is an optional part of PTC and is not necessarily present in all PTC systems. PTC cannot detect some hazards such as obstructions, flooding, or broken rails without knowledge of track circuits.

3.4.3 What PTC is Not

There has been some confusion regarding what PTC means. Some may assume it focuses on improving efficiency, possibly due to confusion with Precision Train Control (Lindsey, 2009). Other sources suggest that PTC always involves wireless networks and GPS (Badugu and Movva, 2013). In both these cases, PTC is conflated with CBTC technology. In reality, PTC is not required to be tied to specific types of detection and signaling technologies, as long as they can fulfill the requirements outlined by Congress.

Different technologies such as GPS or wireless location devices along the train tracks can be used for locating trains. This means PTC implementations can use newer CBTC signaling technology, or they can be implemented on top of traditional fixed-block signaling (Vantuono, 2016). An example of the latter is Enhanced Automatic Train Control (E-ATC), approved by the FRA in 2016.

In addition to this, PTC systems that use CBTC can be deployed alongside a fixed-block signaling system that generates absolute signals. This architecture is similar to that of the hybrid ABS system mentioned before. Essentially, these systems use CBTC to perform permissive signal generation, creating redundancy in signaling as well as enforcement. Figures 6-8 show that the implementation of PTC can take a variety of forms with different degrees of automation and redundancy. These differences lead to different safety and cost profiles.

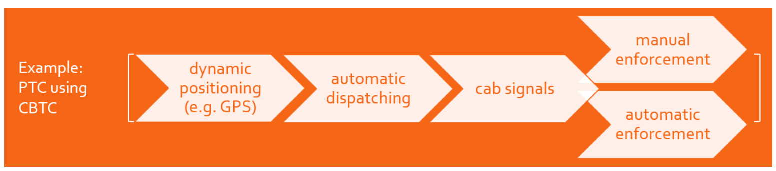

Figure 6: PTC system that completely relies on CBTC and automatic dispatching

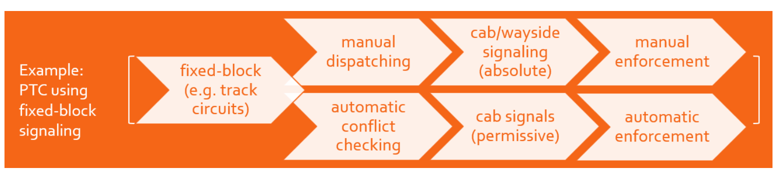

Figure 7: PTC system that completely relies on traditional fixed-block signaling, and uses manual block dispatching for normal operation.

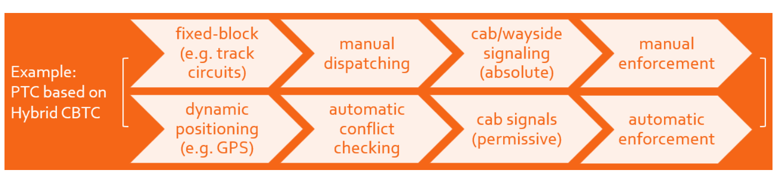

Figure 8: PTC system using CBTC for automatic signaling and enforcement, and traditional fixed-block signaling for manual operation.

3.4.4 PTC vs. Older Systems

PTC can be compared to conventional train protection systems such as Automatic Train Stop (ATS). Like PTC, ATS is defined in federal regulations as a system that performs an "automatic brake application" when approaching a block with "restrictive block conditions" (Government Publishing Office, 2018). These conditions account for occupied blocks, partially aligned switches, and excess train speed. However, ATS and ATS have less stringent safety requirements than PTC. For example, they are not required to handle work zone situations. In addition, ATS and ATS are based on fixed-block systems by definition. Compared to these older systems, PTC is safer and more flexible.

