Train Control Assessment: Norristown High Speed Line

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File Name:	SEPTA Train Control Assessment – Norristown HSL Rev Preliminary Report for Release.pdf
Revision / Date:	Preliminary Report for Release/ March 23, 2018

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1 EXECUTIVE SUMMARY

Early in 2017, SEPTA contracted LTK Engineering Services (LTK) to perform a rail vehicle assessment for each of their rail car fleets, and in November 2017, SEPTA contracted LTK to perform an assessment of the train control features of their rail fleets, as well, including the Market-Frankford Subway Elevated Line, Norristown High Speed Line, Broad Street Subway Line and the Green Line. This is the first in a series of train control assessment reports for each of the lines, and this report covers the Norristown High Speed Line.

In 1991, SEPTA's Norristown High Speed Line (NHSL) received a new fleet of N-5 Vehicles. Concurrent with the introduction of this new fleet of rail cars, SEPTA installed a newly designed automatic train control system for the NHSL, including the wayside signal system and control lines [1] to accommodate the new fleet's performance characteristics.

LTK's train control assessment consisted of a document review, interviews with SEPTA personnel, a sample review of signal block and control line designs, an examination of the capabilities of the existing system versus contemporary train control technology, and instrumented field tests of one- and two-car trains to measure the functionality of the Automatic Train Control (ATC) system. LTK also developed a comprehensive test procedure to perform field tests over a 1.5 mile section of the 13-mile NHSL.

The functions and performance parameters, as defined in the Technical Specifications for the vehicles, most relevant to this assessment for the integrated Cab Signal System (CSS)/ATC system supplied on the NHSL rail vehicles are:

- The vehicle's ATC system allows for operation of two miles per hour (mph) [2] over the mandated speed limits.
- Once the ATC system detects overspeed, the system allows the operator three seconds to respond. During these three seconds, the train control system does not prevent the car from being accelerated.
- The vehicle can accelerate at rates in excess of three mph per second, particularly at speeds of about 35 mph or less.
- If the operator does not acknowledge overspeed with a proper brake application within three seconds of the detected overspeed condition, the ATC system will automatically apply the brakes to achieve a brake rate of two mph per second[3] under normal conditions. (The N-5 Vehicle does not have a brake assurance function that would detect for braking performance below the specified rate, which might be the case when wheel-to-rail adhesion is low, or there is a brake failure.)

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[1] "Control lines", an industry term, refers to the wayside signaling system design elements that represent all possible route progressions, and applicable train speed limits over the railroad.

[2] 75 PPM (15 mph) code rate has an overspeed tolerance of 0 mph (15 mph max speed). All other code rates allow for 2 mph overspeed.

[3] This is referred to as the "B5" brake rate, because this is the brake rate associated with moving the operator's master controller handle to the B5 position.

- The vehicle can take up to 3.2 seconds to detect the cab signal code [4] (speed limit) changes.

- By design, the only brake application that will be called for by the ATC system is a B5 brake rate, which is two mph per second.

- While B5 is the only brake rate that the ATC system can enforce, the vehicle has eight separate brake rates that can be invoked by the operator:

B1: 0.4 mph/s
B2: 0.8 mph/s
B3: 1.2 mph/s
B4: 1.6 mph/s
B5: 2.0 mph/s
B6: 2.5 mph/s
B7: 3.0 mph/s
Emergency: 2.8 mph/s

LTK's key findings are:

1. According to SEPTA personnel, during the new vehicle warranty period (i.e., in the early 1990's), SEPTA discovered cab signal inconsistencies in turnouts which caused cars to routinely lose cab signal, resulting in unintended penalty brake applications. (Track circuit code rates are set to 15 mph for all diverging moves on the line, as well as for several other non-diverging areas on the line where speed is limited to 15 mph.)

   To resolve the unintended penalty brake application in diverging moves, the ATC system was reprogrammed to delay a penalty brake application from 3.2 seconds to 7.5 seconds.

   During non-diverging movements, however, this timer extension allows for a train to move for an extended period of time into an area where the train should be stopped. During field testing when simulating non-diverging operation (75 PPM to 0 PPM), train movement was measured to be 514 feet past where the wayside systems requested that the train stop. This length of movement could cause a train to encroach into a block that another train is occupying. A review of SEPTA provided documents revealed that this type of incursion into areas where the train is supposed to be stopped was not included in the original code and block design.

2. During the January 2018 field testing, LTK observed that the N5 cars could be accelerated in the immediate vicinity of where a speed reduction is required by the train control system. When a speed reduction is commanded by the train control system, there is a three second train operator response time window in which the operator must take action to begin to decelerate the car to the reduced speed. During this three second response time window, the

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[4] Speed limits are transmitted to the vehicle through a cab signal system. Each speed limit (e.g. 55, 45, 30, 15, and 0 mph) is assigned a unique code rate. Wayside system generates code rates based on control line designs which dictate the maximum speed that a vehicle can operate under based on current route conditions. The codes are transmitted through the rails and read by the vehicle which interprets the codes as speed limits.

car can be made to accelerate. In some circumstances such acceleration can increase car speed by as much as 12 mph. (For brevity in the balance of this report, the term “Block-Entry-Acceleration” is used to describe this situation.)

Here is an example of how such action can be detrimental: A vehicle in a 30 mph section of track is approaching a known section where the speed limit will downgrade to 15 mph. The operator can use the two mph overspeed tolerance to operate at 32 mph, and then when the 15 mph rate is detected by the vehicle, the operator can use the three second response allowance to actually accelerate the vehicle, at nominally three mph per second. In these three seconds, the vehicle can accelerate from 32 mph to over 42 mph, at which point, the vehicle is well within the 15 mph section of track.

During the January 2018 testing, “Block-Entry-Acceleration” was measured to add over 500 feet to the stopping distance of the train versus stopping from the designated speed limit. The distance associated with this acceleration, commonly referred to as hyper-acceleration in the industry, is not compatible with the original signal system design.

3. The vehicle performance metrics, as measured during LTK’s testing, were used as inputs to calculate braking distance, and to check consistency between measured and calculated stopping distances[5]. The braking distances were then compared to the control lines and track circuit block layout for Track 1 – Southbound between Villanova and 69th Street, and such comparison indicates that 23 blocks within this area had insufficient braking distance. If “Block-Entry-Acceleration” were to be eliminated, the number of blocks with insufficient braking distance (within the testing area) would decrease from 23 to 4.

4. The ATC System relies on speed sensors on the vehicle, which monitor wheel rotation [6] to calculate speed. While the vehicle’s spin/slide system is an adaptive system that utilizes available wheel-to-rail adhesion to maintain wheel rotation during braking, wheels can still slide which results in inaccurately low speed measurements.

   Stationary vehicle testing, using simulated signals introduced with test equipment, revealed that abrupt changes in speed sensor readings, such as those that would occur during wheel slides, can cause the ATC system’s overspeed timer to be reset. If this event were to occur during an actual overspeed condition the ATC system would reset the operator response timer and could delay braking for three seconds. The ATC System could also fail to recognize an overspeed condition due to slide. This could occur if the operator were to apply brakes in advance of a code change and the brake application caused a slide preventing the ATC System from recognizing overspeed.

   (Wheel slide scenarios were not attempted during dynamic testing, as slippery conditions are difficult to simulate and control.)

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[5] The braking distances measured during testing are within 2.4% of the calculated braking distances.

[6] The speed sensors count wheel rotation, and combined with known wheel circumference and time, is used by the train control system to calculate speed.

5. Other than the issues outlined in items 1-4 above, the January 2018 testing revealed no incompatibilities between the wayside and vehicle design and actual performance with respect to the train control system.

In addition, LTK conducted a design comparison of the existing ATC system on the NHSL line with contemporary train control technologies. While the existing system is comparable with other ATC systems of its era, there have been advancements in train control technology that could offer additional protections to SEPTA. Modern train control systems would provide SEPTA with improved work zone protection, increased resolution for train location, and slide detection / brake assurance features.

LTK recommends that SEPTA take several steps to improve the safety of the Norristown High Speed Line:

Recommendation 1: Issue an order stating that overspeed and “Block-Entry-Acceleration” are not permitted, and audit the adherence to this order by performing routine downloads of the vehicles’ onboard data logger system that records car number, time, speed, code downgrade time.

Recommendation 2. Conduct a full review of the system’s control lines and make any necessary changes. SEPTA will need to develop a new braking model which incorporates the vehicle’s measured performance and reaction times. The braking model formula should then be used to modify the control lines.

Recommendation 3. Engage the ATC system supplier (Alstom) to determine the feasibility of resetting the 75-0 PPM timer to three seconds and removing the three second delay before brakes are applied in overspeed. (Such change will necessarily be correlated with the work under Recommendation 2.)

Recommendation 4. Investigate turnout signaling implementation to remedy the issue of cab signal drop outs on diverging moves. Evaluate the need for turnout signaling improvements against possible changes to the 75 PPM timer. Note that no signaling changes may be necessary provided that the change in recommendation 3 is exercised and the new braking model (Recommendation 2) supports the extended 75 PPM timer.

Recommendation 5. Modifications to the control lines, vehicle and system turnouts should be used as inputs to complete a schedule simulation. Reductions in speed limits and vehicle system reaction times will likely result in slower service times. A schedule analysis can identify alternative operational practices to optimize the updated system for throughput.

Recommendation 6. Consider implementation of a modern train control technology. Due to obsolescence and the age of the wayside, vehicle, and back-office systems on the line and the lack of communications segment, upgrade to a modern train control system such as Communications Based Train Control (CBTC) or Positive Train Control (PTC) will require a major overhaul. Modern systems however, could offer SEPTA increased protections such as brake assurance, increased train location resolution, and improved work zone protection.

2 INTRODUCTION AND ASSESSMENT OVERVIEW

In October 2017, SEPTA tasked LTK with performing a top level review of the train control features on the Norristown High Speed Line. LTK performed a functional assessment of the NHSL to verify that onboard and wayside systems provide effective train control. The assessment considered vehicle service operation, as-built onboard ATC system parameters, as-built wayside ATC system parameters, and integrated system parameters. The assessment was conducted in phases, ranging from document review to field testing. The work performed was grouped into the following phases:

- Review of original procurement technical specifications and maintenance manuals

  LTK reviewed the original N-5 vehicle procurement technical specification to obtain the performance and interface requirements for the brake system and the integrated CSS/ATC system. The maintenance manuals were reviewed to determine if any changes were necessary for the current maintenance practices.

- Dynamic tests to verify brake rates (August 2017)

  Using the parameters specified in the original procurement specification SEPTA/LTK performed brake rate tests on an N-5 vehicle (Car number 135 was used). The objective of the brake rate testing was to verify that the current brake rates of the vehicles are in conformance with the vehicle's as-purchased Technical Specifications.

  Test results indicated that brake rates at the designated performance levels were generally in agreement with the as-built documents, as more thoroughly described in this report.

