New York City Transit

RE-SIGNALING THE CANARSIE LINE

R143 PERFORMANCE
CBTC HEADWAY SIMULATIONS
SUMMARY REPORT

Final

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THE ADVANCED TECHNOLOGY SYSTEMS GROUP

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1. INTRODUCTION

This report summarizes the Canarsie Communications Based Train Control (CBTC) simulation activities that were undertaken in support of the R-143 performance meetings. The R-143 meetings were called by NYCT to establish values for train performance parameters critical to the CBTC design. Simulations were performed to determine end-to-end trip times, the minimum headways for the entire Canarsie Line using varying civil speed profiles and levels of service and emergency braking rates, and the minimum headways at turnback stations.

2. HEADWAY AND TRIP TIMES

Two types of headway evaluations were conducted. The first, uninterfered headway, is defined as the minimum achievable headway, in which a train speed profile is not impeded or interfered by a preceding train. All trains therefore perform at the maximum allowed speed depending on the civil speed limit and the acceleration and braking capabilities of the trains themselves. Operation at uninterfered headways also facilitates a minimum end to end trip time for a given set of station dwell times.

The second type of headway is interfered headway. This is an operation where a following train must reduce speed while closing in on a preceding train. This typically occurs on approach to stations where the preceding train is consuming dwell time. Interfered headway more closely follows NYCT's current criteria used for headway analysis under the conventional wayside signal system which is equipped with station timing. The ability to close up on preceding trains at a lower speed provides for recovery capability for trains under conditions of delay. A 20 mph minimum speed criteria was used to determine the interfered headway, that is, a following train was allowed to slow to a speed no less than 20 mph when closing in on a preceding train.

The end-to-end trip times are defined as the time it takes a train to depart from one terminal station to arrival at the other terminal station. A minimum trip time, given a defined set of station dwell times, will result from uninterfered headway speed profiles. Longer trip times will occur for those trains whose speed profile is interfered with by preceding trains.

Uninterfered headway at the turnback stations is defined as the minimum achievable headway, in which a train speed profile is not impeded by a preceding train, or by the operation of an interlocking. Often, the headway at turnback stations is constrained not only by the performance of the train control system and the train itself, but by the physical layout of the crossovers, their position in relation to the platforms, and dwell considerations of turning back a train crewed by Train Operator and Conductor. Civil speed restrictions imposed upon trains entering terminal station platforms also significantly impact turnback headways where there is only a limited overrun distance at the end of the platform.

3. OVERVIEW OF THE SIMULATION MODEL

The Vista™ CBTC moving block simulation employs a safe braking model as described in Section 3.1. The term Safety Distance (SD), as used in this report, refers to the minimum separation between two following trains. Trains only achieve this minimum separation when they are both stopped. The actual separation of two trains under moving block control is a service braking distance from the speed at which the following train is moving, plus the SD.

3.1 SAFE BRAKING MODEL AND SAFETY DISTANCES

The SD is calculated as the difference between the service braking distance from any one point, and a worst case scenario stopping distance from that same point. The worst case scenario for the following train includes:

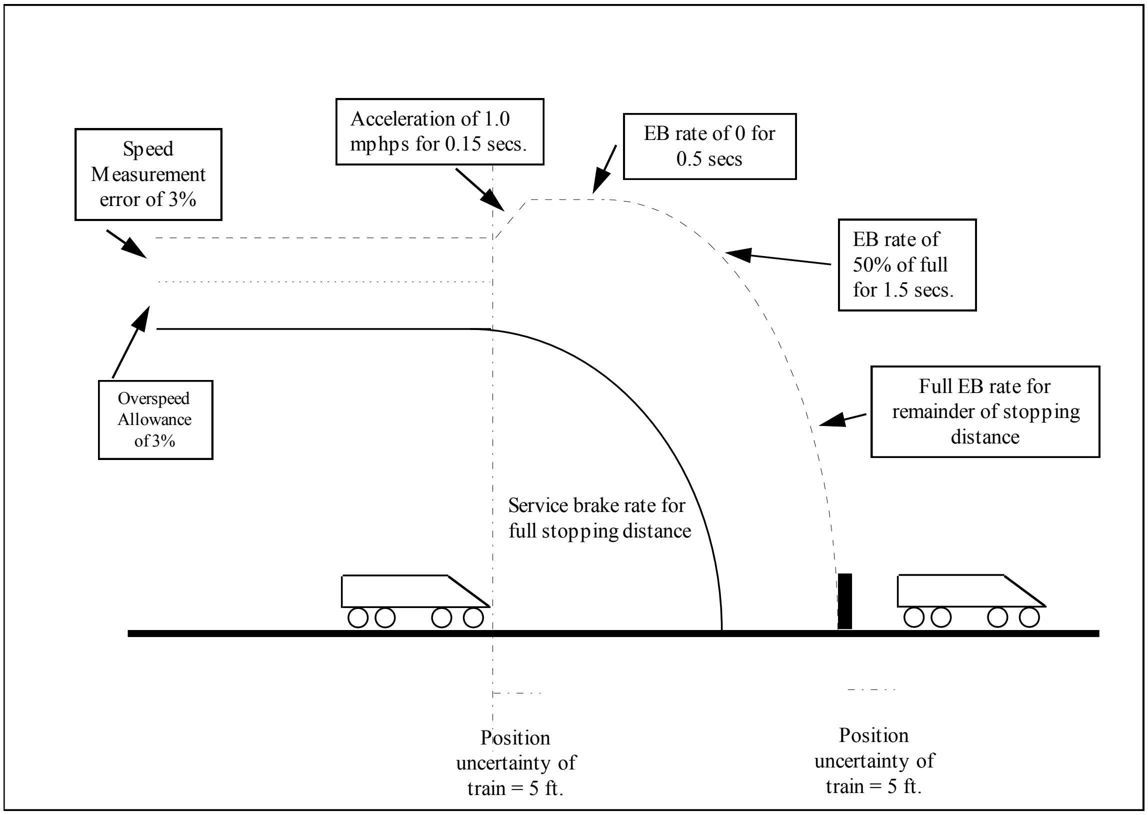
- The train is traveling at a speed higher than the nominal civil limit due to allowable overspeed and tolerance errors of the onboard speed measurement system
- At the point at which the train should begin to brake, it actually accelerates at maximum value for a worst case detection and propulsion cut off time
- The emergency brakes are applied with an extended build up characteristic to a guaranteed level
- The guaranteed level of emergency braking devalues the nominal brake rate to account for low adhesion between wheel and rail, failures of the emergency brake system, and sets of brake equipment which may be cut-out for operational reasons
- Uncertainty in the position of both leading and following trains
- The effect of gradient