3.5 Technical Challenges of PTC

3.5.1 Negative Performance Effects

A concern about implementing PTC is whether or not it will negatively affect railway performance. Although PTC might provide greater safety, it could also be too restrictive and unnecessarily slow down trains. In the past, "the freight railroad industry has been reluctant to fit speed control devices due to the often heavy-handed nature of such devices having an adverse effect on otherwise safe train operation" (Badugu and Movva, 2013). Historically, trains have relied only on signals and human judgment to ensure safety. If trains have been operating safely this way for decades, why limit the power of train operators who are experienced in properly controlling their vehicles? Implementing PTC may mean that train operators must slow down when they know that it is safe to proceed, reducing the efficiency of a railroad line. The FRA has recognized this challenge, and even admitted in 2009 that "PTC was in fact likely to decrease the capacity of freight railroads on many main lines" (Badugu and Movva, 2013). Thus engineers must work to design PTC systems that allow for the same, or even better, levels of efficiency as that of signaling systems without PTC.

3.5.2 Robustness and Reliability

PTC systems also need to be robust against unpredictable factors ranging from unintended disruptions to hacking. Because PTC relies on wireless signals for communication between trains and a control center, it must account for these situations. Wireless signals tend to behave inconsistently and cannot be relied upon to be active at all times. So designers of PTC must ensure that there are fallbacks when wireless signals cannot be received. Using PTC as an additional measure on top of another signaling system ensures that there is enough redundancy to avoid collisions even when PTC cannot work. Additionally, the control center must be able to identify any train that has gone offline so that it can be brought back as soon as possible. The system must be able to tolerate broken components and be easily repaired.

Hacking is another major issue with the development of PTC. Engineers must take adequate safety measures to prevent unauthorized tampering with PTC signals. If an attacker could falsely tell a train to stop or send false locations signals to a control center, he could cause derailments and collisions. Railroad technology has been vulnerable to attack in the past. In 2008, a teenager was arrested for tampering with the streetcar system in Lodz, Poland. He had reverse engineered the signals used to control track switches and caused derailments by changing the switches to point the wrong way (Sweeney, 2014).

3.5.3 Interoperability

PTC has various implementations, so different companies may have incompatible PTC systems. Because trains owned and managed by different companies often share the same stretch of tracks, PTC systems must be designed for interoperability in order to function together effectively (Sweeney, 2014). Otherwise, it could be possible that a PTC system does not account for trains from different companies and fails to apply brakes correctly. This could lead to collisions that PTC should have prevented. To avoid this, engineers should eventually work to make PTC compatible across all railways.

Currently a unified PTC system is not feasible due to the state of PTC adoption. Some rail companies have almost completely implemented PTC, while others have virtually no PTC. Additionally, rail companies would not want to share design details for PTC with their competitors. They have no business incentive to do so. One way to increase PTC compatibility across different companies is for engineers to come up with standard operating interfaces for PTC systems. This makes it easier for companies to independently follow compatible design principles.

4 Ethical and Social Issues

4.1 Cost and Funding

Implementing PTC country-wide is indeed a technical challenge, but not one that cannot be overcome with enough money and time. The greater challenge is to overcome the associated societal challenge, that is, find the source of money. Having mentioned all the potential of PTC, especially in terms of lives to be saved, it is surprising PTC is still open to heated debate for financial reasons. Having covered the technological issues, we know why it will cost billions for a system that interoperates and agrees with the standards of various railways companies. Yet if we continue to delay implementing this, we will lose more lives to simple human error. We mentioned that some train derailments have been caused by something as simple as an easy-to-identify locked rail switch (Chatterjee, 2008) or by an operator texting and overlooking wayside signals. The solution is to overcome the money barrier and support investments that are pro-PTC.

In any human endeavor, human error is unavoidable and should be replaced by tested automation if possible. During the Metrolink train collision in Los Angeles, the engineer who was texting made a human error that caused the death of 25 people (Chatterjee, 2008). This could have been prevented if an automated system to stop the train had been in place. As mentioned in the signaling technologies section, the fact that trains move only on predetermined tracks makes their movements easy to identify, in contrast to something such as a self-driving car. This makes train control a good candidate for automated control. However, even PTC comes with its own technical challenges: "Railroads have had to develop highly complex braking algorithms for both freight and passenger trains that account for numerous factors, and not just the obvious ones like velocity, track gradient or weight. We need to account for outside elements like weather, the brake systems installed on different rail cars and the fact that railroads rely on customers for cargo weight data" (Young, 2016). Not only overcoming these aforementioned technical challenges but also getting people together to solve such a problem makes designing PTC a difficult feat.