- Block Design Review

  A review of SEPTA control line drawings was conducted to determine signal conditions and block spacing. In 1991, a safe braking analysis was used to redesign the block layout before the delivery of the N-5 fleet. The most recent version of the control line charts is dated 5/16/02, and was used for LTK's analysis.

  As part of the review, LTK performed a preliminary analysis of selected control lines using a more current braking distance model. For the selected control lines, stopping distances using entry speeds of 70, 55, 30, and 15 mph were calculated and compared to the block layout. This analysis was conducted under the assumption that the vehicle was operating under the maximum allowed recognition and response conditions, and maximum speed tolerance conditions, as defined in the original technical specification.

  Results of the review identified potential conflicts among the block lengths, track code speeds, and brake system performance.

- Performance Testing (January 2018)

  Performance testing was conducted to verify the wayside system and vehicle system operation, and to validate the braking model used in the control line analysis. The testing include three elements: vehicle static tests, vehicle dynamic tests, and wayside sample control line and distance verification.

Static and dynamic field tests were conducted for single car operation (Car No. 153), two car operation (Car Nos. 153, and 152), and for control line verification.

As each phase was completed, the results were presented and the next steps were discussed with SEPTA.

3 BACKGROUND: NORRISTOWN HIGH SPEED LINE

The Norristown High Speed Line runs between 69th Street Terminal in Upper Darby and the Norristown Transportation Center in Norristown (Figure 1). The line has a total of 22 station stops, and operates local and express service. The maximum authorized speed on the line is 70 mph (Subsequent to commencing this assessment the maximum speed was reduced to 55 mph.) Service is operated 22 hours a day. Headways are typically 20 minutes.

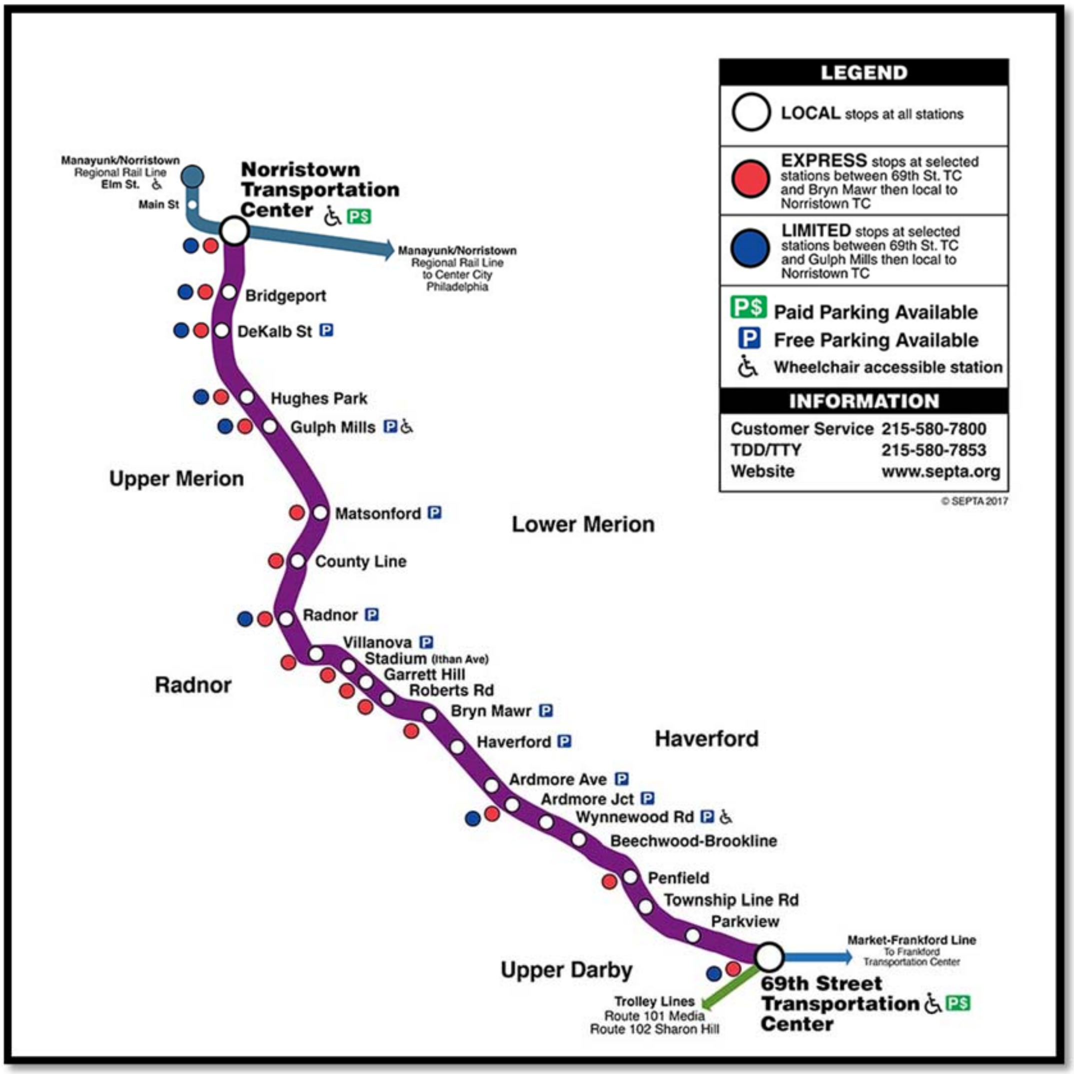

Figure 1. Norristown High Speed Line Map

The vehicles have operating cabs at each end and typically operate as one car trains, with two car trains being operated during peak periods. The track configuration is such that the vehicles always operate in the same orientation.

3.1 Wayside Infrastructure and Control lines

The Norristown High Speed Line is 13.4 route miles in length. The line has eight interlockings. The wayside train control equipment is Microlok I logic controllers. The wayside traffic signals are four aspect units which display speed restrictions in single colors

When a train is authorized to leave a terminal, it checks in via VETAG which communicates with the wayside system establishing the route. The dispatcher monitors train location and has the ability to change wayside switches and clear signals, but these changes are governed by vital wayside logic, i.e. the wayside logic will not permit any unsafe dispatcher-initiated changes.

Train movement through work zones is not controlled by the wayside system but is authorized through the dispatcher via voice radio. Work zones that require track outages are established between interlockings, and the distance between interlockings can be longer than 2 miles. In 2016 SEPTA installed trip stops on the vehicles for use as work zone protection. Trip stops system operation occurs when a wayside based trip arm collides with a vehicle mounted stop cock which is directly connected to the vehicle's brake system to enforce an emergency brake application. SEPTA maintainers can place trip arms at the boundary of work zones so that any unwanted vehicle violation of a work zone is met with an emergency brake application.

The train control system, as it generally exists in 2017, was implemented on the NHSL coincident with the introduction of the new N-5 vehicles in 1991. LTK is aware of two significant changes made to the control lines since 1991:

1. Originally all diverging routes used 15 mph (75 ppm) codes. Due to increased run time, however, SEPTA added wayside logic controlled timers which allowed diverging trains to operate at 30 mph through the first section of the block, and after the timer expires, the speed is reduced to 15 mph (This information is noted, but testing on diverging routes was not performed due to SEPTA operational restrictions, and the design details of this change were not available to LTK.)

2. In August 2017, SEPTA removed all 70 mph code rates on the line and made several other signal aspect changes to reduce speeds going into 69th Street Terminal. These changes became effective August 27, 2017. As of the release of this report, the changes have not been documented with control line chart revisions ("As-in-Service" [7]). Table 1 below shows the blocks where code rates were reduced.

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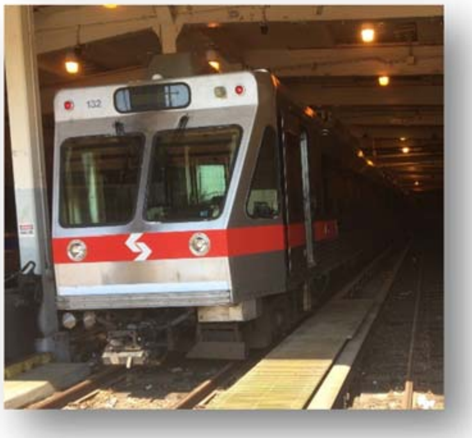
[7] "As-in-Service" refers to the effort of redrawing signal plans according to the changes that were made in the field, having them checked by a qualified signal engineer, and filing them as the plan of record within SEPTA.

Table 1. Updated Code Rates

Block	Original Speed Limits	August 2017 Revised Speed Limits
703	55	30
704	55	30
705	30	15
706	30	15
1tk w/ switches #12N & 21R	15	15
2 tk w/ switches #12R &21N	15	15
All blocks that were originally 70 mph	70	55
Note: LTK verified the above revised speed limits in the test zone, as defined Appendix E.		

3.2 The NHSL N-5 VEHICLE

The Norristown High Speed Line N-5 fleet consists of 26 vehicles of the same type. The vehicles were delivered from ABB between 1991 and 1993. All 26 vehicles were part of the original procurement contract.



The N-5 vehicle has an operator's cab at both ends of the vehicle, equipped with a master controller that has four power positions (Power Level P1 through P4), and eight braking positions (Brake Level B1 through B7 and Emergency Brake). Each brake level is associated with a defined brake rate expressed in miles per hour per second; the brake rates for each brake level are listed in Table 3.

The vehicle has a deadman feature, typical of transit vehicles, which monitors certain operator actions, and in the absence of such actions will essentially presume that the operator is incapacitated and take over to apply a full service brake application (Level 7). A deadman-initiated brake application can be recovered by the operator, by moving the master controller to brake level 5, 6, or 7.

The following modifications related to the ATC system and brake system have been performed on the N-5 vehicles, since original delivery:

- During vehicle procurement acceptance testing it was discovered that while going through switches, at a speed of 15 mph, there was a problem with code dropout, because the track receiver was not mounted on the truck. To address this problem, the dropout time was extended to 7.5 seconds, but only at this speed, through a change in the software. (1991)
- ATC Speed probe change out - wiring changes (1995)

- Control cable update due to traction motor cables rerouting due to ATC interference (1995)
- Replaced original GRS ATC speed probe with Krauss-Maffi style speed probe (1995)
- Installation of suppression diodes for the anti-skid valves in both brake control units (1996)
- Restored ATC mechanism to work at original antenna sensitivity (1996)
- Installed KM6 Vent Valves and D-2 trip cocks (2014) (car-mounted trip cocks work in conjunction with wayside trip arms, and the extent to which trip arms are installed was not reviewed as part of this report)

3.2.1 System Parameters Overview

Table 2 provides the original vehicle system performance parameters which relate to train control:

Table 2. Vehicle System Parameters

Item	Performance Parameter
Vehicle	
Acceleration	Max. Startup Acceleration: 3.9 mph/s Max. Allowable Jerk Rate: 2.0 mph/s^2
Braking	See Table 3
Over Speed Condition	See Table 4
Spin/Slide Conditions	At a speed differential of 3 mph the motoring or braking tractive effort is reduced to zero, with intermediate differentials producing proportional reductions.
	Synchronous wheel spin/slide conditions are detected by a rate of change of 6 mph/s for motoring or dynamic braking, and 9 mph/s for friction braking.
Reaction Times	Cab signal equipment responds to 75 PPM to 0 PPM code changes in 7.5 seconds. The CSS responds to all other code changes within 3.2 seconds.
	ATC requests B5 brake application in 3 seconds
Wayside	
Logic Control Type	Ansaldo (formerly US&S) Microlok I
Signal Type	Color Light Signals
Back Office	
Traffic Control	Ability to change switches and clear signals. Cannot communicate directly with vehicles. Receives no information regarding ATC cut-out or Test mode.