The Canarsie Line CBTC specification establishes the following target SDs:

- 10 feet to a home signal and a bumper block in ATO
- 25 feet to a train ahead in ATO (safety distance)

The actual, achievable SDs are sensitive to gradient and brake rates. On level, tangent track, combinations of service and emergency brake rates of 1.25 mphps and 1.5 mphps respectively, or 1.75 mphps and 2.0 mphps respectively, have been shown analytically to result in SDs close to the desired values. The effect of a down grade will be to extend the SD significantly depending on the percentage value of the grade. The Vista^{TM} moving block model calculates SDs based upon the location of the train, the average gradient ahead of the train, the value of service braking rate, and the value of emergency braking rate. The safe braking model described above is shown in Exhibit 1.

Exhibit 1. Safe Braking Model Used in Headway Simulations



3.2 MOVING BLOCK IMPLEMENTATION

The moving block simulation employed uses a 2.0 mphps rate for braking to scheduled stops at stations and braking for permanent speed restrictions, but calculates SDs and stopping profiles to unscheduled stops (for trains ahead, home signals displaying a red aspect, and other obstructions) based on the service brake rates defined. The rate of 2.0 mphps can be changed if this is required for further analysis.

Exhibit 2 illustrates the “ideal” uninterfered speed distance profile for a train moving into a station behind a preceding train.

Exhibit 2. Uninterfered Train Speed/Distance Profile into a Station

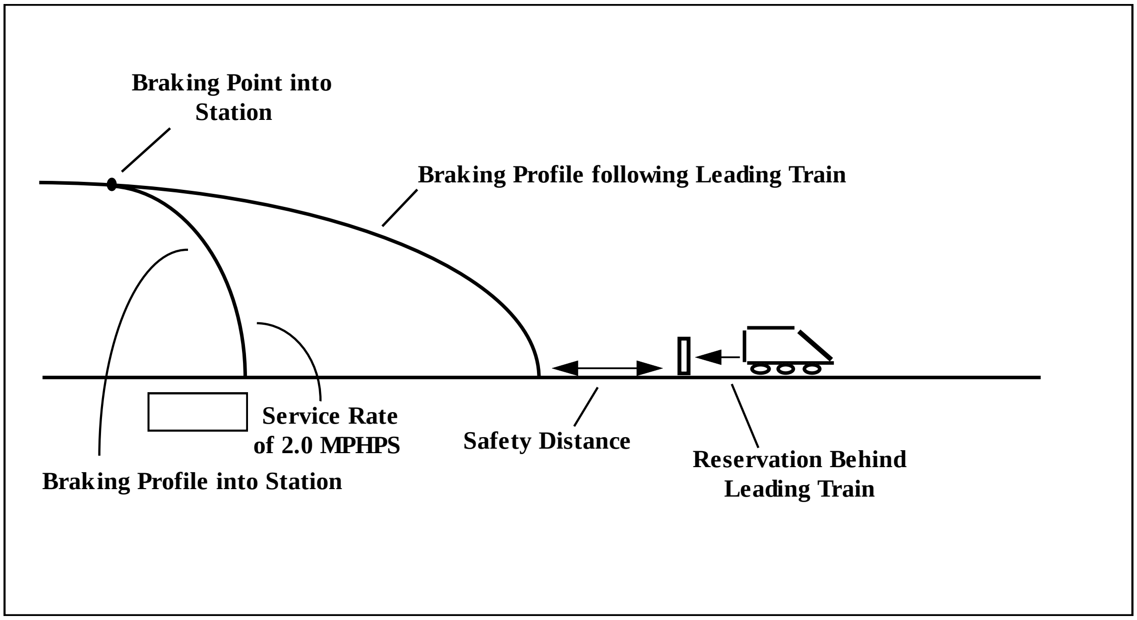
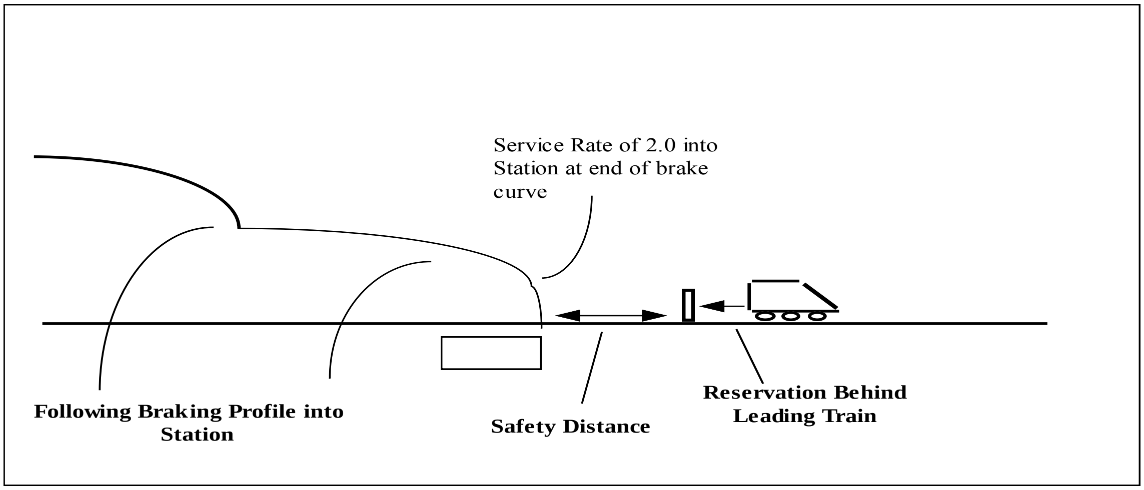


Exhibit 3 illustrates the speed distance profile of a train closely following another train, forcing the follower to slow to a threshold speed which it is able to maintain as the leading train pulls out of the station. The following train is forced to stay a total distance of SD plus braking distance (at the service rate built into the safe braking model) until it reaches a point where it can brake into the station at a service rate of 2.0 mphps. This is described as interfered operation.