For this reason, designing PTC is very costly which discourages railroad companies from implementing it in a timely manner. After the above-mentioned Metrolink accident, Congress gave railroad companies a deadline until 2015 to implement PTC in their lines in the RSIA. However, this deadline got postponed to 2018. In the meanwhile, track derailments continued to take lives (Graham, 2017). Train commuters were injured and killed in Washington because rail companies thought that PTC was too costly to implement on time. The main expense of PTC is the development operations and the research on the technology. Development increases the costs tremendously as opposed to existing solutions that can be simply bought from a third party, since PTC is not a readily-developed, commonplace technology. There are many different cost estimates for building PTC, ranging from \$6 billion to \$22 billion (Cullen, 2018). This variation is due to the nonstandard type of implementation, which also suggests how the PTC implementation for each railway company will vary. As a result, unpredictability of the costs makes it very difficult to set a budget. More importantly, since the federal deadline to implement PTC is lenient, the project can take a while. However, projects that go overtime also go over budget, which can add to the predicted costs.

Funding from the government could play a huge role in delivering PTC sooner and therefore for less money. Unfortunately, the current government funding is oftentimes a small fraction of the total cost of implementation. For instance, the USDOT granted \$197 million for the development of PTC to 17 regional transportation authorities in the U.S. The largest of these grants gave \$33.75 million to the New York State Department of Transportation (USDOT FRA, 2017). Considering the scale of the billions of dollars that are necessary to implement a PTC system, these grants in the scale of tens of millions of dollars are insufficient. There is an urgent need to implement PTC, and a desire to overcome the economic barrier needs to meet this urgency.

Considering the value of human life against economic convenience for rail companies creates an ethical dilemma. Since these factors are hard to weight objectively, it brings about the question: what is the price tag for human lives? We can attempt to answer this question using duty ethics as the ethical framework. Duty ethics, by definition, is the "the class of approaches in ethics in which an action is considered morally right if it is in agreement with a certain moral rule" (Poel, 2011). The relevant moral rule in this case is to uphold the protection of human life as the most important virtue. The mere premise of PTC is to prevent fatal crashes, so our attitude towards the speed of implementing it should align with this concern. Money cannot be valued at the expense of human lives, because the role of money is to bring welfare to all of humankind.

Another ethical problem involves the use of proprietary PTC implementations. If rail companies were required to share their PTC implementation details with each other, this could reduce the overall cost of implementing PTC for everybody. Union Pacific, for instance, has equipped over 98% of its overall infrastructure with PTC (Union Pacific, 2018). If Union Pacific shared implementation details of this technology to other railroad companies, they would have to spend less on research and development of PTC. Of course, Union Pacific has a financial incentive to protect its technology with patents. It is not financially beneficial for one railroad company to make anything easier for a competitor.

The ethical consideration is the decision between sharing PTC technology to save the lives of train passengers or to keep the technology private for financial benefit. The ethical framework of utilitarianism best addresses this dilemma. Utilitarianism is an ethical framework in which actions are judged by the amount of pleasure and pain they bring about and the greatest happiness for the greatest number is preferred (Poel, 2011). Based on this principle, the decision to keep PTC technology proprietary can be explained through the incentive to have safer trains than competitors. This turns into financial benefit, and higher earnings means increased overall happiness of Union Pacific executives and employees. However John Stuart Mill has his own take on the extent of utilitarianism and the happiness it brings. He coined the "no harm principle" which is defined as "the principle that one is free to do what one wishes, as long as no harm is done to others". According to the no harm principle of utilitarianism, no ethical decision should harm human life. But keeping PTC proprietary goes against this principle, as it endangers human lives. Union Pacific causes deaths by keeping its PTC implementation proprietary, because it fails to prevent avoidable train accidents. To meet the no harm principle, Union Pacific should open-source its PTC implementation so that other railroad companies can reimplement the technology rather than developing their own. Making this decision will not only reduce the cost of PTC but also make its country-wide adoption much faster. Such a decision can prevent the next tragedy preceding the adoption of PTC by other railway companies.

4.2 PTC is Not a Silver Bullet

We have already seen that PTC by itself does not necessarily detect some hazards such as rockslides and broken rails, since federal regulations do not include that as part of PTC. But there can be additional loopholes in the protection provided by PTC, which can still allow accidents to happen.