3.2.2 Brake System (Reference: Technical Specification Sections 12.4 and 13.4)

The N5 fleet utilizes a blended brake system of both friction and dynamic braking. The friction braking is achieved with disc brake units. There are two units installed on each axle of the vehicle. (The N5 fleet is not equipped with track brakes.) The brake system was designed to meet all performance requirement found in SEPTA's Technical Specification sections 2.6.3 and 2.6.4 when operating a fully loaded two car train, and sections 12.2.4 and 12.2.5 when one truck on one car has lost propulsion and dynamic braking. The SEPTA Technical Specification defined the jerk rate associated with service braking performance. (Jerk rate is the rate of change of acceleration usually expresses in mph per second per second)

The dynamic braking is both rheostatic and regenerative, and is capable of producing all service brake rates for car loads up AW2. Dynamic braking is achieved by using the inverters and traction motors. The braking is coordinated such that the total braking effort requested will always be met with a blending of friction and dynamic braking, however, if dynamic braking is inoperative the vehicle will still provide the same brake effort for rates B1 through B5 and in emergency. The spin-slide function is active for all brake rates (further defined in section 3.2.3). The specified brake rates for each brake level are shown in Table 3.

Table 3. Specified Brake Rates

Brake Level	Specified Blended (Dynamic & Friction) Brake Rate	Specified Friction Only Brake Rate	Jerk Limited	Controlled Via
B1	0.4 mph/s,+.25, -.15	0.4 mph/s,+.25, -.15	Yes	Master Controller
B2	0.8 mph/s ,+.25, -.15	0.8 mph/s ,+.25, -.15	Yes	Master Controller
B3	1.2 mph/s,+.25, -.15	1.2 mph/s,+.25, -.15	Yes	Master Controller
B4	1.6 mph/s,+.25, -.15	1.6 mph/s,+.25, -.15	Yes	Master Controller
B5	2.0 mph/s,+.25, -.15	2.0 mph/s,+.25, -.15	Yes	Master Controller, **ATC**
B6	2.5 mph/s,+.25, -.15	2.0 mph/s,+.25, -.15	Yes	Master Controller
B7	3.0 mph/s,+.25, -.15	2.0 mph/s,+.25, -.15	Yes	Master Controller
Emergency	2.8 mph/s,+.25, -.15	2.8 mph/s,+.25, -.15	No	Master Controller, Mushroom Pushbutton

3.2.3 Spin/Slide Detection (Technical Specification, Section 14.0)

The propulsion, dynamic brake, and friction brake utilize spin/slide detection/correction system. The spin/slide detection system is active for all propulsion and braking rates (P1-P4, B1-B7 and Emergency) The spin/slide detection functions to improve propulsion and braking performance and minimize wheel tread damage in low adhesion conditions. (Wheel spin can occur during acceleration; wheel slide can occur during braking.)

Wheel spin/slide is detected via a signal relaying the greatest speed differential between any two of the four axles. A signal is provided to cause a reduction in acceleration/braking effort, and the reduction is increased, is maintained, or is reduced until the wheels start to roll.

3.2.4 Sanders

As information, the N-5 vehicles are equipped with sanding equipment to provide better braking and acceleration traction, such as during weather conditions that negatively affect wheel-to-rail adhesion. The sanding equipment consists of a sand box, two sand traps, a magnet valve, and an isolating cock. The sanding equipment is located at each end of the car arranged to dispense sand in front of the leading wheels of the train. There are two modes of operation: automatic and manual. Automatic sanding occurs when the vehicle speed is above 1 mph in power or 5 mph in braking, and when a wheel spin/slide condition is detected. When spin or slide is detected, the sanding magnet valve is energized to dispense sand for two to ten seconds.

The manual sanding mode can be initiated while the car is in run mode, and the “SAND” switch on the emergency stop/power panel is activated. When manually initiating sand will be dispensed for two to five seconds.

As part of the train control assessment LTK did not review the condition of the vehicle sanding equipment.

3.2.5 Cab Signal System (CSS)

The N-5 vehicles are equipped with a micro-processor based continuous coded speed-aspect cab signal system (CSS). The cab signal equipment operates at 100 ± 1.5 Hz frequency with a six aspect signal system. Table 4 provides the aspect code rates and their respective over speed criteria. The on board cab signal equipment responds to any code change within 3.2 seconds.

Table 4. CSS Aspect Code Rates

Code Rate (PPM)	Authorized Speed	Over speed criteria
420	70 mph	72 mph
270	55 mph	57 mph
180	45 mph	47 mph
120	30 mph	32 mph
75	15 mph	15 mph
0	0 mph	1 mph
Stop & Proceed	15 mph	15 mph

Vehicle speed is measured by a tachometer system that monitors wheel revolutions. This system, however, can provide incorrect readings during wheel slip/slide conditions. When a wheel slides, or locks up, wheel rotation will reduce, and this reduction will be incorrectly interpreted by the vehicle as a reduction in train velocity.

The cab signal display is integrated with the speedometer. The maximum permitted speed is indicated by illuminated LEDs, which are provided at 5 mph intervals. The display also includes a red over speed indicator. Figure 2 provides the integrated speedometer/cab signal display.

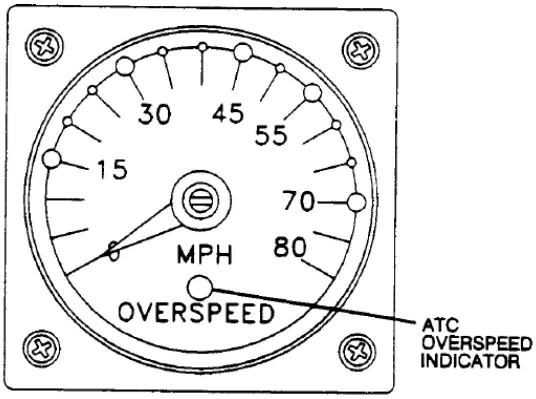


Figure 2. Cab Signal Display

3.3 AUTOMATIC TRAIN CONTROL FEATURES (Technical Specification Section 16.0)

The N-5 vehicles are equipped with an Automatic Train Control (ATC) system. The ATC system is integrated with the CSS and automatically stops the train whenever the authorized speed is exceeded. The system is interfaced with the service brake control lines and the master controller. However, the system is not interfaced with the emergency brake system. Figure 3 depicts the undercar ATC system diagram.

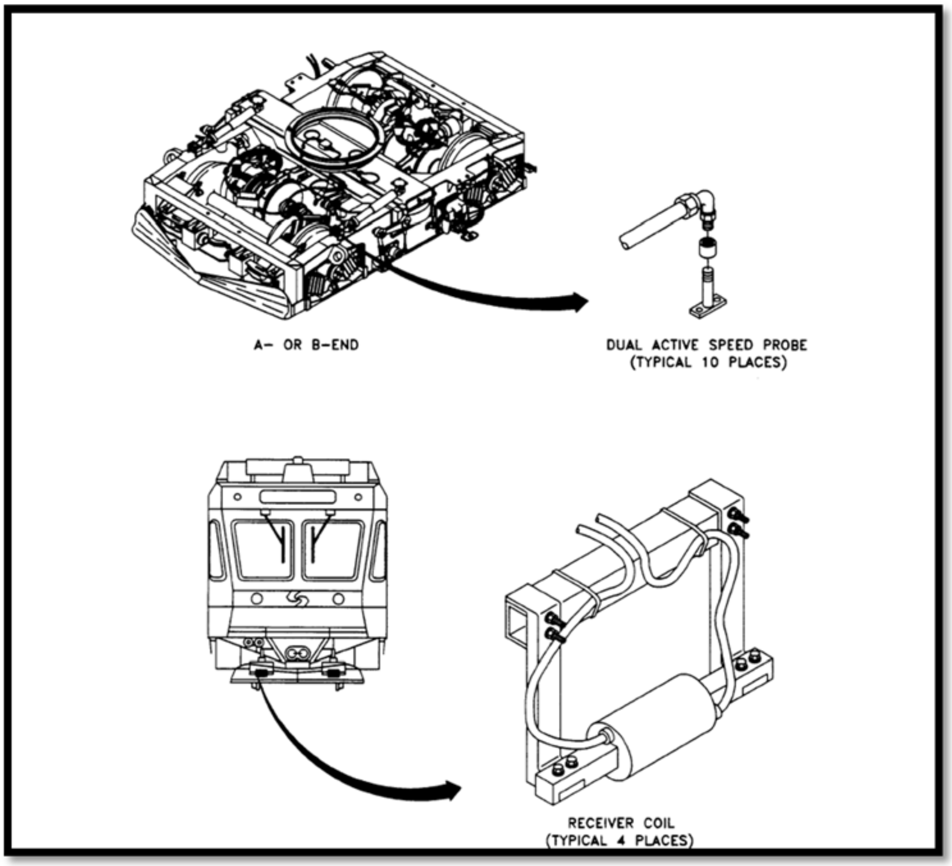


Figure 3. N-5 Undercar ATC System Diagram

The Automatic Train Control (ATC) system provides an automatic enforcement of speed limits, by initiating a full service penalty brake application (B5 Brake Rate, defined in Table ***3***) when one of the following three conditions are met:

- ATC system power is lost.
- The train is travelling at a faster speed than the authorized cab signal for three or more seconds, and the operator takes no action. (For this system, action is defined as applying the brakes at level B5, B6 or B7 until the train speed is below the authorized speed.)
- The train receives a more restrictive cab signal speed aspect, and the operator does not take action within three seconds.

To meet the requirements of the system, the operator must maintain brake application until the vehicle is travelling below the authorized speed. If the brake application at the prescribed level is not maintained, the full service irrevocable penalty brake application (B5 Brake Rate) will be applied immediately.

4 FIELD TESTING

Three field tests were performed by SEPTA/LTK between August 2017 and January 2018 to assist in the assessment of the ATC system:

August 2017: Brake tests were performed to confirm that the car's braking performance remains within the design specifications.

January 2018: Vehicle ATC tests were conducted to measure the performance of the integrated systems. Reaction times of the CSS, ATC and brake system were measured, as well as the ATC induced stop distance and the brake rates. The effects of "Block-Entry-Acceleration" and of the increased 75 PPM – 0 timer were quantified through stop distance testing.

January 2018: A control line verification test was completed to verify that the control lines within the vehicle testing area (Southbound on 1 track between West Overbrook and 69th Street) matched the design plans.

