Ottawa Light Rail

CAPITAL TRANSIT PARTNERS

REPORT

Operations Reference

Ottawa Light Rail Transit Project

Ottawa, Ontario

Presented to:

City of Ottawa Rail Implementation Office

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1. EXECUTIVE SUMMARY

This document serves as a summary of the operational analysis activities performed during Preliminary Engineering (PE) (see Section 3) and the development of the Preliminary Service Plan in preparation of the release of the RFP (see Section 4).

Operational Analysis

The operations analysis performed during the PE phase of the OLRT project was based on the travel demand forecasts for 2021 and 2031 provided by the City of Ottawa. Specifically, the system was analyzed in terms of its ability to support the peak hour peak section passenger loads of 11,360 pphpd (persons per hour per direction) in 2021 occurring westbound between Lees and Campus stations and 18,040 pphpd in 2031 eastbound between Bayview and LeBreton stations

An analysis of peak passenger capacity found that the required passenger demand at the peak load point can be accommodated by operating 4-car trains (assuming a typical 30-metre LRV) every 3.25 minutes in 2021 and every 2.10 minutes in 2031. An ultimate capacity of 24,000 passengers can be supported with 150-metre trains operating at 2-minute headways. Based on the projected headways and preliminary run times, fleet requirements were estimated. In 2021 an estimated 18 trains would be required in service, resulting in a fleet of 80 LRVs with 10% spares (assuming typical 30-metre vehicles).

CTP subsequently performed a computer model simulation of the proposed LRT operation using nominal peak headways of 3 minutes in 2021 and 2 minutes in 2031. Simulations were based on the alignment design(s) and signal system criteria available during the PE phase. The simulation provided run times, assisted in refining the system design, and validated the capability of the system to support the proposed operations. Both manual (MTO) and automatic (ATO) train operations were simulated resulting in end to end run times of approximately 24 and 23 minutes, respectively.

A discrete analysis of terminal capacities undertaken early in the PE phase led to significant modifications of terminal configurations from the initial (EPR) designs in order to support the anticipated 2-minute headways.

An analysis of the ability of the system to operate during track outages was also performed with a goal of supporting maintenance activities during revenue service operating at 15-minute headways. This led to the addition or relocation of crossovers in strategic locations. In the final PE alignment, the tunnel segment from the LeBreton Crossover to the Campus Crossover is the critical segment with an estimated operational headway restriction of approximately 16.5 minutes. The 15-minute headway goal can be achieved everywhere else on the system. Consideration should be given in future designs to improve the operating flexibility through the tunnel.

Preliminary Service Plan

Using the results of the Operations Analysis, a Preliminary Service Plan was prepared in coordination with OC Transpo as a basis for the RFP and Project Agreement. The service hours and service levels are shown below.

Service Periods and Non-Peak Service Levels

Period		From	To	Headway (min)
Weekdays				
Early Morning		5:00	6:30	8
Morning Peak		6:30	9:00	*varies*
Midday		9:00	14:45	5
Afternoon Peak		14:45	18:00	*varies*
Early Evening		18:00	21:30	5
Late Evening		21:30	23:00	8
Night	Mon – Thurs	23:00	1:00	15
	Friday	23:00	2:00	15
Weekends & Holidays				
Base		6:00	19:00	5
Evening	Saturday	19:00	2:00	8
	Sunday / Holiday	19:00	23:00	10

The 2021 and 2031 peak hour loads were used in combination with OC Transpo's long term organic growth projections to develop peak hour demand through 2048. Peak period service headways and train consists have been established based in order to meet or exceed these demand projections over the 30 year term.

Peak Period Service Plan

	2018-21	2022-24	2025-27	2028-30	2031-35	2036-40	2041-45	2046-48
Peak Headway (min)	3.25	2.80	2.45	2.15	2.00	2.40	2.25	2.20
Consist Length	120-m	120-m	120-m	120-m	120-m	150-m	150-m	150-m
Trains in Peak Service	**17**	**19**	**22**	**24**	**26**	**22**	**24**	**24**

A more detailed description of the various analyses and results are presented in the report with relevant backup material provided in the Appendices.