An example is the 2012 derailment of an Amtrak Wolverine train in Niles, Michigan. A maintenance worker had attempted to manually correct a malfunctioning switch to its normal position; however, the switch had moved into the opposite position, which would divert the train into a nearby train yard. The maintenance worker failed to confirm the location of the switch, instead assumed it was in the correct position, and then used a jumper cable to bypass a switch alignment detector (NTSB Niles, 2013). The goal was probably to get the switch to show up as correctly aligned, so as to allow the next train to pass, before further investigating a possible detector error.

The train system used a variant of PTC called Incremental Train Control System (ITCS); however, since the sensor was manually bypassed, it did not detect the incorrect alignment. The inbound train was allowed to proceed, traveling at 60 mph; upon reaching the switch, it was unexpected diverted into the train yard (which had a speed limit of 30mph), derailed because of its high speed, and nearly collided with parked train cars (Vantuono, 2016).

This incident is a clear demonstration that PTC is not a silver bullet that can protect against every case of operator error. The reality is that all systems are probably bypassable; it would be very inconvenient if this was not the case, since repair or maintenance work, as well as system upgrades, would require at least temporarily bypassing its protections. However, the worker mentioned above did not observe proper operating procedures (which involved double-checking with his supervisor), nor did he exercise enough caution in the process.

We can examine the ethics of this action using the framework of duty ethics, which is is defined as "the class of approaches in ethics in which an action is considered morally right if it is in agreement with a certain moral rule" (Poel, 2011). There is often a trade off between convenience and safety in engineering. Maintenance procedures on critical systems are often complex and include multiple safeguards to ensure safety. The reciprocity principle of duty ethics, which states that people should not treat one another as mere means, suggests that we should value others' welfare. In this case, railroad employees have a duty to ensure the safety of the passengers and train crew.

According to the NTSB investigation, the maintenance worker in question seemed to have been in a hurry to attend a family event later that day, and could have been frustrated with having to troubleshoot a switch malfunction (NTSB Niles, 2013). He likely chose to bypass proper operating procedures for his own convenience, endangering the passengers and train crew in the process.

The solution to this problem should be socially oriented. Railroads should continue to put focus on their safety education programs to raise employee awareness. Proper operating procedures must be established for maintenance work, and manual bypassing of the system must be considered an exceptional, last resort action. In addition, institutional and infrastructural changes can facilitate caution; PTC systems can be designed in a manner to discourage tampering, possibly by making it inconvenient to do so. For example, this could involve requiring multiple keys to open the equipment box, to discourage employees from taking unilateral action.

4.3 Safety and Reliability Issues

PTC will require all trains on a railroad network to relay information about their current location and speed such that a potential crash can be programmatically detected and prevented. This introduces a concern for information security and terrorism prevention, and forces individuals to make a decision between opaqueness and transparency. In traditional database systems, large amounts of data are usually centralized and then relayed back upon querying by clients. The safety of this data depends on the security of the database and the database-client communications.

4.3.1 Potential Form of Attacks

Since signals between the control center and trains are wireless, an attack can be in the form of spoofing or disrupting the signals. If attackers spoof a signal, they could potentially issue incorrect movement authorizations that cause trains to collide with each other. Alternatively, they could simply interfere with signals so that the PTC system no longer works. This could cause major disruptions to service, loss of life, and monetary damage. Thus it is critically important to protect against these types of attacks.

4.3.2 Expert Commentary on the Risk of Breach

In modern PTC systems, there is a "lack of formal, industry-wide network security standards", which poses a major issue for achieving protection (Morris, 2016). Instead, each PTC system can set its own security standards, which may not be adequate to defend against attack. The issue of hacking is notorious for being a widespread problem in the internet age, where major data breaches occur almost every year. Almost anything that relies on wireless communications can be attacked, and the lack of consistent security standards leaves the rail system extremely vulnerable. One security researcher with the U.S. Industrial Control Systems Cyber Emergency Response Team (ICS-CERT) has warned that the "chances of a breach are dangerously high" in PTC systems (Emley, 2016).