4.1 Brake Rate Test (August 2017)

In August 2017 SEPTA contracted LTK to perform a brake rate test on one sample N-5 vehicle (No. 135). An analysis of the results of the preliminary brake tests conducted was performed through two independent tools (Matlab and Excel) to cross-check results. The table below compares the requested brake rate with the specified brake rate with the specified rate and the average recorded rate. For comparison, the results of a SEPTA brake rate test that was completed in 2000 have been included. The specified rates were extracted from Section 12.4.2 of the N-5 Technical Specification.

Table 5. Brake Rate Test Results

Requested Brake Rate	Specified Rate, per N-5 Technical Specifications	SEPTA Brake Rate Test (2000) (Car 141), Appendix E	Average Recorded Rate (2017) (car 135), Appendix D
B1	0.4 mph/s,+.25, -.15	0.50 mph/s	0.63 mph/s
B2	0.8 mph/s ,+.25, -.15	0.92 mph/s	1.30 mph/s
B3	1.2 mph/s,+.25, -.15	1.13 mph/s	1.82 mph/s
B4	1.6 mph/s,+.25, -.15	1.47 mph/s	2.11 mph/s
B5	2.0 mph/s,+.25, -.15	1.99 mph/s	2.52 mph/s
B6	2.5 mph/s,+.25, -.15	2.54 mph/s	2.74 mph/s
B7	3.0 mph/s,+.25, -.15	3.09 mph/s	3.03 mph/s
Emergency	2.8 mph/s,+.25, -.15	2.8 mph/s [Note 1]	3.64 mph/s
Emergency + B7	5.8 mph/s,+.25, -.15	5.68 mph/s	6.17 mph/s
Note 1: SEPTA performed test activated emergency with the master controller and then moved the position to coast as the car stopped.			

The brake system performed as expected and all brake rates met or exceeded the required specified rates. The differences between the 2000 results and the 2017 results are attributed primarily to the sources of the data: the 2000 test results are based on averaging values recorded from an on-board accelerometer, and the 2017 test results used the data captured by the on-board data recorder.

4.2 Wayside and Vehicle ATC Testing (January 2018)

4.2.1 Vehicle ATC System Tests

The recognize and response timeframes for final as-built configuration, except for the 75 ppm code, were determined to be less than those timeframes specified in the original procurement specification.

Table 6. On-Board CSS/ATC System Performance Parameters

System Parameters	Original Specified Performance Requirements	Actual Measured Performance Parameters
On-Board ATC Overspeed Time (time allotted for Operator to recognize and respond)	3.0 seconds	2.7 seconds (See Note 1.)
On-Board Cab Signal Code change hold time (time allotted for system to recognize and confirm code signal change)	3.2 seconds	2.6 seconds
On-Board Cab Signal Code change hold time for 75-0 PPM/15 mph (time allocated for system to recognize and confirm code signal change)	3.2 seconds (See Note 2.)	7.2 seconds

Vehicle Acceleration Effort	Up to 3.0 mphps	Up to 3.25 mphps
B5 Brake Rate (penalty brake level)	-2.0 mphps	-2.0 mphps or better
Overspeed Set Point (except 75PPM/15 mph)	3 mph for 2 seconds	2 mph for 2 seconds
Overspeed Set point for 75 PPM/15 mph	0 mph	0 mph
Table 6 Notes: (1) The operator response timer was able to be reset during static testing by simulating a wheel slip/slide event. Further details on this anomaly are provided directly below this table. (2) While going through switches, at a speed of 15 mph, there is a problem with code dropout, because the track receiver is not mounted on the truck. To correct this problem, the dropout time is extended to 7.5 seconds, but only at this speed, through a change in the software. This change appears to have been implemented as a result of qualification testing.		

Static vehicle testing revealed one anomaly in the onboard CSS/ATC system that allowed the system operator response timer to reset once the system identified the overspeed condition. To obtain this result LTK utilized the ATC Portable Test Unit (PTU) that was provided by the system supplier when the cars were delivered. The PTU has the ability to output simulated cab signal codes and vehicle speeds to the vehicles ATC system through a cable connection. To reset the timer, LTK created the following static simulation:

- Train is traveling at a constant speed of 30 mph.
- A code downgrade from 120-75 PPM was issued 5.08 seconds into the test.
- Once the code downgrade was recognized by the ATC system, the overspeed timer started.
- Before the timer expired and penalty brakes could be requested, however, the simulated speed was reduced from 30 mph to 0 mph. This sharp reduction in speed was designed to simulate a wheel slip/slide event (as discussed in Section 3.2.5, wheel slip/slide can result in incorrect speed measurements due to sudden reduction in wheel rotation).
- After a period of 1.28 seconds the simulated speed was restored to 30 mph.
- The ATC system requested brakes 11.28 seconds into the test, which was 7.54 seconds after the code was downgraded.

This penalty brake request was initiated 2.24 seconds later than in other simulations where the speed was not dropped out to simulate wheel slip/slide. A graph of this simulated test is shown in Figure 5. This test was not replicated during dynamic testing as such test conditions are difficult to simulate on an active railroad.

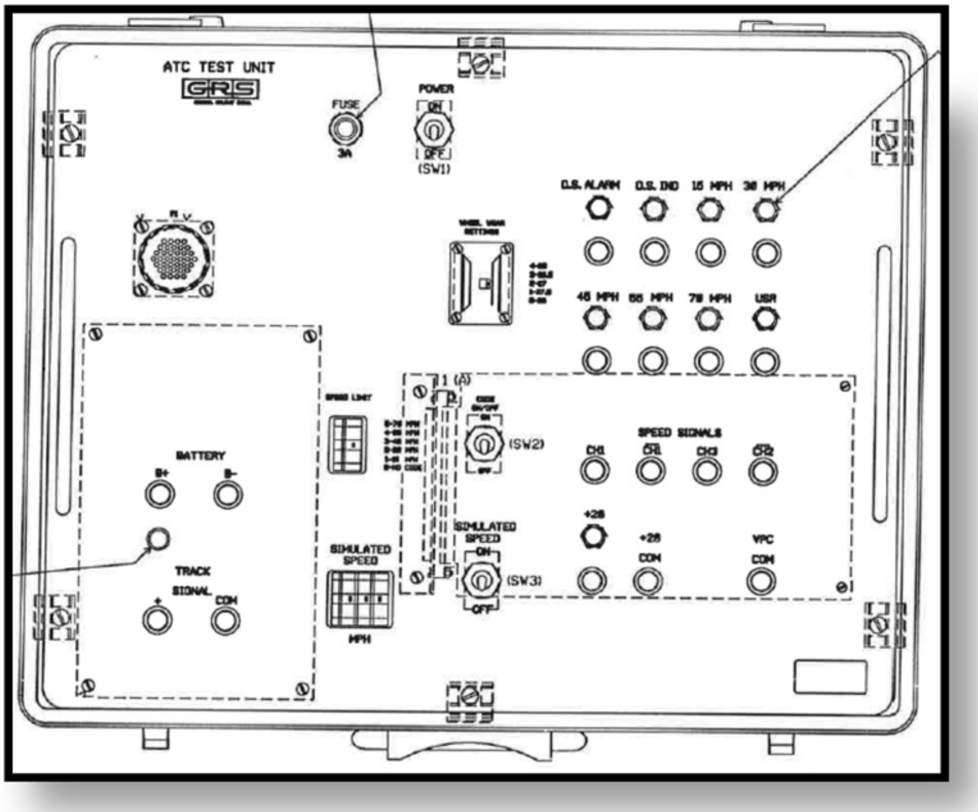


Figure 4. ATC PTU Unit

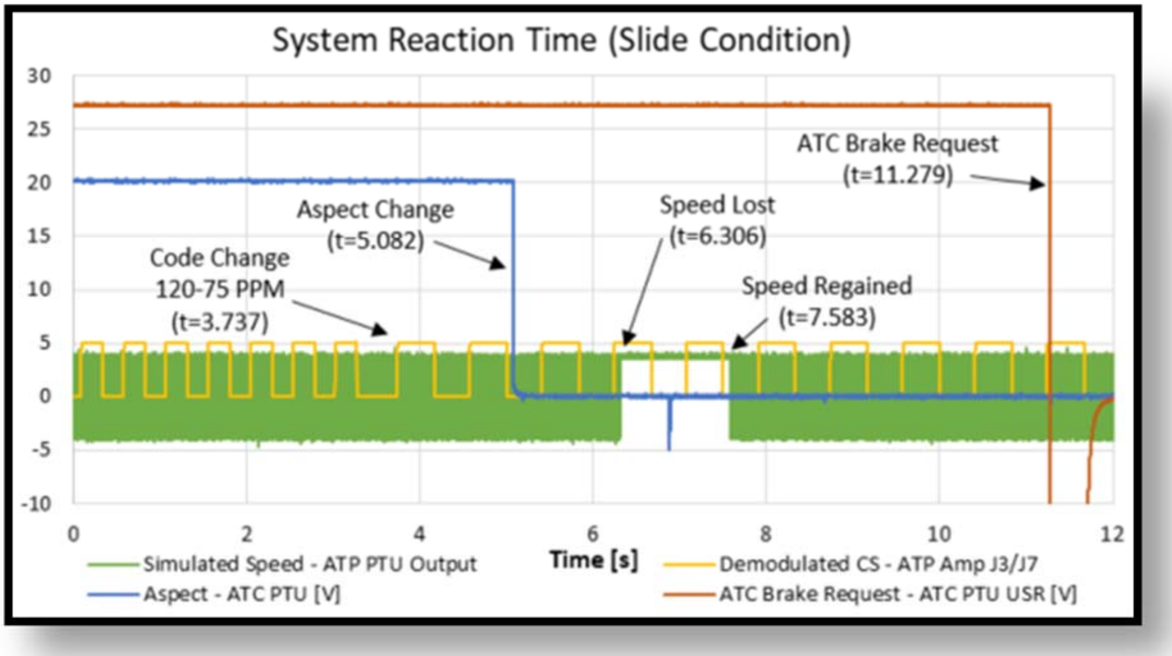


Figure 5. Operator Response Timer Reset During Simulated Wheel Slide Event

During the course of the field testing, the operator demonstrated that the NHSL N5 vehicles are capable of accelerating at 3.25 mph/s. This acceleration, coupled with performance timing parameters of the CSS/ATC system, gives the operator the opportunity increase speed in anticipation of the vehicle entering a known code downgrade point. This action, described as "Block-Entry-Acceleration", was demonstrated during the field testing. The demonstration showed that the train speed could be increased by as much as 12 mph before the system enforced the new code speed. (See Figure 6.)