2. INTRODUCTION

This document serves as a summary of the operational analysis activities performed during Preliminary Engineering (PE) and in preparation of the release of the RFP. The operational analysis work completed to date is based on the travel demand forecasts for 2021 and 2031 prepared by the City of Ottawa in January 2011, as well as technical analyses of passenger capacities and the operations simulation. The operational analysis activities summarized in Section 3 of this document informed the development of the Preliminary Service Plan discussed in Section 4.

3. SUMMARY OF OPERATIONAL ANALYSIS DURING PE

This section presents the underlying demand requirements, capacity analysis, and the analysis and refinement of the system design to support the anticipated operational requirements.

3.1 Ridership Demand Forecasts

Ridership demand forecasts were prepared by the City of Ottawa and provided to the OLRT project in January 2011. Forecasts were provided for the AM peak hour (peak of the peak) in terms of boardings and alightings at each station for the following scenarios:

1. Year 2021 Tunney's Pasture to Blair LRT system without STO (Société de transport de l'Outaouais) transfers from Gatineau
2. Year 2031 Baseline to Blair LRT system with STO transfers from Gatineau and North/South LRT line at Bayview.

The 2021 scenario did not include passengers transferring from STO services from Gatineau as it is assumed STO bus service will continue to serve downtown directly in that timeframe. The 2031 information assumes that passengers on STO services will transfer from Gatineau at Bayview.

Table 3-1 shows the boardings and alightings data provided for the 2021 scenario AM Peak Hour, while Table 3-2 shows the same data for the 2031 scenario. Eastbound and Westbound Peak Hour loads were calculated, with the maximum peak load segment occurring westbound between Campus and Lees stations at a load of 11,360 pphpd (persons per hour per direction) in 2021 and between Bayview and LeBreton at a load of 18,040 pphpd in 2031. It is noted that the proposed peak loads would likely represent the highest passenger volumes on a Light Rail System in North America.

In addition to the identified peak loads, the ridership forecasts also show high volumes of passenger flows (boardings plus alightings) at the terminal stations, the downtown stations, and at major transfer stations including Hurdman and Bayview. High station passenger flows increase dwell times (as discussed in Section 3.3.2) and influence the design of stations including the widths of platform pedestrian circulation elements.

Table 3-1: 2021 AM Peak Hour without Transfers from Gatineau Station

	Eastbound			Westbound		
LRT Station	Boardings	Alightings	**EB Load**	Boardings	Alightings	**WB Load**
Tunney's Pasture	9,930	0	**9,930**	0	2,950	**0**
Bayview	220	390	**9,760**	140	570	**2,950**
LeBreton	130	440	**9,450**	60	380	**3,380**
Downtown West	440	2,550	**7,340**	680	2,860	**3,700**
Downtown East	480	3,850	**3,970**	700	4,320	**5,880**
Rideau Centre	1,730	2,090	**3,610**	1,420	2,300	**9,500**
Campus	330	1,770	**2,170**	430	1,410	**10,380**
Lees	210	280	**2,100**	460	150	**11,360**
Hurdman	950	1,140	**1,910**	3,200	540	**11,050**
Train Station	20	170	**1,760**	20	80	**8,390**
St. Laurent	560	580	**1,740**	910	330	**8,450**
Cyrville	20	290	**1,470**	220	100	**7,870**
Blair	0	1,470	**0**	7,750	0	**7,750**
Total	**15,020**	**15,020**		**15,990**	**15,990**	

Table 3-2: 2031 AM Peak Hour with Transfers from Gatineau Station

	Eastbound			Westbound		
LRT Station	Boardings	Alightings	**EB Load**	Boardings	Alightings	**WB Load**
Baseline	5,980	0	**5,980**	0	2,260	**0**
Iris	610	40	**6,550**	20	150	**2,260**
Queensway	70	200	**6,420**	310	60	**2,390**
Lincoln Fields	6,650	840	**12,230**	190	1,260	**2,140**
New Orchard	220	40	**12,410**	70	30	**3,210**
Cleary	180	110	**12,480**	30	60	**3,170**
Dominion	190	30	**12,640**	40	30	**3,200**
Westboro	550	100	**13,090**	90	200	**3,190**
Tunney's Pasture	1,080	690	**13,480**	170	1,240	**3,300**
Bayview	4,870	310	**18,040**	140	730	**4,370**
LeBreton	150	940	**17,250**	230	490	**4,960**
Downtown West	300	4,380	**13,170**	1,710	3,680	**5,220**
Downtown East	380	5,990	**7,560**	850	5,260	**7,190**
Rideau Centre	160	3,510	**4,210**	2,060	3,220	**11,600**
Campus	400	2,160	**2,450**	520	1,620	**12,760**
Lees	260	340	**2,370**	560	180	**13,860**
Hurdman	1,830	1,610	**2,590**	3,900	1,380	**13,480**
Train Station	50	150	**2,490**	50	50	**10,960**
St. Laurent	680	950	**2,220**	1,200	600	**10,960**
Cyrville	50	350	**1,920**	170	50	**10,360**
Blair		1,920	**0**	10,240		**10,240**
Total	**24,660**	**24,660**		**22,550**	**22,550**	