4.3.3 Ethical Analysis of Security

With this risk in mind, train companies must decide whether it is better to expedite the implementation of PTC, opening up avenues to attack, or to selectively implement it after adequate security developments have been made. In this consideration, security implementations are more important than implementing a vulnerable PTC posthaste. It is important to realize that the main premise of implementing PTC is to prevent deaths; deploying a system can be hacked defeats the purpose of implementing PTC to begin with.

We can again summon duty ethics for this instance. Our duty here is to do our best in equipping our PTC systems with the current security technology we have and not rush a PTC implementation to merely meet a deadline and risk people's lives to potential cyberattacks. Although some train derailments could occur if PTC is not implemented in time, many more could happen if the entire rail system has PTC and is attacked by terrorists. This would lead to more deaths and injuries than simply delaying PTC's deploy date until it is safe.

To prove our point, we can summon utilitarianism to analyze our two options. There is a negative utility for the unhappiness caused by the additional tragedies that will happen due to PTC's delay. On the other hand, there is a possibility of hackers wreaking havoc as we give them a system that makes it really easy for them to do so. The latter has the potential to cause more deaths than the former, since a system-scale abuse can cause the collision of many trains in a short time period. Therefore, overall humankind happiness will be maximized if PTC is delayed until adequate network safety standards are established.

4.4 Labor Issues in Train Operation

Some definitions of PTC are subjective and therefore vague, in which it is compared to the cruise control of a car or the autopilot mode of a plane. In fact, PTC is no more than an automatic braking system. It relies on real-time information from nearby trains, signal posts, current track information, and track curvature to identify if a slowdown is needed. It first warns the engineer in control so that the train can reduce to a safe speed. If the warning is overlooked, then brakes are automatically applied. In this scheme, there is still a need for an engineer to accelerate and decelerate the train, and make appropriate decisions.

4.4.1 Alleviation of concerns

Due to the above-mentioned misconception, a question raised against PTC is whether or not train operators will lose their jobs, which is of course ungrounded. PTC is expected to override the operator's decisions when there is potential for an accident, such as slowing down if the posted speed limit is not met. One recent crash happened because the train was moving in about twice the posted speed limit (Satlin, 2015). In the prospected PTC implementations, there is no plan that will completely automate train operations, hence engineers are still needed.

4.4.2 Improvement to labor economy

In fact, PTC can potentially add more jobs to the economy. Union Pacific has invested over $2 billion and hired about a thousand engineers to work on the development of PTC (Union Pacific, 2018). Therefore, PTC is in fact beneficial for labor economy: in addition to saving lives by preventing crashes, it has the long-term economic advantage of creating new jobs.

4.5 Legislative and Regulatory Issues

4.5.1 Congress delay

As discussed previously, legislation is in place to mandate all railway companies to adopt PTC soon. However, the deadline that Congress imposed with the RSIA in 2008 has been pushed back once already, and it now appears that it will be furthered delayed to 2020. Since its initial deadline of December 2015, there have been several fatal crashes that may have been avoidable if PTC was in operation on the trains.

4.5.2 Rights Ethics Application

The ethical framework of utilitarianism has already been described above. Another ethical framework through which decisions can be evaluated is Rights Ethics. Rights ethics deals with the rights that all people have. These rights may be given by social convention or by a legal system. The United States Declaration of Independence lists some of the country's legal rights; Thomas Jefferson and the other writers believed that every person has the right to "life, liberty, and the pursuit of happiness." We choose this ethical framework because modern problems involving government agencies frequently deal with rights ethics. For example, the Second Amendment causes fiery ethical debates on TV and on the internet daily. We will use a Rights Ethics framework to evaluate the previous actions and possible future improvements of Congress, the FRA, the NTSB, and the USDOT.

4.5.3 Current Progress

As seen in Table 2, many railway companies are making significant progress toward full PTC implementation. PTC significantly decreases the probability of human-caused train crashes by acting as an automated safety net in the case of driver error. The technology exists and, in many cases, is already working as expected. Railway companies which are not installing PTC as quickly as possible (or at all) are acting unethically by not doing everything possible to protect people's rights to life and safety.