Exhibit 3 Interfered Train Speed/Distance Profile into a Station



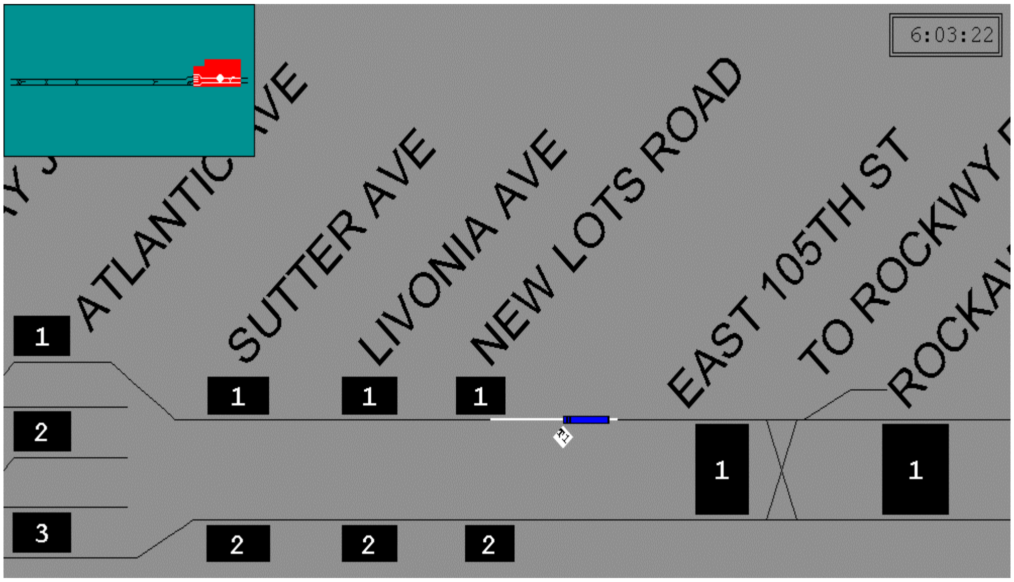
3.3 CBTC MOVING BLOCK MODEL

The Vista™ moving block model calculates the dynamic performance of a particular train based upon the input characteristics and the defined set of Davis equations (a set of industry standard equations of motion specific to trains) which relate speed/distance to tractive effort capability, train length, weight, curve friction, and aerodynamic drag effect. The Train Performance Calculator (TPC) generates train movement calculations.

In addition to SDs and braking characteristics, the model also emulates a three-second delay which represents estimated delays inherent in the CBTC system for computer processing and data communication between train and wayside.

The simulation overview screen dump in Exhibit 4 shows a single train (Train T1) operating between East 105th Street and New Lots Road in the normal direction of traffic. The light colored bar ahead of the train represents the “reservation” of the train which includes the position uncertainty of the front of the train, the safety distance, and a distance representing the effect of the CBTC system 3 second communication and processing delay. The light colored bar behind the train accounts for the position uncertainty of the rear of the train. The computed “firm” position of the train is represented by the dark colored segment in the middle of the bar.

Exhibit 4 Moving Block Operation Simulation Overview Screen Dump



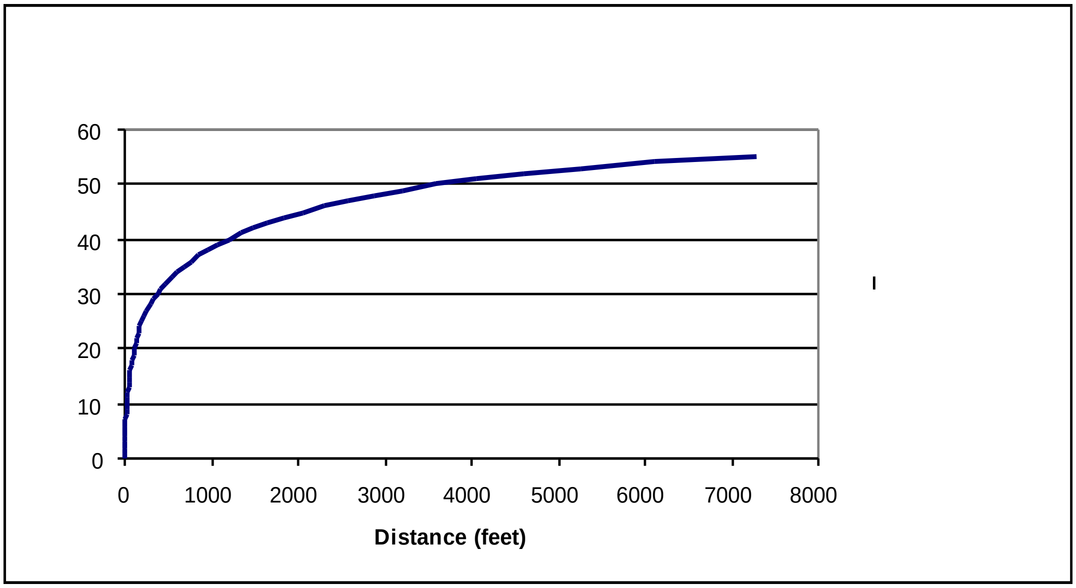
3.4 TRAIN PERFORMANCE

All simulations were conducted with R-143 train data, assuming Automatic Train Operation (ATO). Exhibit 5 contains the actual characteristics used for the R-143 cars in these simulations. Tractive effort was derived from the defined CBTC Acceleration Curve characteristic described in NYCT Drawing 253-9013, and reproduced in Exhibit 6.

Exhibit 5. Train Characteristics

Train Characteristics	R-143
Weight per car	58.5 tons (loaded)
Length of each car	60 feet
Train Consist	8 cars
Acceleration Performance	As per Drawing. 253-9013
Braking Rate	Adjustable by input command

Exhibit 6 Car Performance Acceleration Curves.



4. METHODOLOGY

4.1 MEASUREMENT OF HEADWAY

Headway of both uninterfered and interfered patterns were determined for a variety of combinations of brake rates and station dwell times. Dwell is particularly critical in the determination of headway. For example, an additional five (5) seconds of dwell at the critical location on the line will add five (5) seconds to the headway.