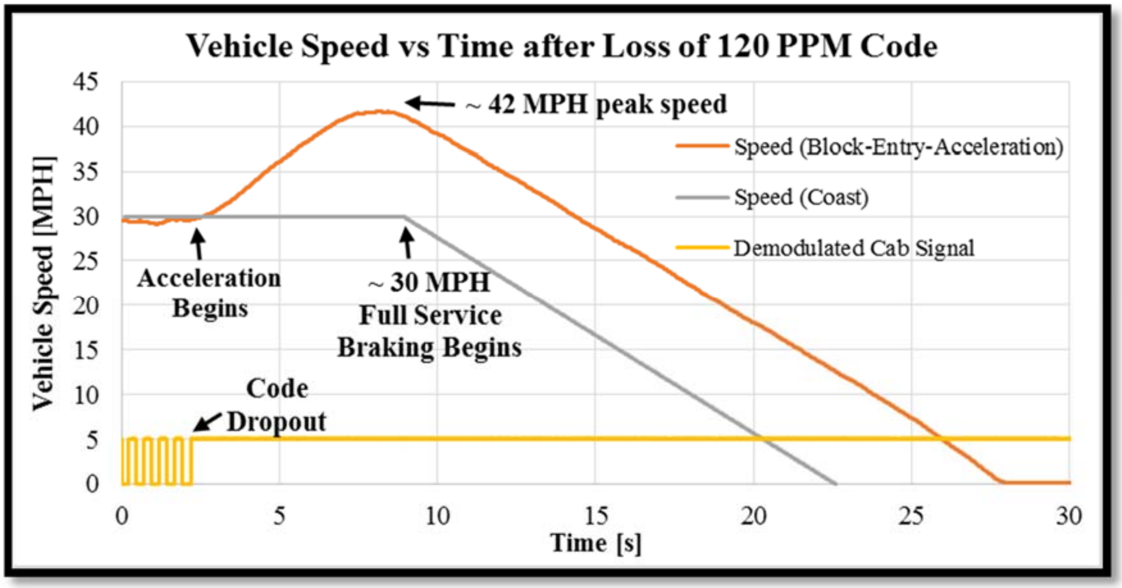


Figure 6. Comparison of "Block-Entry-Acceleration" and "Non-Block-Entry-Acceleration" stops upon encountering a 120-0 code rate change, as measured during performance testing.

4.2.2 75 PPM – 0 PPM Code Rate Hold Time Change

As previously noted, during acceptance testing the timer for the cab signal system to acknowledge a code change from 75 PPM (15 mph) to 0 PPM was extended from 3.2 seconds to 7.5 seconds. This extended timer allows for the train to travel for the 7.5 seconds of code change recognition time, and then for the 3 seconds allotted for the operator to recognize and respond to overspeed (10.5 seconds total). During testing the distance traveled during this 10.5 second time interval allowed the train to travel 514 feet into a block with a 0 code. The assessment indicated that this change was not addressed in the control line design.

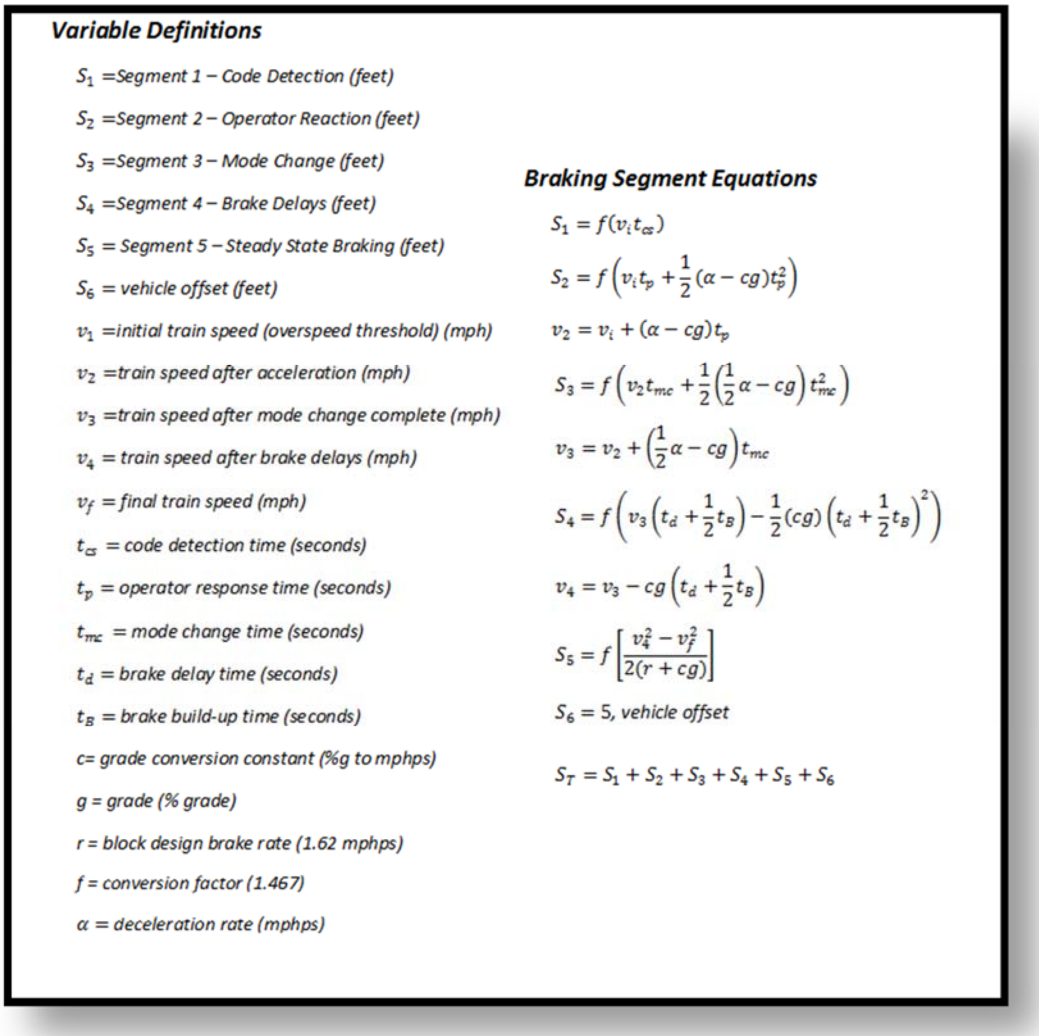
4.2.3 Control lines

Field testing was conducted between West Overbrook and 69th Street southbound on one track to verify compliance with design documents. The testing confirmed that the control lines matched the SEPTA provided design documents for the selected area.

5 WAYSIDE CODE ANALYSIS

5.1 Preliminary Braking Model Development

LTK performed a desktop analysis of wayside control lines and blocks. Control lines were taken from SEPTA document NHSL Cab Code Changes dated August 27, 2017. The theoretical stopping distances were calculated for selected control lines at 55, 30, and 15 mph largely following the guidelines described in IEEE Standard 1698. Vehicle parameters and response times recorded during this study, and described in section 4.2.1, were used as inputs to the calculations, rather than the design specification values, to provide accurate results. LTK developed the following equations for the braking model to complete the analysis.



Variable Definitions

S_1 =*Segment 1 – Code Detection (feet)*
S_2 =*Segment 2 – Operator Reaction (feet)*
S_3 =*Segment 3 – Mode Change (feet)*
S_4 =*Segment 4 – Brake Delays (feet)*
S_5 = *Segment 5 – Steady State Braking (feet)*
S_6 = *vehicle offset (feet)*
v_1 =*initial train speed (overspeed threshold) (mph)*
v_2 =*train speed after acceleration (mph)*
v_3 =*train speed after mode change complete (mph)*
v_4 = *train speed after brake delays (mph)*
v_f = *final train speed (mph)*
t_{cs} = *code detection time (seconds)*
t_p = *operator response time (seconds)*
t_{mc} = *mode change time (seconds)*
t_d = *brake delay time (seconds)*
t_B = *brake build-up time (seconds)*
c= grade conversion constant (%g to mphps)
g = grade (% grade)
r = block design brake rate (1.62 mphps)
f = conversion factor (1.467)
α = *deceleration rate (mphps)*

Braking Segment Equations

$$S_1 = f(v_i t_{cs})$$

$$S_2 = f\left(v_i t_p + \frac{1}{2}(\alpha - cg)t_p^2\right)$$

$$v_2 = v_i + (\alpha - cg)t_p$$

$$S_3 = f\left(v_2 t_{mc} + \frac{1}{2}\left(\frac{1}{2}\alpha - cg\right)t_{mc}^2\right)$$

$$v_3 = v_2 + \left(\frac{1}{2}\alpha - cg\right)t_{mc}$$

$$S_4 = f\left(v_3\left(t_d + \frac{1}{2}t_B\right) - \frac{1}{2}(cg)\left(t_d + \frac{1}{2}t_B\right)^2\right)$$

$$v_4 = v_3 - cg\left(t_d + \frac{1}{2}t_B\right)$$

$$S_5 = f\left[\frac{v_4^2 - v_f^2}{2(r + cg)}\right]$$

$S_6 = 5$, *vehicle offset*

$$S_T = S_1 + S_2 + S_3 + S_4 + S_5 + S_6$$

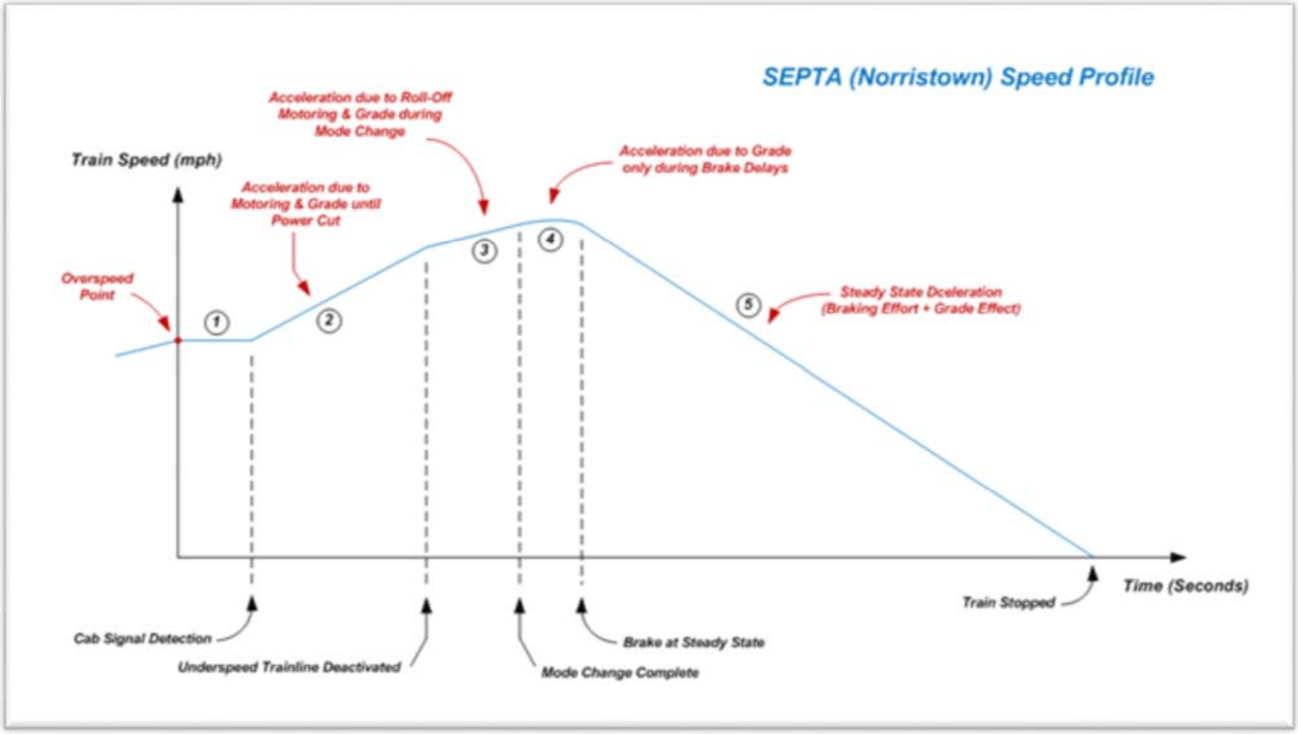


Figure 7. Braking Model Segment Outline

The preliminary braking model was developed using the following assumptions.