3.1.1 Weekday Demand Distribution

To provide a basis for an all-day service plan for operational analysis Capital Transit Partners (CTP), in coordination with the City's Rail Implementation Office (RIO) and OC Transpo evaluated the current travel demand patterns over the course of the day to develop a weekday travel demand distribution. This distribution was used to scale the peak hour demand over the course of the day and also to define the durations of peak and off-peak periods. Ridership information from OC Transpo provides the foundation for the distribution and includes percentages of daily ridership by period, percentages of ridership of AM and PM peak period occurring within the peak hour, as well as information on the Route 95 bus that operates on the OLRT route today and was used to identify the timing of the peak periods. The resulting ridership distribution is shown in Figure 3-1 and includes the percentage targets for Early Morning, AM Peak, Midday, PM Peak, Early Evening and Late Evening, as provided by OC Transpo. According to OC Transpo experience, the AM peak hour carries 50% of the AM peak period, while the PM peak hour carries roughly 33%, indicating a much flatter peaking effect in the afternoon. The AM peak hour is expected to occur between 8:00 a.m. and 9:00 a.m. As this distribution is an approximation based on a limited set of data points, it is recommended that additional field data is obtained by / from OC Transpo to refine the daily demand distribution on the OLRT system prior to finalizing the LRT operating plan.[1]

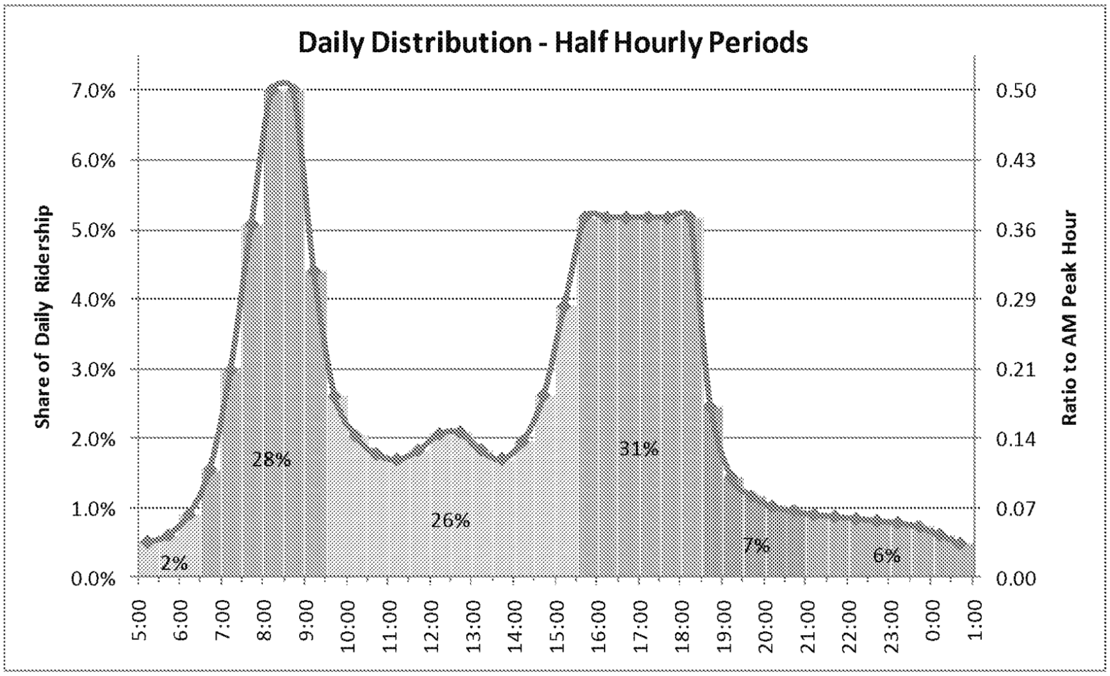

Figure 3-1: Weekday Ridership Distribution: Half Hour Periods

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[1] OC Transpo established specific periods and service levels for the development of the Preliminary Service Plan described in Section 4.