4.1.1 Uninterfered Headway

The technique used to measure uninterfered headway was to dispatch two consecutive trains from one end station to the other end station, and to examine data output of the simulator for delays. Separate runs were made with variations in dwell times and brake rates. The dispatch technique varied the initial dispatch times between the two trains, initially using an estimated value of headway and then, if no evidence of delays to the following train was indicated, reducing the separation incrementally until just before the following train's speed profile is interfered with by the leading train at one location on the line.

The separation increment which just avoids this occurrence is the minimum uninterfered headway for the line. It is not necessarily the lowest headway in any section of the line but will be the limit for scheduling close headway service.

4.1.2 Interfered Headway

The technique used to measure the interfered headway is similar to that for measuring uninterfered headway and consisted of successively dispatching two trains, in both the northbound and southbound directions, at a separation closer than the identified uninterfered headway value and by triggering a flag when a following train was forced to an unscheduled reduction of speed to less than 20 mph, that is when not actually braking normally into a station stop. Observation of the results identified the headway time value and the location. Initially the limiting interfered headway for the line was determined, the final set of simulations determined the limiting headway on a station to station basis.

4.2 MEASUREMENT OF TRIP TIMES

Simulation runs were also performed in order to determine the end-to-end trip times. A trip time is defined for the purpose of the study as being the time between dispatch from one terminal station to arrival at the terminal station at the other end of the line. Trip times were only measured for uninterfered operation, and are highly dependent upon station dwell times. Separate runs were made with variations in dwell times. The first set of runs was made with a standard twenty seconds dwell at all stations (terminal stations were not considered in the end to end runs). The second set of runs was made with the dwell time distribution as listed in Exhibit 9. A third set of runs was made with zero seconds dwell at all stations, this enables a simple calculation of trip times to be made if different patterns of dwell times is to be evaluated, the trip time is then the zero (0) dwell value added to the aggregate dwell time in any new pattern.

4.3 STATION DWELL TIMES

As mentioned above, dwell times are critical in the determination of minimum headway. Two sets of station dwell times were used for the R-143 performance simulation activities. The simplest set was a blanket twenty (20) seconds dwells at all stations. The more complex set is listed in Exhibit 7. These times were developed in conjunction with Rail Transit Operations (RTO) and represent the combined peak hour dwells on the Canarsie Line. During the morning rush the northbound service is heavily loaded, in the evening, the southbound is the heavily loaded service. For the purposes of simulation, dwell is defined as the period between wheel stop and wheel start at a station.

Exhibit 7 Station Dwell Times (Combined AM and PM Rush)

Station	Dwells (in seconds) (South & North Bound)
8th Avenue	NA
6th Avenue	40
Union Square	40
3rd Avenue	25
1st Avenue	40
Bedford Avenue	40
Lorimer Street	40
Graham Avenue	25
Grand Street	25
Montrose Avenue	20
Morgan Avenue	20
Jefferson Street	20
De Kalb Avenue	25
Myrtle Avenue	40
Halsey Street	25
Wilson Avenue	20
Aberdeen Avenue	20
Broadway Junction	40
Atlantic Avenue	20
Sutter Avenue	25
Livonia Avenue	20
New Lots Avenue	20
East 105th Street	25
Rockaway Parkway	NA

4.4 MEASUREMENT OF HEADWAY AT TURNBACK STATIONS

Uninterfered headways for trains arriving at the 8th Avenue and Rockaway Parkway turnback stations were determined using a brake rate combination of 1.25/1.5 mphps (service brake/emergency brake). Dwell times in the turnback analsis are critical in the determination of results. Occupation of the interlocking by the next arriving train can exceed the nominal dwell time for the train waiting to depart significantly. Once the interlocking was free for a departing train, and the nominal dwell had already expired, a further 5 seconds delay before the train departed to simulate Train Operator response to the depart indication and the subsequent closure of the train doors. Nominal values of 70 and 120 seconds were used for dwell. The following values were also made for interlocking operation:

- 5 seconds for Conductor reaction time to close the train doors
- 5 seconds loss-of-shunt timing for over-switch track circuits
- 6 seconds for the combination of CBTC processing and switch movement

Due to the different travel times for trains departing terminal stations either on the straight route through the interlockings or on the diverging route, it should be noted that the time between platform departures is slightly different to the headway of trains as they pass a common point on the track just clear of the interlocking.

4.5 CIVIL SPEED LIMIT PROFILES

The Canarsie Line civil speed profile was developed throughout the course of the simulation activities. At the time of the development of the Design Brief, a civil speed limit profile was derived from the existing signal system drawings. The profile was considered at the time to be conservative in that the intermittent nature of the speed control afforded by a wayside color light signal and tripstop system enforces lower speeds than permitted by civil constraints. This accounts for acceleration of a train just after it passes a tripstop.

Prior to the R-143 Performance simulations, the civil speed profiles were reviewed with the conclusion that they were overly conservative and did not take advantage of the continuous overspeed protection offered by a CBTC system.

Following the October 22, 1998 R143 Performance Meeting, the civil speed limit profiles were further examined in conjunction with CPM and RTO. Further upgrades of speeds were made which incorporated a maximum speed of fifty two (52) mph. This ensures that an absolute top speed of fifty five (55) mph cannot be exceeded, with allowances to account for speed measurement errors in the CBTC equipment. These errors can be introduced by inaccuracies in the devices themselves and variations in the wheel diameters between actual and perceived. A five percent (5%) margin of error was assumed which resulted in the fifty two (52) imposed top speed limit.

The finalized civil speed profile is contained in Appendix A of this report.

5. <u>RESULTS</u>

5.1 CBTC HEADWAY RESULTS

The results of the headway simulation analysis are presented in the following Exhibits. Exhibit 8 presents a tabular summary of the simulations resulting in minimum uninterfered headway times with 20 seconds dwells.

Exhibit 8. Minimum Uninterfered Headway Simulation Run with 20 Second Dwells

Direction	SB/EB Rate Combination	Uninterfered Headway	Interference Point
NB	1.25/1.50	1:56	Lorimer St.
SB	1.25/1.50	1:43	Union Square Ave.
NB	1.75/2.0	1:28	Jefferson St.
SB	1.75/2.0	1:33	East 105th St.

Exhibit 9 presents a tabular summary of the simulations resulting in minimum uninterfered headway times with the Exhibit 7 Dwell Times and using SDs calculated from the two combinations of service and emergency brake rates.