4.5.4 Evaluation of Congress

By continuing to push back the deadline for PTC implementation, the U.S. government is also violating these rights. Congress initially gave railway companies over seven years to implement PTC. Congress and President Barack Obama then passed the two (or four) year extension in 2015 because railway companies were complaining about the high cost of implementation (Shaer, 2016). Since the first deadline, there have been at least four fatal passenger train wrecks in the United States. If the U.S. government had been steadfast in its initial deadline and done more to assist the companies in implementing PTC, these crashes may have been avoidable. Therefore, by not acting strongly enough in its stance on PTC, Congress and the major transportation agencies have acted unethically. They did not fully consider the possible injuries and fatalities due to PTC's slow installation.

5 Recommendations

5.1 Engineering Recommendations

5.1.1 Secure Implementation

We recommend that PTC be implemented only after adequate cybersecurity standards are put in place. Engineers must ensure that the wireless communication networks that PTC uses are not susceptible to attack. Protocols should exist to ensure strong encryption of train to control center communications, so that wireless data cannot easily be intercepted. Additionally, in the case that an attacker attempts to block communication signals, train operators should have a standard way of conducting their trains without PTC. There must be a failsafe to ensure that trains can safely return to a station without PTC. Even if developing and enforcing these standards slows down the implementation of PTC, engineers must ensure that PTC will not end up causing more harm than benefit. Preventing the risk of terrorists hacking and derailing PTC equipped trains is worth the effort.

5.1.2 Decentralization of Communications

Additionally, engineers could increase train cybersecurity by implementing a decentralized communication protocol. This model has pros and cons compared to a centralized system. In a decentralized PTC network, each train will regularly demand information from all the other trains in the network, which will be passed train-to-train until all the trains are up-to-date. This information can generally contain location, speed and the number of wagons, which may affect braking distance. Each train can analyze this information alongside their own speed and location to predict a chance for collision.

5.1.3 Pre-Shared Key Encryption

Security in a decentralized PTC network can be ensured by pre-shared key encryption. Essentially, trains in the network will receive a copy of a predetermined password and encrypt their communication with it and the same password can be used to decrypt this information. As a result, false information relayed by an attacker would be discarded as the attacker cannot know the pre-shared key. This pre-shared key can be decided and managed by a central authority, but the system will work without interference by this authority once all the trains are equipped with the key.

5.1.4 Comparison to a Centralized System

Such a security protocol will be safer than a centralized system where all trains connect to and receive information from the same server. The main reason is the power withheld by the said server makes it more attractive to attackers. If this central server receives a Distributed Denial of Service (DDoS) attacks (a set of attacks where the server is made unavailable to the trains due to an attacker issuing too many bogus requests into the communication channel), then the communication between all the trains is lost and the entire network is compromised.

Moreover, a centralized system will require perfect uptime and cannot be lenient on serving all trains in a timely manner. A few minutes of a lack of communication among all trains could mean the collision of two trains. In contrast, the unavailability of a single train in the network for a brief period is unlikely to be catastrophic, since communication among all the other trains is not affected. For these reasons, it is more meaningful to choose a decentralized, pre-shared key-encrypted system for train communication than a centralized one.

5.2 Railroad Companies and Management

5.2.1 Train Ticket Taxation for Funding

The need to develop PTC is urgent, and sharing the cost of the system with fellow train passengers is an effective way to raise money for it. Specifically taxation on train tickets is an effective way of raising money for the development of this system, in conjunction with train companies working together to develop a common PTC solution. This is feasible considering the amount that can be derived from a small increase per train ticket: for an average train ticket of $62, a 5% increase per ticket price (an average $3) for 31.3 million annual customers will incur about $100 million per year (Bellstrom and Wieczner, 2011). On its own, this is still not enough to feed a billion-dollar budget, but if all railway companies did the same, then there would be sufficient funding to cooperate a single PTC project for the benefit of all participating railways. Increasing the budget for railway security is the direction that many railway companies around the world are taking, especially India, which is a strong indicator for the direction that U.S. railways should take (BusinessToday.in, 2018).

Of course, the price increase won't be specific to Amtrak: this train ticket tax will be imposed on all railways that did not implement PTC yet. This condition will be an incentive for railway companies to implement PTC faster since they will want to lower their ticket prices.