3.2 Peak Capacity Analysis

This section presents a capacity analysis undertaken early during the PE phase to assess previous analyses included in the Environmental Project Report (EPR) and to inform project designers of the operational performance requirements of the OLRT System based on the projected travel demand. This analysis led to a recommendation for 120-metre platforms at opening and a 150-metre platforms in the ultimate configuration as documented in the "*Proposed Light Rail Station Lengths of 120 meters with Provision for Expansion to 150 meters*" technical memorandum included in Appendix A.

CTP developed a capacity analysis to determine the required service levels (headways and train consists) to support the projected peak hour travel demand in 2021 and 2031, which would form the basis for the design of the current system. Additionally, CTP also evaluated the possibility for accommodating an ultimate demand of 24,000 pphpd beyond 2031. The post 2031 capacity needs are given consideration in the current design by anticipating, and thus not precluding, future capacity enhancements including the expansion of station platforms for longer consists.

The capacity analysis performed by CTP is based on a typical 30-metre double-ended LRV fleet operated in four- or five- car consists. For the purpose of maximizing capacity, this is a conservative assumption as there is a significant amount of non-passenger space due to the unoccupied operator cabs and coupler areas. It also assumes a traditional layout with a 2+2 seating arrangement. It was recommended that the LRV concept for Ottawa be optimized to meet the high ridership forecasts (possibly including the use of married-pairs and/or 2+1 seating arrangements).

The capacity calculations were based on a fifteen minute peak of the peak passenger loading standard of a seated load plus up to five standees per square meter at the peak load section in accordance with industry guidance as contained in the *Transit Capacity and Quality of Service Manual, 2nd Edition* (TCRP Report 100). The calculations rely on a Peak Hour Factor (PHF) of 0.80 based on other, similar high frequency operations. The PHF accounts for demand variations during the peak hour and is defined as the peak hour load divided by four times the peak 15-minute load. In other words, the projected demand over the peak hour must not be more than 80% of the supplied capacity. Many transit agencies, including OC Transpo, define their loading standard as an average over the peak hour, rather than over the peak 15 minutes. The above fifteen minute load standard and PHF are generally equivalent to an average peak hour load standard of 3.5 standees per square meter.[2] Table 3-3 below shows that the required passenger demand at the peak load point can be accommodated by operating 4-car trains every 3.25 minutes in 2021 and every 2.10 minutes in 2031. Additionally, the table shows that the ultimate capacity beyond 2031 can be met by operating 5-car (150 m) consists every 2 minutes.

Additional vehicle capacity enhancements discussed previously would further reduce the frequency of service to be provided or conversely reduce the standee density at the peak load point. Based on this analysis, CTP recommended that the 180-metre protected platform areas identified in the Environmental Project Report could be reduced to 150-metre protected areas while still meeting the projected build-out demand of the system. (Refer to "*Proposed Light Rail*

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[2] OC Transpo established a max. load of 3.33 standees per square metre as discussed in Section 4.

Station Lengths of 120 meters with Provisions for Expansion to 150 meters" memo in Appendix A.)

Table 3-3: Vehicle Capacity Investigation

	Capacity through 2031		**Capacity beyond 2031**
	120-metre Train Length		**150-metre Train Length**
Vehicle Type	Double-ended 30-m LRV		Double-ended 30-m LRV
Number of Cars in Consist	4	4	5
Peak Period Headway	**3.25**	**2.10**	**2.00**
Vehicle Capacity (5 standees/m^2)*	203	203	203
Train Capacity	812	812	1015
Supplied Capacity (spc/hour/direction)	**15,000**	**23,200**	**30,500**
Effective Passenger Capacity (PPHPD) (PHF=0.80)	**12,000**	**18,600**	**24,400**

* Peak 15-minute load standard – equivalent to hourly average of 3.5 standees/m^2

The charts shown in Figure 3-2 and Figure 3-3 combine the peak link load projections and proposed peak hour service capacities for 2021 and 2031. They also show the average standee densities along the line. The outlined standee densities indicate where the projected loading would exceed OC Transpo's current load standard for buses of 2.5 standees per square meter. It has been discussed that higher loading densities on rail than on bus are common. Furthermore, these charts indicate that the OC Transpo bus loading standards would be exceeded only for short durations during the peak hour.