- The initial speed is assumed to be 2 mph over the allowable operating speed (except for when traveling in a block with a 75 PPM code rate (15 mph speed limit), in those situations the speed is 15 mph with no overspeed allowance) (Technical Specification Section 16.6.1).
- 2.65 second delay time for the ATC system to recognize code downgrade (Technical Specification Section 16.4.2)
- After code recognition the vehicle performs a simulated “Block-Entry-Acceleration” during the allotted 2.7 second operator response period.
- 0.8 second mode change time for the vehicle to transition from power mode to braking mode (note that acceleration continues until the mode change is complete)
- 0.8 second delay time for the brake level to build to the requested rate. This value is the average measured value based on the vehicles actual performance (2018 testing).
- 0.5 second brake build-up time to 90% brake application. This value is the average measured value based on the vehicles actual performance (2018 testing).
- The average brake rate is assumed to be 1.62 mph/s. This rate was used in the original Braking Model developed in 1991. This rate provides a safety factor (reduces the specified B5 brake rate by approximately 25%) to account for reductions in brake performance that could occur. This level of safety factor is comparable with those used in the industry.

5.2 Braking Model Validation

The theoretical brake model was validated by incorporating the actual measured performance parameters from the vehicle testing described in Section 4 of this report. After substituting the measured parameters, for maximum entry speed, acceleration rate, braking rate, recognize and respond times, into the brake model, the projected stop distances generated by the Braking Model were within 2.4% (less than a 10 foot difference in stopping distance) of the actual values recorded during the field testing. (See Figure 8.)

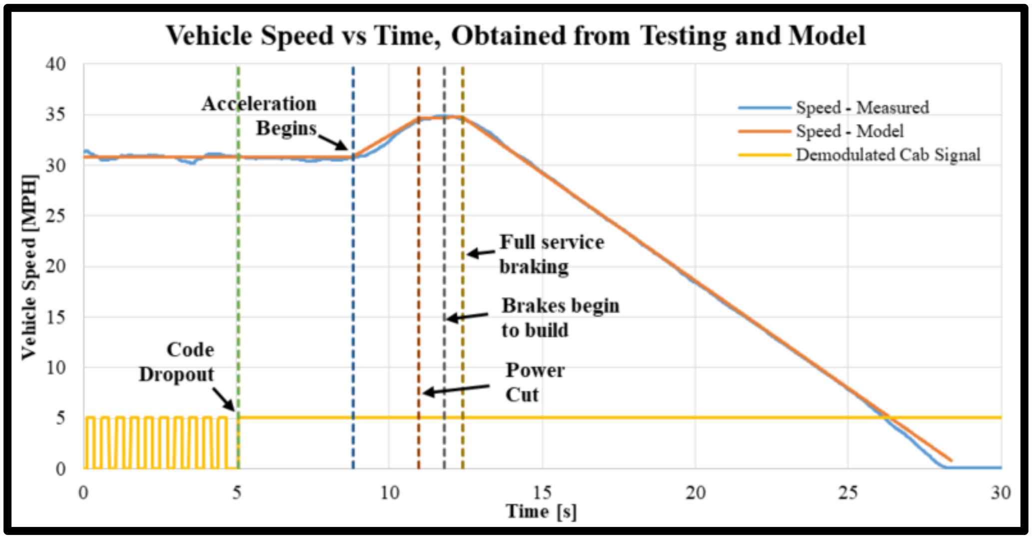


Figure 8. Comparison of vehicle speed vs time as obtained from the braking model and vehicle performance testing

5.3 Preliminary Control Line Analysis

After the braking model was validated, it was used as the primary input tool for a preliminary analysis of the control lines in the area where testing was conducted (West Overbrook to 69th Street). The stop distances calculated from the braking model were overlaid on control line sections to determine whether adequate braking distance was available based on the current configuration.

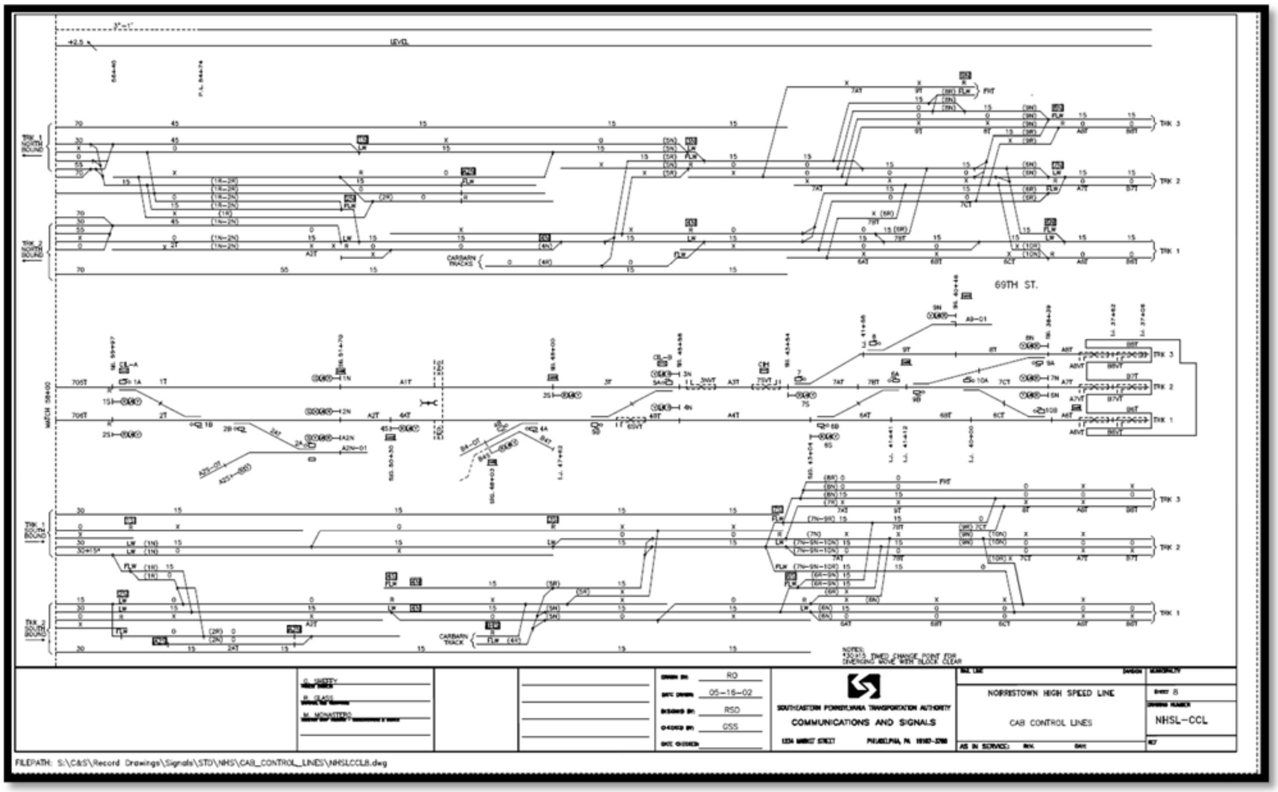
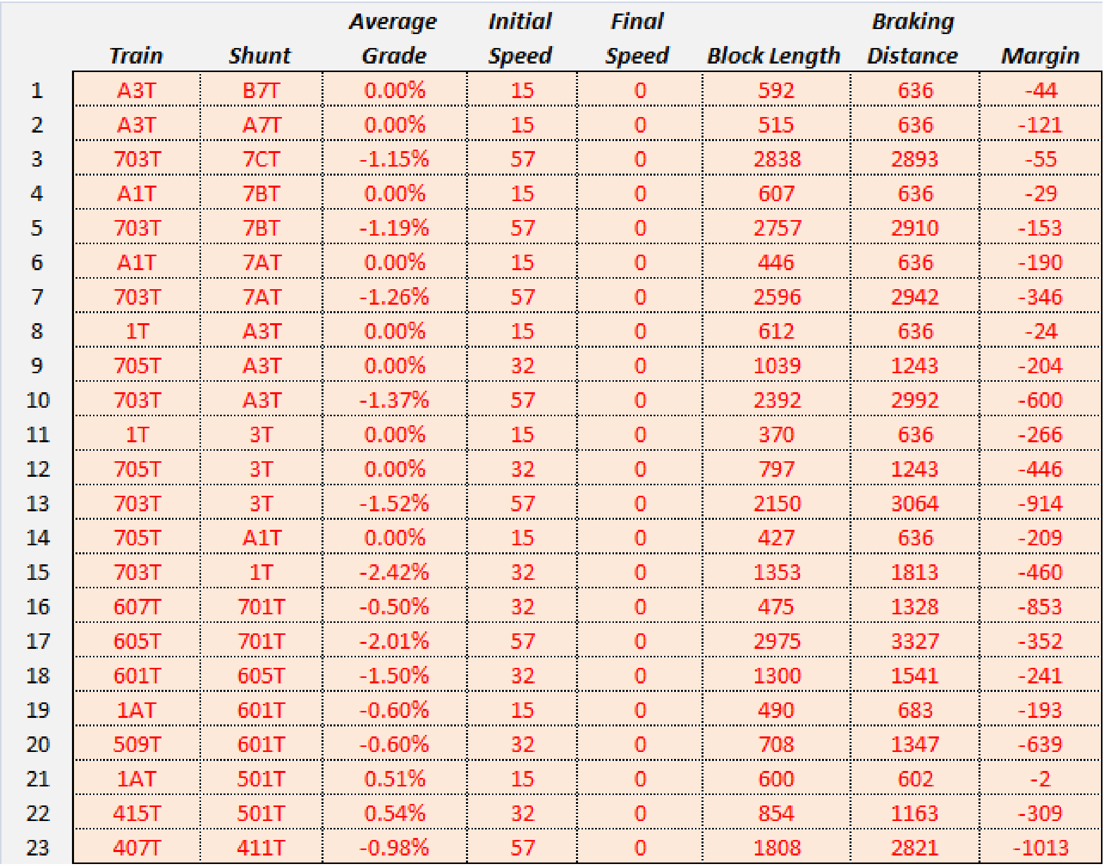


Figure 9. Sample Norristown Control Lines

The results of the preliminary analysis indicate that there are 23 blocks with insufficient braking distance with regard to the current control line configuration.