Exhibit 9. Minimum Uninterfered Headway Simulations with Exhibit 7 Dwells

Direction	SB/EB Rate Combination	Uninterfered Headway	Interference Point
NB	1.25/1.50	2:16	Lorimer St.
SB	1.25/1.50	2:08	Union Square Ave.
NB	1.75/2.0	1:47	Lorimer St.
SB	1.75/2.0	1:38	East 105th St.

Exhibits 10 presents the interfered headway simulation results. The results show the interfered headways of each station to station section, using the Exhibit 7 Dwell Times and with a SB/EB rate combination of 1.25/1.5 mphps

Exhibit 10. Interfered Headway Simulation Results Using a Minimum 20 mph Criteria and Exhibit 7 Station Dwells.

Station	Headway (NB)	Headway (SB)
8th Avenue		
6th Avenue	1:18	1:17
Union Square	1:16	1:17
3rd Avenue	1:12	1:05
1st Avenue	1:16	1:18
Bedford Ave.	1:15	1:17
Lorimer Street	1:16	1:17
Graham Avenue	1:03	1:02
Grand Street	1:02	1:02
Montrose Avenue	0:58	0:56
Morgan Avenue	0:57	1:01
Jefferson Street	0:59	0:56
De Kalb Avenue	0:58	1:02
Myrtle Avenue	1:16	1:38
Halsey Street	1:03	1:02
Wilson Avenue	0:57	0:57
Aberdeen Street	0:58	0:58
Broadway	1:15	1:26
Atlantic Avenue	0:57	0:59
Sutter Avenue	1:02	1:00
Livonia Avenue	0:57	0:58
New Lots Avenue	0:57	0:57
East 105th Street	1:02	1:15
Rockaway Parkway		

5.2 CBTC END-TO-END RUN TIME RESULTS

Exhibit 11 presents a tabular summary of the end-to-end run time simulation results with three patterns of dwell times, including zero, 20 second, and Exhibit 7 dwells.

Exhibit 11. End to End Run Times with Varied Dwell Time Patterns

Direction	Dwell Times	Run Times
NB	(0 second dwells)	26:26
SB	(0 second dwells)	25:29
NB	(20 seconds dwells)	33:24
SB	(20 seconds dwells)	32:27
NB	(Exhibit 7 dwells)	36:19
SB	(Exhibit 7 dwells)	35:22

Speed/distance profiles for the simulations of run times determined with uninterfered operation are illustrated in Exhibits 12.1 and 12.2.

Exhibit 12.1. Speed Distance Profile for Canarsie Line, Southbound

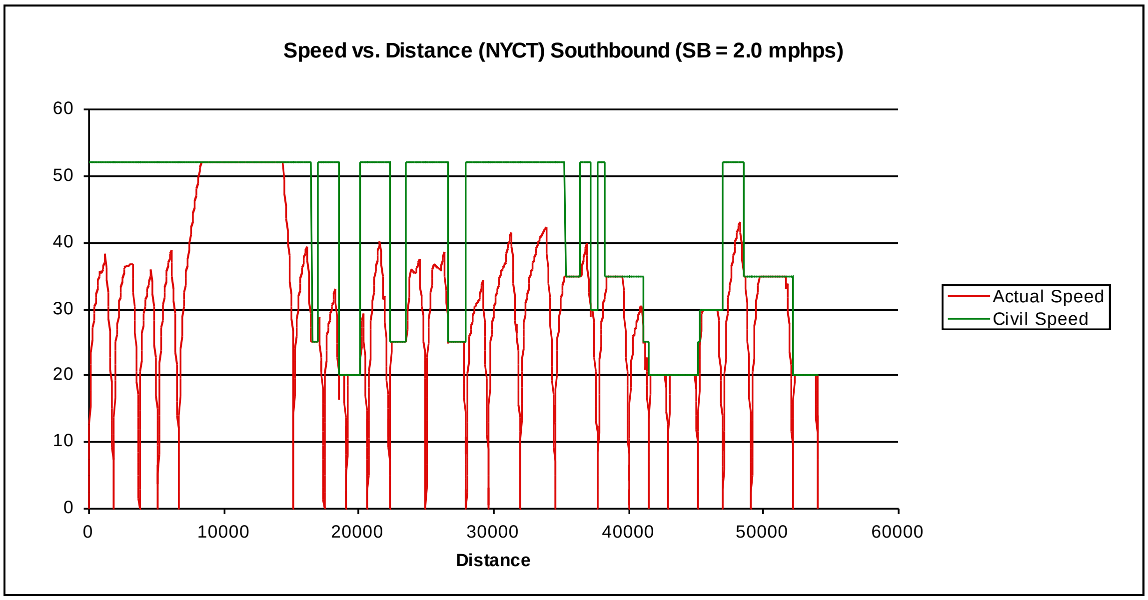
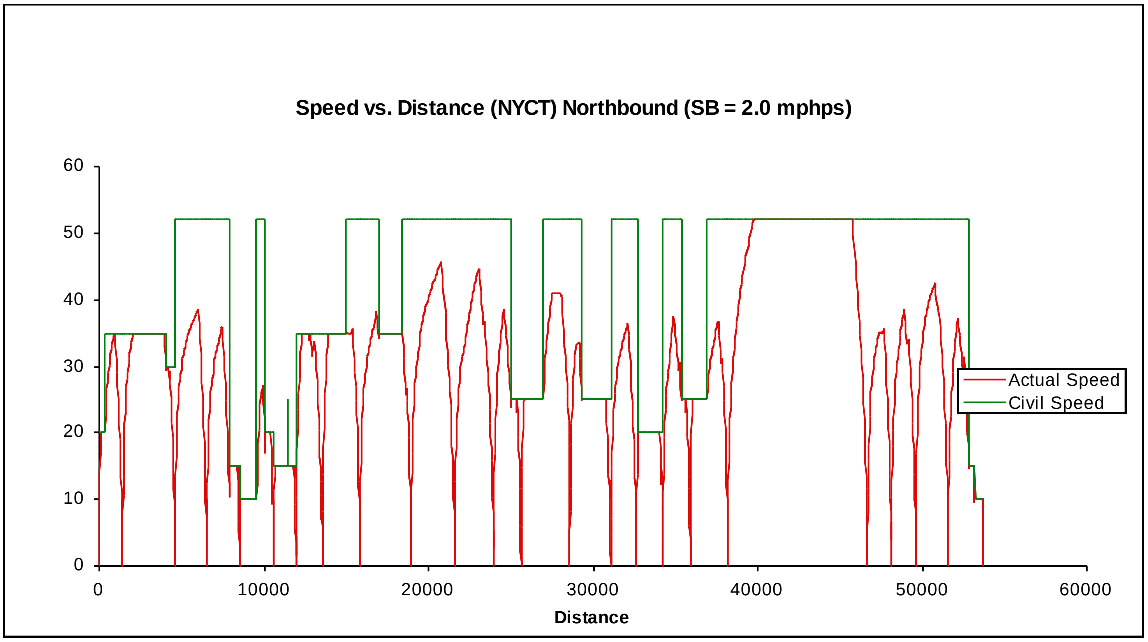