5.3 Congress and Regulators

5.3.1 Increasing Funding

The main reason an extension was granted to railway companies was economical; the companies complained that the cost of PTC was too high. To prevent these types of complaints from arising again, regulators should find a way to further help the companies economically. As previously described, Congress has allocated some money to help companies throughout this process. However, this money is clearly not enough. The economics of PTC has been discussed at length above; it is sufficient now to say that the cost is extremely high. Regulators must set aside the necessary funding to assist railway companies in PTC implementation. This funding will come from the main source of Congress's funding: federal income tax.

5.3.2 Budget Increase

The FRA recognizes the need for immediate full scale PTC; much of their budget is typically dedicated to funding PTC implementation. In 2017, the FRA requested $3.7 billion from the government for the RSIA. $1.25 billion of this was to be set aside "for PTC implementation grants to commuter and short line railroads" (FRA Budget Estimates, 2017). However, the Congress granted a total of $6.6 million for PTC (Congress, 2017). This is a drastic reduction which will significantly hinder the FRA's ability to help railway companies. It is recommended that Congress begins to fund the FRA at the level they believe is necessary. PTC implementation only needs to happen once; a large windfall for one or two years will ensure that trains are all equipped with this important technology.

5.3.3 Rider's Right to know about PTC-equipped trains

Lastly, the FRA along with individual train companies have failed to be transparent about which trains have implemented PTC. Passengers have the right to know if they are boarding a train that has the best safety vehicles available. Therefore, it is recommended that regulators require train companies to place labels when customers purchase a train ticket to inform them if the train they plan on boarding is equipped with PTC and that the route they are travelling on is operating PTC fully. The labels would be similar to that of the warnings on cigarettes. The FRA is responsible for requiring train companies to implement PTC. By mandating transparency, train companies will feel pressure to further invest in PTC and implement the safety technology quicker since passengers will be more aware of the dangers and possibly more skeptical about buying train tickets. Only, 29.5% of railroad companies have submitted their PTC Safety Plan to the FRA as of September, 2017 (FRA Individual PTC Progress, 2017). Passengers should be informed if the train they are boarding is taking the appropriate measures to ensure that they are safe. With the potential of passengers feeling wary about riding on trains, they will look for other modes of transportation which will hurt train companies financially. With the potential loss of business along along with government laws, deadlines, and potential fines, train companies will be more incentivized to fully adopt and invest in PTC technology.

6 Conclusion

Train safety is an important issue because of the numerous injuries and deaths that have occurred in train collisions and derailments. There have been 147 deaths in the past decade due to preventable train accidents, and more will occur if train companies do not work to improve safety (Bureau of Transportation Statistics, 2017). It is urgent that we implement PTC to put an end to the majority of fatal train accidents. PTC will do so by controlling a train's speed and stopping train-to-train collisions. It takes away the possibility of human error, a major contributor to many train accidents.

However, legislators have delayed the implementation of PTC by pushing back PTC enforcement deadlines. Most railroad companies were expected to be using the technology by 2015, but Congress extended this to 2018 with a highly-probable extension to 2020. Further extensions may be necessary because PTC development efforts today are still too low. If railroad companies do not intend to create a safety culture, then this safety culture must be legally imposed. Yet by letting railroad companies continue to operate without PTC, Congress is leaving commuter safety to chance.

PTC adoption is imperative because the train industry currently uses decades-old technology to ensure safety, which is inadequate for today's world. Older systems such as the fixed block system rely on train operators paying attention to and correctly responding to wayside signals. This is not a robust solution because operators sometimes lose focus and fail to heed these signals, resulting in accidents. In general, any signaling system runs an unavoidable risk of human error. Although emergency measures such as trip stops offer additional protection against human error, they are inadequately implemented. Large sections of rail still rely only on signaling to prevent accidents. Tolerating even a single preventable train accident is one accident too many, because PTC exists and it can stop these tragedies.

The high cost of PTC has made railroad companies reluctant to implement it. To address this, we recommend for federally-enforced taxation to be imposed on railway companies that do not use PTC. These taxes will push companies to implement it sooner to reduce their expenses, as well as generate federal funding to help develop the technology. In addition to taxation, we also suggest that money generated from the federal income tax should be added to the PTC budget. We estimate that the combination of these two should generate the desired budget size to collectively implement an open-source PTC implementation for all railway companies to easily integrate.