Table 7 identifies signal blocks for which the calculated stopping distances exceeded the design lengths.

Table 7. Wayside Code Analysis Anomalies (1.62 mph/s brake rate)



	Train	Shunt	Average Grade	Initial Speed	Final Speed	Block Length	Braking Distance	Margin
1	A3T	B7T	0.00%	15	0	592	636	-44
2	A3T	A7T	0.00%	15	0	515	636	-121
3	703T	7CT	-1.15%	57	0	2838	2893	-55
4	A1T	7BT	0.00%	15	0	607	636	-29
5	703T	7BT	-1.19%	57	0	2757	2910	-153
6	A1T	7AT	0.00%	15	0	446	636	-190
7	703T	7AT	-1.26%	57	0	2596	2942	-346
8	1T	A3T	0.00%	15	0	612	636	-24
9	705T	A3T	0.00%	32	0	1039	1243	-204
10	703T	A3T	-1.37%	57	0	2392	2992	-600
11	1T	3T	0.00%	15	0	370	636	-266
12	705T	3T	0.00%	32	0	797	1243	-446
13	703T	3T	-1.52%	57	0	2150	3064	-914
14	705T	A1T	0.00%	15	0	427	636	-209
15	703T	1T	-2.42%	32	0	1353	1813	-460
16	607T	701T	-0.50%	32	0	475	1328	-853
17	605T	701T	-2.01%	57	0	2975	3327	-352
18	601T	605T	-1.50%	32	0	1300	1541	-241
19	1AT	601T	-0.60%	15	0	490	683	-193
20	509T	601T	-0.60%	32	0	708	1347	-639
21	1AT	501T	0.51%	15	0	600	602	-2
22	415T	501T	0.54%	32	0	854	1163	-309
23	407T	411T	-0.98%	57	0	1808	2821	-1013

Note: Figure 10 shows the control line used (for Track Circuit 3T shunted) in rows 11 through 13 of Table 7. The calculated braking distances are 266, 446 and 914 feet greater than the associated block lengths identified in the design documents.

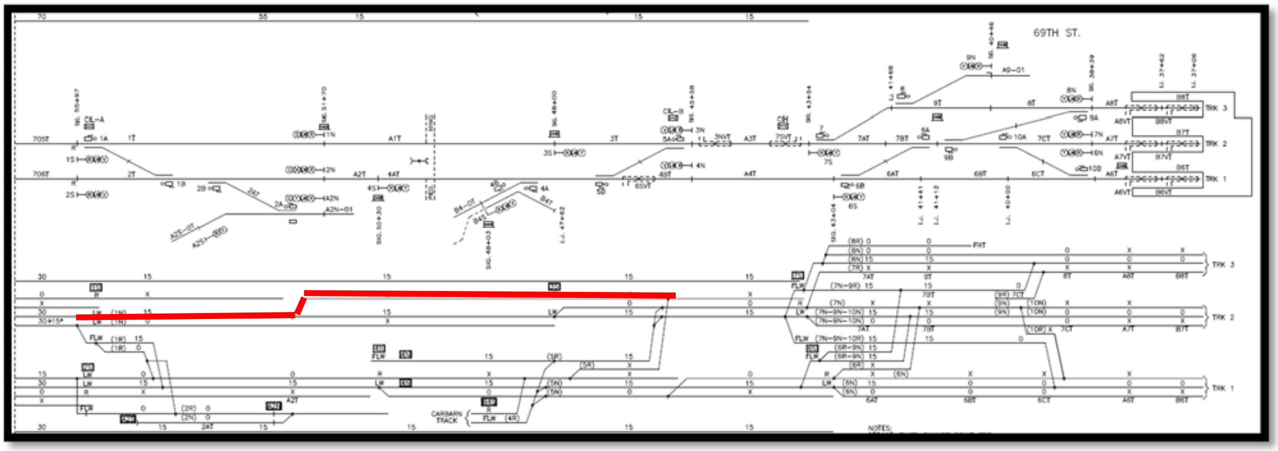
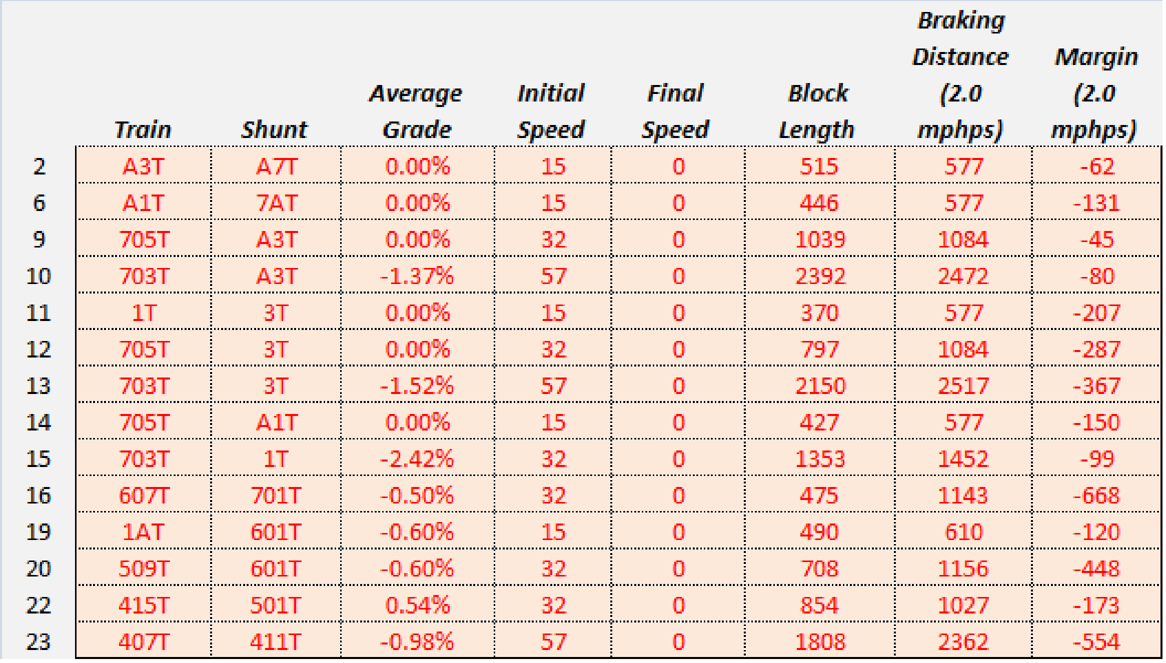


Figure 10. NHSL Control Line Track 1 SB (58+00 to 45+58)

A second analysis was performed using the assumption of a 2.0 mph/s brake rate. Table 8 identifies signal blocks where the stopping distance exceeds the existing block length. These results indicate that even if the trains perform at the optimal brake rates, there would still be the potential for blocks without adequate braking distances.

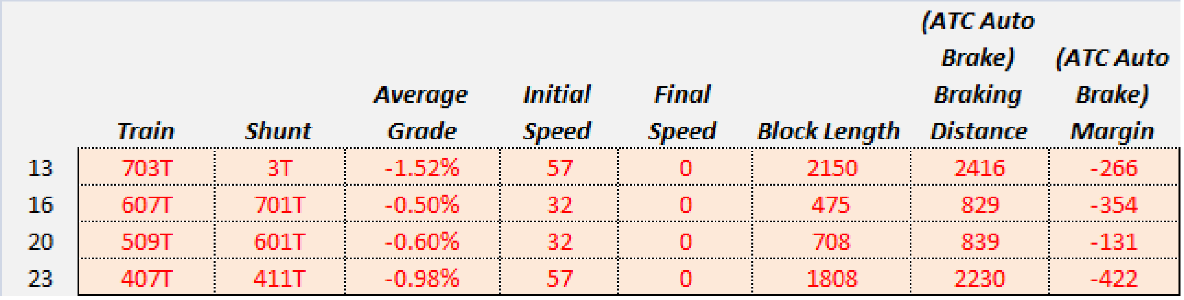
Table 8. Wayside Code Analysis Anomalies (2.0 mph/s brake rate)



	Train	Shunt	Average Grade	Initial Speed	Final Speed	Block Length	Braking Distance (2.0 mphps)	Margin (2.0 mphps)
2	A3T	A7T	0.00%	15	0	515	577	-62
6	A1T	7AT	0.00%	15	0	446	577	-131
9	705T	A3T	0.00%	32	0	1039	1084	-45
10	703T	A3T	-1.37%	57	0	2392	2472	-80
11	1T	3T	0.00%	15	0	370	577	-207
12	705T	3T	0.00%	32	0	797	1084	-287
13	703T	3T	-1.52%	57	0	2150	2517	-367
14	705T	A1T	0.00%	15	0	427	577	-150
15	703T	1T	-2.42%	32	0	1353	1452	-99
16	607T	701T	-0.50%	32	0	475	1143	-668
19	1AT	601T	-0.60%	15	0	490	610	-120
20	509T	601T	-0.60%	32	0	708	1156	-448
22	415T	501T	0.54%	32	0	854	1027	-173
23	407T	411T	-0.98%	57	0	1808	2362	-554

Finally, an analysis was conducted to determine the effect that the removal of "Block-Entry-Acceleration" would have on the braking distances. Preliminary analysis indicates that if "Block-Entry-Acceleration" was eliminated, the number of stopping distance anomalies is reduced from 23 to 4. Note that this model does not alter the 7.25 second cab signal detection time for a 75 PPM to No Code condition and utilizes a 1.62 mphps brake rate. See Table 9.