Exhibit 12.2. Speed Distance Profile for Canarsie Line, Northbound



5.3 CBTC HEADWAY RESULTS AT TURNBACK STATIONS

The results of the headway simulation analysis at the turnback stations are presented in the following Exhibits. Exhibit 13 presents a tabular summary of the simulations resulting in minimum uninterfered headway times using varied dwells for 8th Avenue.

Exhibit 13. 8th Avenue Turnback Station Headway Results

Departing Headway	Station Dwells (seconds)	Measured Headway (seconds)			
Interlocking Departing Headway	70	68	129	68	129
Platform Departing Headway	70	72	125	72	125
Interlocking Departing Headway	120	118	124	116	126
Platform Departing Headway	120	122	120	120	122

Exhibit 14 presents a tabular summary of the simulations resulting in minimum uninterfered headway times using varied dwells for Rockaway Parkway.

Exhibit 14. Rockaway Parkway Turnback Station Headway Results

Departing Headway	Station Dwells (seconds)	Measured Headway (seconds)					
Interlocking Departing Headway	70	99	152	86	165	73	178
Platform Departing Headway	70	113	138	100	151	87	164
Interlocking Departing Headway	120	149	152	136	165	123	178
Platform Departing Headway	120	163	138	150	151	137	164

6. CONCLUSIONS

In conclusion, the simulation activities developed and enhanced throughout the process, produced results that are within a range which can be considered acceptable for achieving the target scheduled peak service operating headway on the Canarsie Line. In the majority of locations, an interfered headway of between 60 and 75 seconds for an eight car consist is achievable.

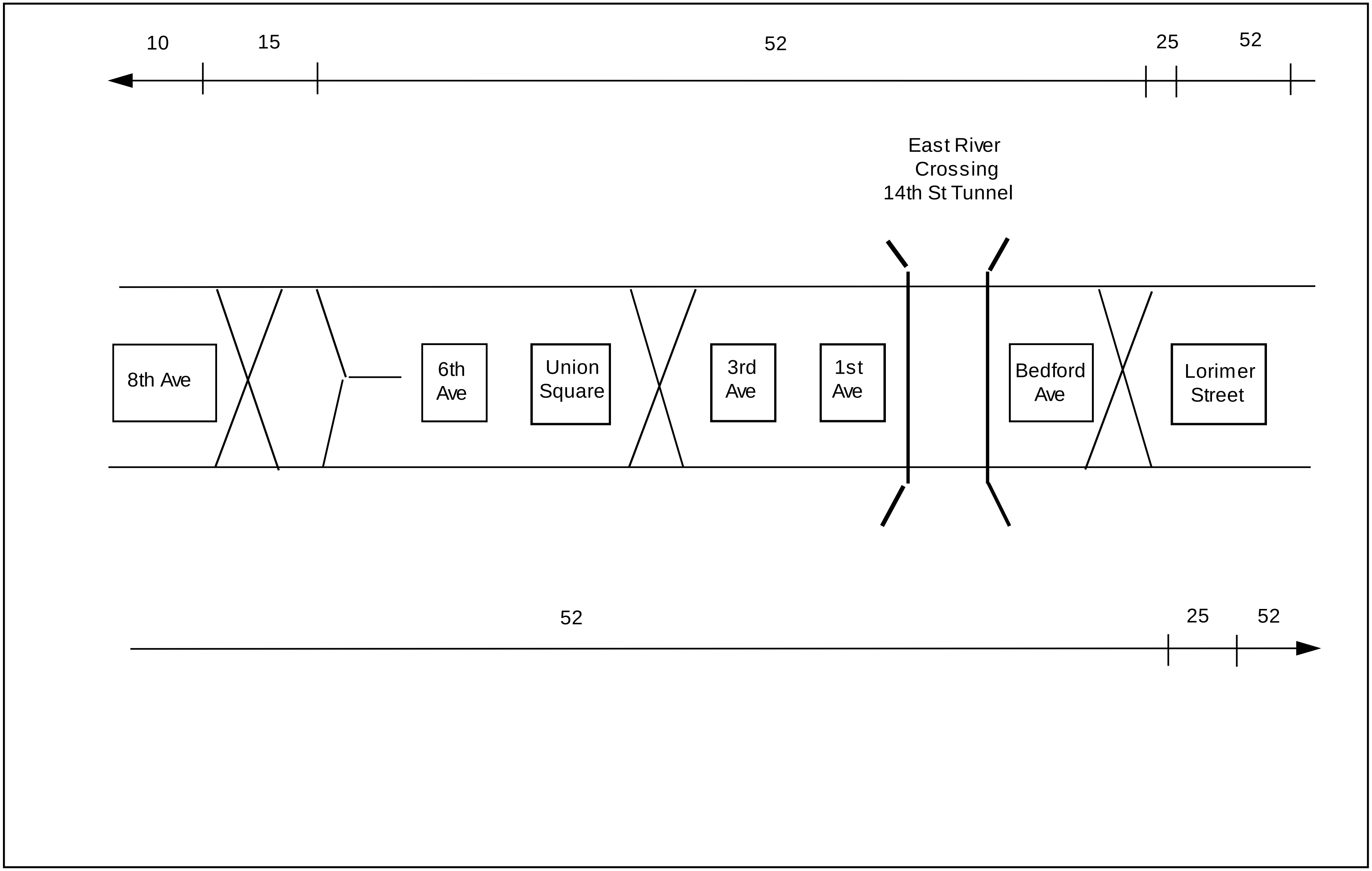
By taking full advantage of the continuous overspeed protection which allows train operation up to the civil speed limit (allowing for tolerances) at all times, CBTC operation results in trip time savings over the existing Canarsie Line operation.