Another issue with PTC is the potential for cybersecurity issues. Because PTC uses wireless communications between trains and a control center, this leaves trains vulnerable to hacking. Currently no consistent cybersecurity safety standards exist across different railroad companies, which is a major problem when designing PTC. If a train is hacked, the attacker could cause collisions or derailments. Because PTC should increase safety, not compromise it, we recommend that PTC is delayed until adequate cybersecurity measures are adopted. Train communications should be encrypted and there should be a way to recover from attacks. Since all valid trains should be known beforehand, each can easily be equipped with a secret key for encryption. Thus we recommend pre-shared key encryption to prevent potential attacks.

In the future, we can expect that PTC will become standard on all railroads. Other transportation methods such as cars and planes have increased safety standards over time, and trains should follow suit. Even today, many wonder why PTC has not been widely implemented. Trains are an easy target to improve safety, as they only travel on fixed tracks and are operated by professionals. For something that can be controlled so well, it is reasonable to expect that accidents such as derailments due to excessive speed and train-to-train collisions should not occur. But railroad companies will continue to drag their feet in this matter, as they do not want to change their current operating methods. Due to the cost of development and organizational inertia, they will likely ask for more deadline extensions before adopting the technology. But eventually the government must intervene and enforce the use of PTC in order to make trains safer for everyone.

To emphasize the urgency of PTC, we can argue the following: since we have the technology to ensure a higher standard of safety, it is an ethical responsibility to use it. This logic can be supported in different areas of work such as environment protection. For example, we make factories pay to implement scrubbers: filtering mechanisms that eliminate air pollution before it goes out of the chimney (Johnson, 2018). It is an ethical responsibility to keep our air clean, and we have a technological advancement to meet this concern. An example in building construction would be the safety harnesses, hard hats, vests etc. that workers are mandated to use according to the work they do, for the sake of their own safety. Why would we not want the same level of safety for our train-riding citizens when we have the capacity for it?

In short, PTC is a promising technology to ensure passenger safety in railways but we have yet to fully exploit it. It must first overcome financial barriers, receive more strict enforcement from Congress, adhere to modern cybersecurity standards, and be complemented with employee training and awareness programs to reach its full potential. In this report we addressed these problems and offer specific solutions, alongside their ethical implications. Now it is up to the decision-makers to help get things on track.

Definitions

ABS Automatic Block Signaling.

ATC Automatic Train Control.

ATS Automatic Train Stop.

CBTC Communications Based Train Control.

DDoS Distributed Denial of Service.

E-ATC Enhanced Automatic Train Control.

FRA United States Federal Railroad Administration.

GPS Global Positioning System.

ICS-CERT U.S. Industrial Control Systems Cyber Emergency Response Team.

ITCS Incremental Train Control System.

Metrolink Southern California Regional Rail Authority.

NTSB National Transportation Safety Board.

PTC Positive Train Control.

RSIA Railroad Safety Improvement Act.

USDOT United States Department of Transportation.

WMATA Washington Metropolitan Area Transit Authority.

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This check list, signed by a member of the team, is to be submitted with the Final Report.

- ☐ Printed one sided
- ☐ 1.5 Spacing
- ☐ 11 pt Times Roman or similar serif font
- ☐ Pagination
  (title page numbered "i" but not displayed; remainder of front matter numbered using small Roman numerals ii-. . . . . . ; first page of report numbered beginning 1 in the bottom center)
- ☐ Heading and subheadings throughout report (see sample passed around in discussion section)
- ☐ 7-9 pages of text per group member
- ☐ In-text citation format is that specified in Course Manual (e.g. (Jones, 2009) or some variant thereof). Other forms of citation (e.g. MLA or bracketed numbers) should not be used
- ☐ Bibliography is in the form specified in the Course Manual.
- ☐ Provide two copies of the report:
  - ☐ Bind one copy with a coil or comb binding (available any photocopy shop)
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- ☐ Due date is Monday, December 11, NLT 5:00 pm unless other arrangements are made.
- ☐ At the time of turn in, a box of large manila envelopes and bulldog clips (for the loose copy of the report) will be available outside of Boelter Hall 6417 for submission.

This report meets the requirements noted above

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