Table 9. Wayside Code Analysis Anomalies
(1.62 mph/s brake rate, Block-Entry-Acceleration Removed)



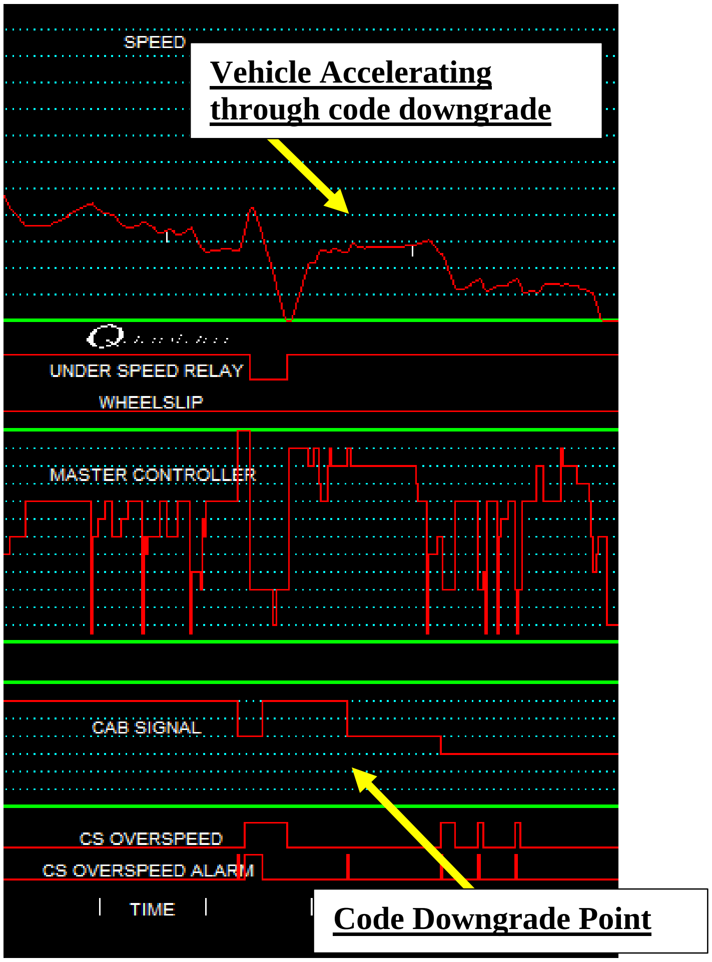
	Train	Shunt	Average Grade	Initial Speed	Final Speed	Block Length	(ATC Auto Brake) Braking Distance	(ATC Auto Brake) Margin
13	703T	3T	-1.52%	57	0	2150	2416	-266
16	607T	701T	-0.50%	32	0	475	829	-354
20	509T	601T	-0.60%	32	0	708	839	-131
23	407T	411T	-0.98%	57	0	1808	2230	-422

6 RECOMMENDATIONS

LTK's recommendations regarding the Norristown High Speed Line train control system are described below. The recommendations are organized by department/function for reference purposes.

6.1 Transportation

SEPTA should issue an update to the operating rules on the NHSL to mandate the elimination of the practice of "Block-Entry-Acceleration". Routine audits of operation can be conducted to monitor compliance by downloading vehicle event recorder logs and documenting when vehicles have been accelerated after a signal downgrade. Rules violations should be assessed when any "Block-Entry-Acceleration" is observed.



Vehicle Accelerating through code downgrade

Code Downgrade Point

Figure 11. Example of Block-Entry-Acceleration Viewed Through the Quantum Data Logger QDP Software Interface

6.2 Communications & Signaling

The preliminary braking model and control line review conducted as part of this study indicate insufficient braking distance allocation in the existing control line design. The preliminary analysis focused on approximately 110 signaling blocks associated with Track 1 – Southbound between Villanova and 69th Street, and found 23 blocks that have deficient braking distance. LTK recommends that a control line/stop distance analysis be conducted over the entire signaling alignment to determine other potential problem areas. The analysis may result in the need for signaling modifications and associated update to the control line drawings.

The 75 PPM to 0 PPM cab signal recognition timer was extended to 7.25 seconds due to ineffective cab signal performance on the line’s turnouts. This timer may be acceptable as currently defined depending on the effect of other potential changes. (i.e., if stopping distance becomes available with implementation of ATC auto braking resulting in the elimination of “Block-Entry Acceleration” – See Table 9)) Investigation of the existing turnout signaling deficiencies and potential improvements may be necessary if system modifications cannot support the 7.25 second cab signal recognition timer for 75 PPM to 0 PPM.

6.3 Vehicle Engineering

The 10.5 second time period allowed for recognition and response actions (7.5 seconds system time and 3.0 seconds operator time) is excessive in some situations, e.g., it could result in the vehicle travelling more than 500 feet before initiating the stop sequence which would not be compatible with a STOP signal block.

SEPTA should also consult with the system supplier to determine if removal of the operator response window is feasible. Note that if B5 braking was activated by the ATC System as soon as overspeed was detected, and the operator was just required to acknowledge within 3 seconds by moving the master controller, “Block-Entry-Acceleration” would no longer be possible and the number of deficient signal blocks could be significantly reduced (See Table 9).

SEPTA should also consider the potential benefits of an ATC System containing a decelerometer. ATC Systems that include this device can provide brake assurance as well as protection against failure to recognize or premature termination of an overspeed condition. This type of change would eliminate the operator response timer reset identified in section 4.2.1. While retrofit to add a decelerometer to the existing system is unlikely, SEPTA should consider and discuss these options for potential employment in future ATC Systems.

6.4 Operations

Any changes made as a result of the control line/block analysis process described above should be evaluated for their effect on revenue schedule times. During LTK’s preliminary control line analysis blocks with 70 mph code rates were not of concern. It may be advisable to reinstitute 70 mph speeds to help lessen the schedule effects of reducing some of the slower speeds.

6.5 Management

The results of the CSS/ATC system assessment performed and the tests conducted indicate that there are areas for improving the functionality and performance of the NHSL train control system. Since the time when the NHSL CSS/ATC system was introduced into service operation, the technology associated with train control systems has advanced significantly worldwide. In the USA, the advancement was fueled by Rail Safety Improvement Act (RSIA 2008) and the codification of positive train control (PTC) requirements by FRA. (See 49 CFR 236 Subpart H.) Because SEPTA's NHSL operation does not fall under FRA regulations, there are a number of avenues available to SEPTA to implement changes to the existing NHSL train control system. In this section the existing train control system has been baselined and the short list of options has been provided to allow a level of comparison. The list is not exhaustive, but includes potential modification to the existing train control system, a communications based train control (CBTC) moving block train control system similar to that utilized for the Green Line LRV, and three FRA approved positive train control systems. Depending on the course followed, the system changes may affect some or all of the operating segments, i.e., on board, wayside, back office/control center, and communications. It is important to note, due to the age of the existing systems, that upgrade to a newer train control technology would likely require the replacement of most of the vehicle, wayside, communications and back office train control equipment that is in place currently.

In Table 10, the current ATC system on the NHSL is compared with other modern train control technologies to emphasize additional safety features that could be offered to SEPTA by overhauling the train control system on the line.

Table 10. Train Control Comparison Matrix

System Features and Functions		Automatic Train Control - NHSL	Modified Automatic Train Control	Communications Based Train Control (Similar to Green Line)	Positive Train Control - Advanced Civil Speed Enforcement System (transponder based system, arranged as a vital overlay)	Positive Train Control - Enhanced-Automatic Train Control (Automatic Train Control with other features to achieve core Positive Train Control system requirements)	Positive Train Control - Interoperable Electronic Train Management System (GPS and communications based system)
Prevent train to train collision		Cab Signal System and Automatic Block Signaling	Cab Signal System and Automatic Block Signaling	Moving block with safe between train distance (Automatic Train Control system calculates safe train separation, enforces stop)	Overlaid with Cab Signal System, Automatic Train Control	Overlaid with Cab Signal System and Automatic Train Control; Automatic Block Signaling block separation	Enforces Cab Signal System codes (if applicable), wayside signals, civil speed, safe distance between trains and directives
Prevent overspeed derailment		Cab Signal System codes enforced by Automatic Train Control warning followed by penalty brake application	Penalty brake initiated by overspeed condition (no delay)	Automatic Train Control system enforces civil speed limits	Transponder provides civil speed data	Cab Signal System codes enforces by Automatic Train Control	Onboard track database provides civil speeds
Prevent work zone incursions		Out of service between interlocks, controlled by dispatcher	Out of service between interlocks, controlled by dispatcher	Work zones are set by dispatcher	Temporary speed restrictions set from dispatcher sent over interlocking radio; or, temporary speed restriction transponder sets placed by work crew	Temporary speed restriction set by dispatcher, enforced by Automatic Train Control, minimum length is entire block	Dispatcher sets-up work zone based on track database; optional EIC communication with back office and train
Prevent movement through improperly aligned main line switches		Routing information displayed to dispatcher, track circuits, and interlocking logic	Routing information displayed to dispatcher, track circuits, and interlocking logic	Automatic Train Control system enforces proper direction of travel; routing information is displayed to dispatcher, track circuits, and interlocking logic	All switches must be monitored; switch position communicated to train moving through interlocking via interlocking radio (wayside radio)	Wayside communicates to train, Automatic Block Signaling track circuits; all switches must be monitored and communicated to back office	Wayside and back office communicate directly with train, Automatic Block Signaling track circuits; all switches must be monitored and connected to wayside interface unit (WIU)
Penalty brake sequence		Senses code change/code violation, generates warning, allows time for operator to recognize and respond, if response is correct no penalty, if response is not correct penalty brake is actuated.	Senses code change/code violation, generates warning, penalty retrievable when underspeed condition is restored	System calculates warning curve based on civil speed and safe between train distance; if speed exceeds warning curve, operator has 2 seconds to react, if speed is not reduced sufficiently, penalty brake is applied and train must come to a stop	On-board computer monitors train location and enforcement points based on transponders; provides warning and enforcement if system senses need to stop prior to operator action	Enforced by Automatic Train Control; senses code change/code violation, generates warning and penalty brake application, allows operator time to recognize and respond, if response is correct system allows operator can release brake when proper speed is achieved, if response is incorrect penalty brake is maintained.	On-board computer monitors warning curve against braking curve, if system senses need for reduced speed or stop, initiates warning, allows time for operator to recognize and respond by initiating corrective action, continues to monitor warning curve against enforcement curve, if there is a conflict applies penalty brake.
Speed control		Monitors actual speed against code rate; issues warning (refer to Penalty brake sequence)	Monitors actual speed against code rate; issues penalty as soon as overspeed occurs (refer to penalty brake sequence)	Civil speed and maintain safe distance between trains	Enforces signals, civil speeds based on transponders, temporary speeds based on updates via radio	Monitors actual speed against code rate. Enforced by Automatic Train Control (refer to Penalty brake sequence)	Enforces signals, civil speeds in track database, safe distance between trains, temporary speed restrictions (bulletins)
Train location		No GPS location; within a block	No GPS location; within a block	No GPS location; on board reads transponder, between transponders on board Tachometers (2 per vehicle) and Doppler RADAR measure movement to determine vehicle location. Location re-set at each transponder.	No GPS location; calculated relative to transponder using dead reckoning (wheel tach)	No GPS location; location limited to within a block	GPS location; track database with dead reckoning (wheel tach)
Communications		Voice radio only	Voice radio only	Voice radio; on board Automatic Train Control to wayside; on board data radio to/from wayside; wayside to/from back office via ground based network	Voice radio; on board data radio to/from wayside; wayside to/from back office via ground based network; optional cellular for radio configuration updates	Voice radio; Automatic Train Control antenna	Voice radio; combination of data radio, Wi-Fi/WiMax and cellular may be used as communication channels (if interoperability with Freights then interoperable data radio is required); selected communication channel must provide to/from link among train, wayside and back office.

7 References

- N-5 Technical Specification
- SEPTA Drawing NHSL-CCL
- 49 CFR 236 Subpart H

8 Appendices

A. Control Line Diagram

B. Stopping Distance Equations

C. Diagram explaining various reaction times

D. LTK Test Reports

E. SEPTA Provided Documents