The emergency brake rate of 1.5 mphps appears to be a conservative number which supports the desired headway capabilities. The confirmation of this number as a Guaranteed Emergency Brake Rate is being undertaken as a separate test and engineering exercise.

As expected, CBTC performance does not impose the limiting constraint on Canarsie Line headways, both terminal stations impact the minimum headway significantly. Significant reduction in sustainable headway could be achieved by remodeling the Rockaway Parkway interlocking, relocating the turnous adjacent to the north end of the platforms.

APPENDIX A

SIMULATION CIVIL SPEED PROFILE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East River Crossing 14th St Tunnel
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Bedford Ave
Lorimer Street
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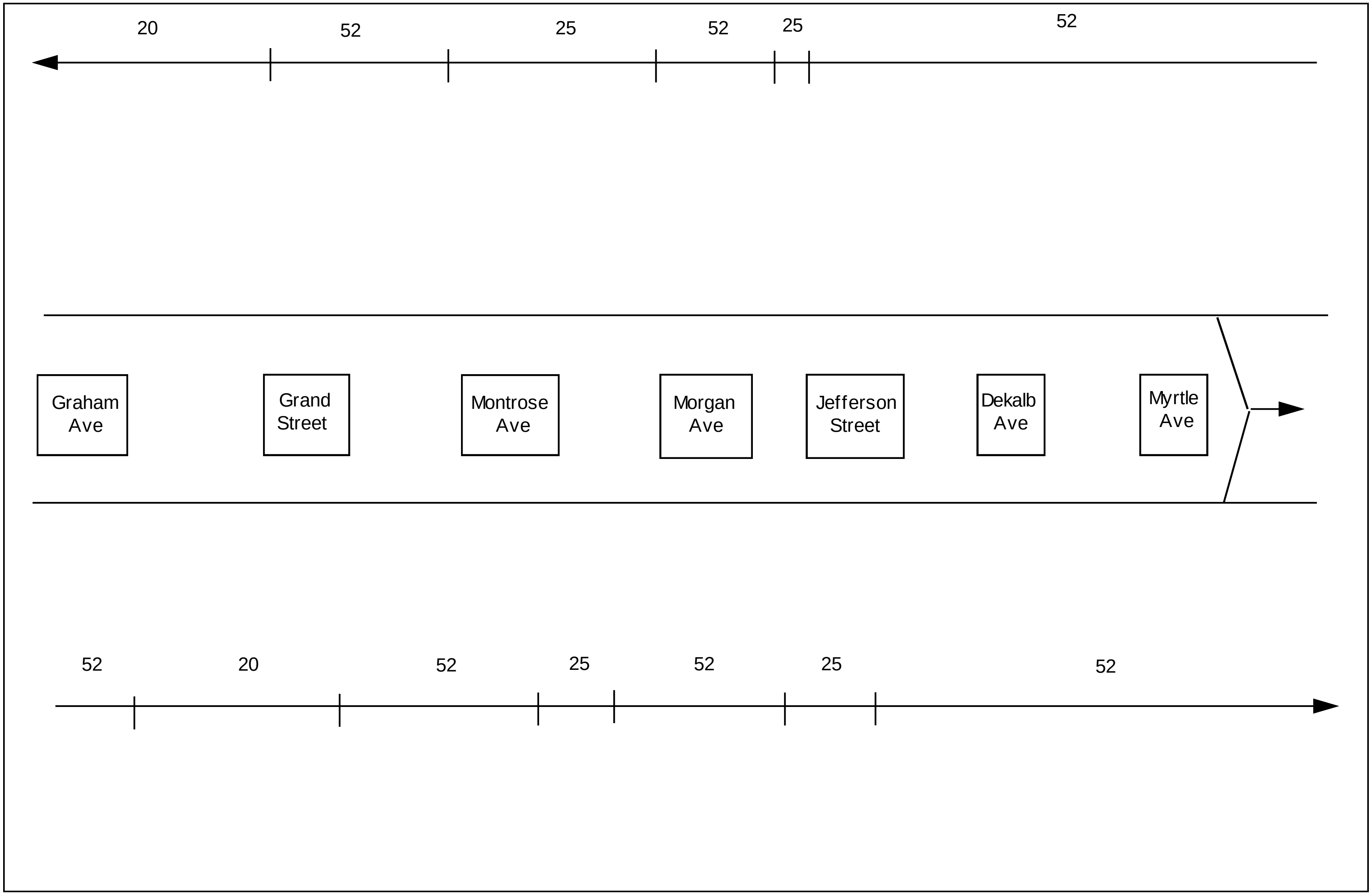
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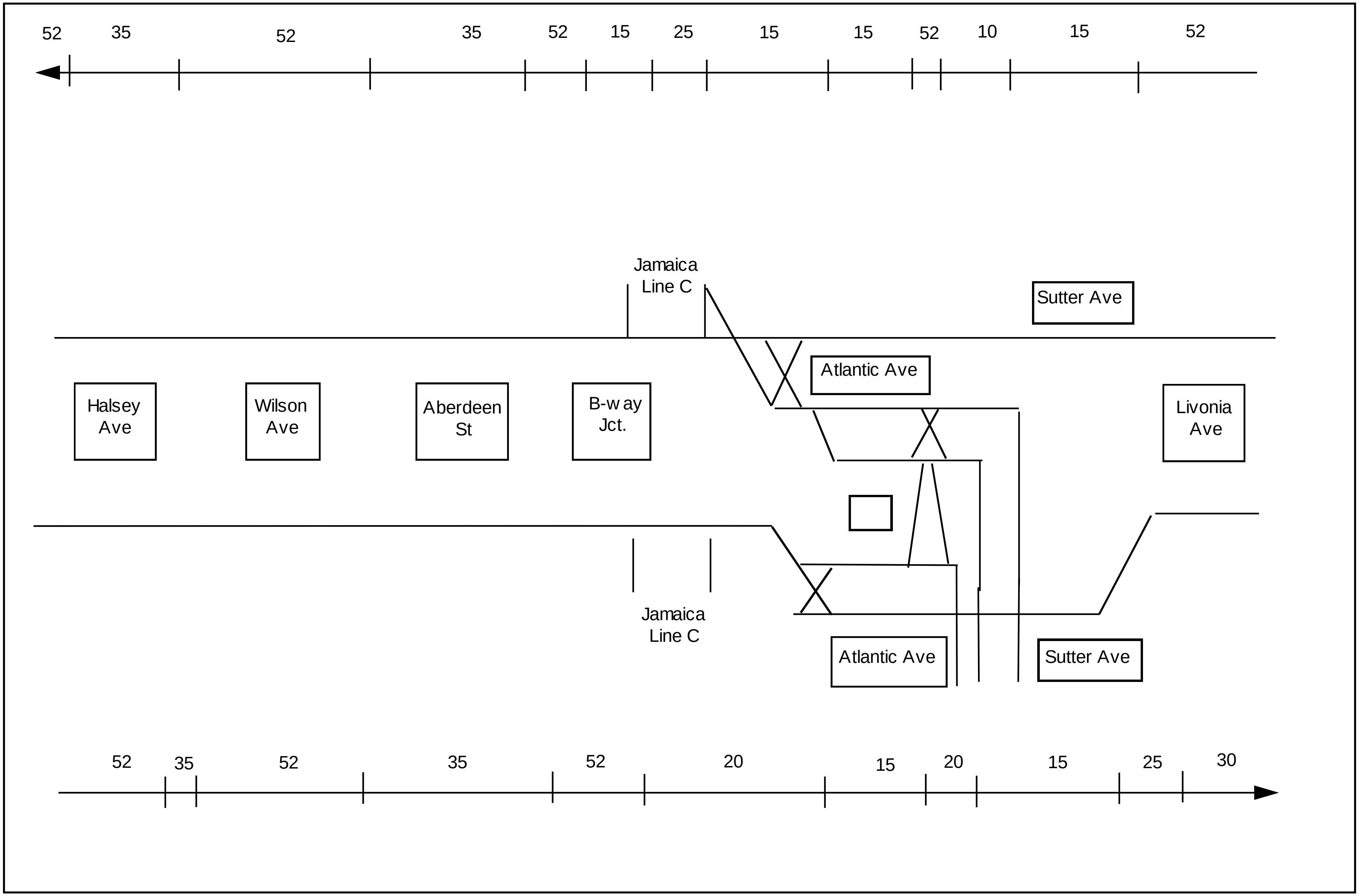
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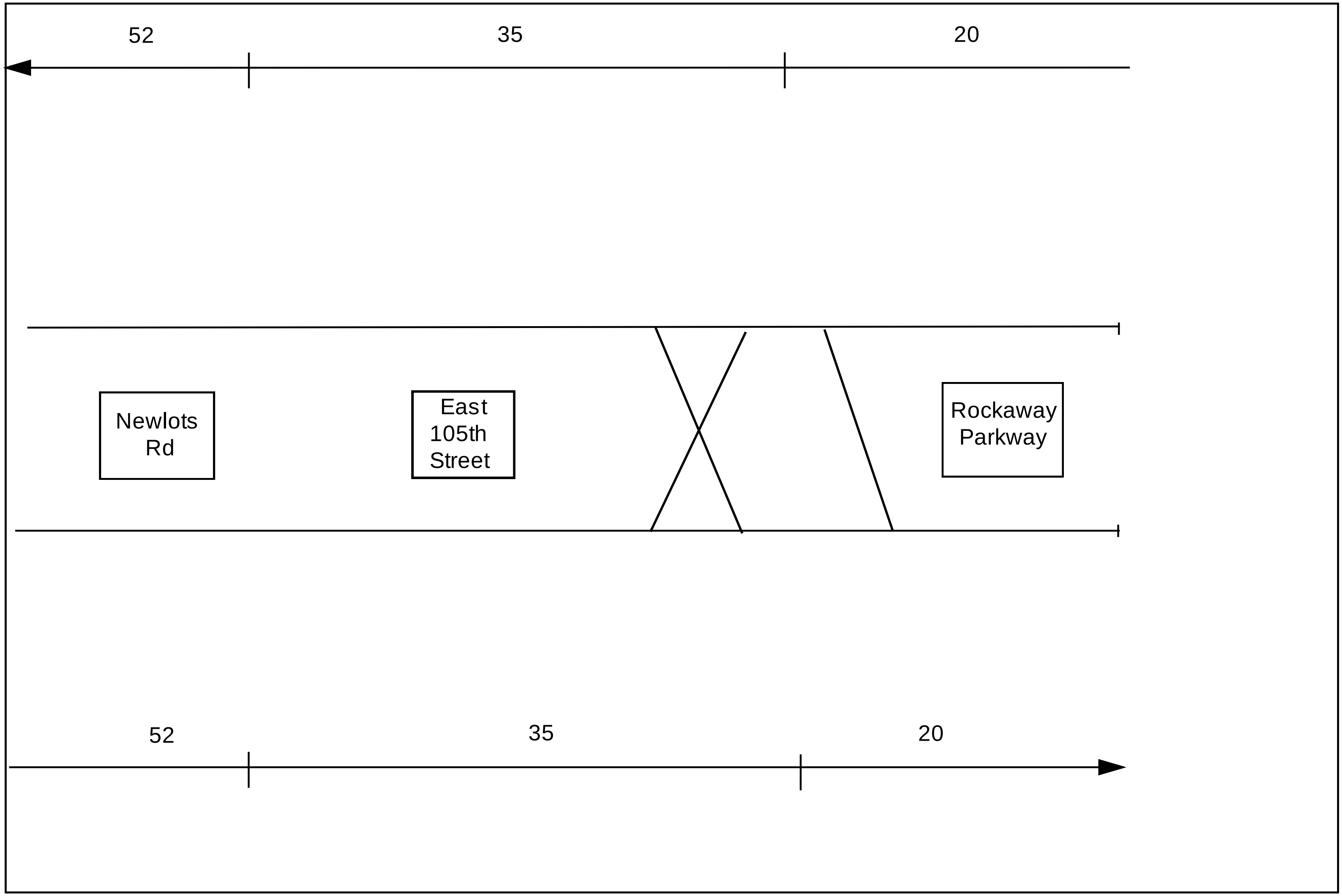
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