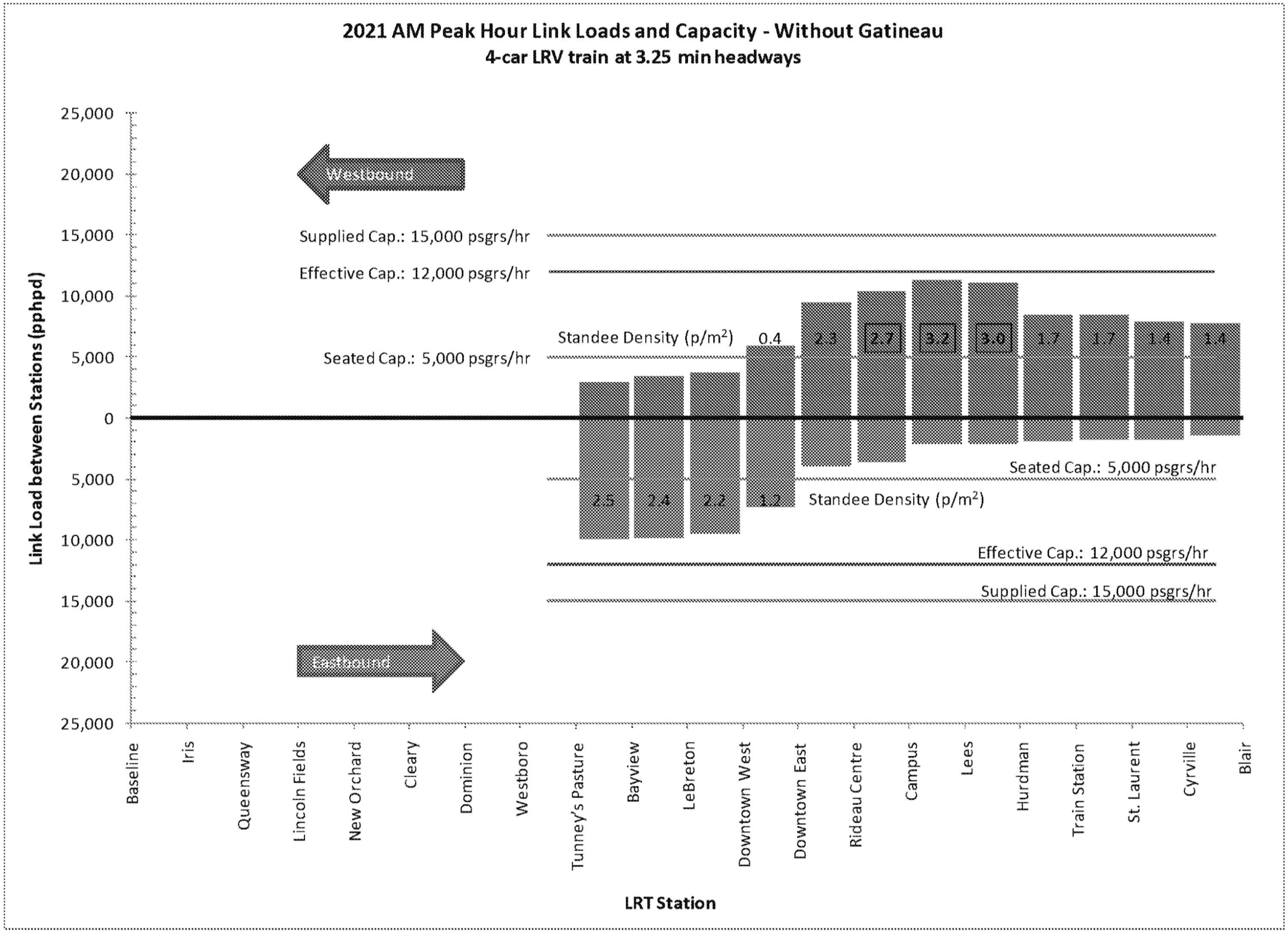

Figure 3-2: 2021 Peak Link Loads and Capacities – Without Gatineau Transfers

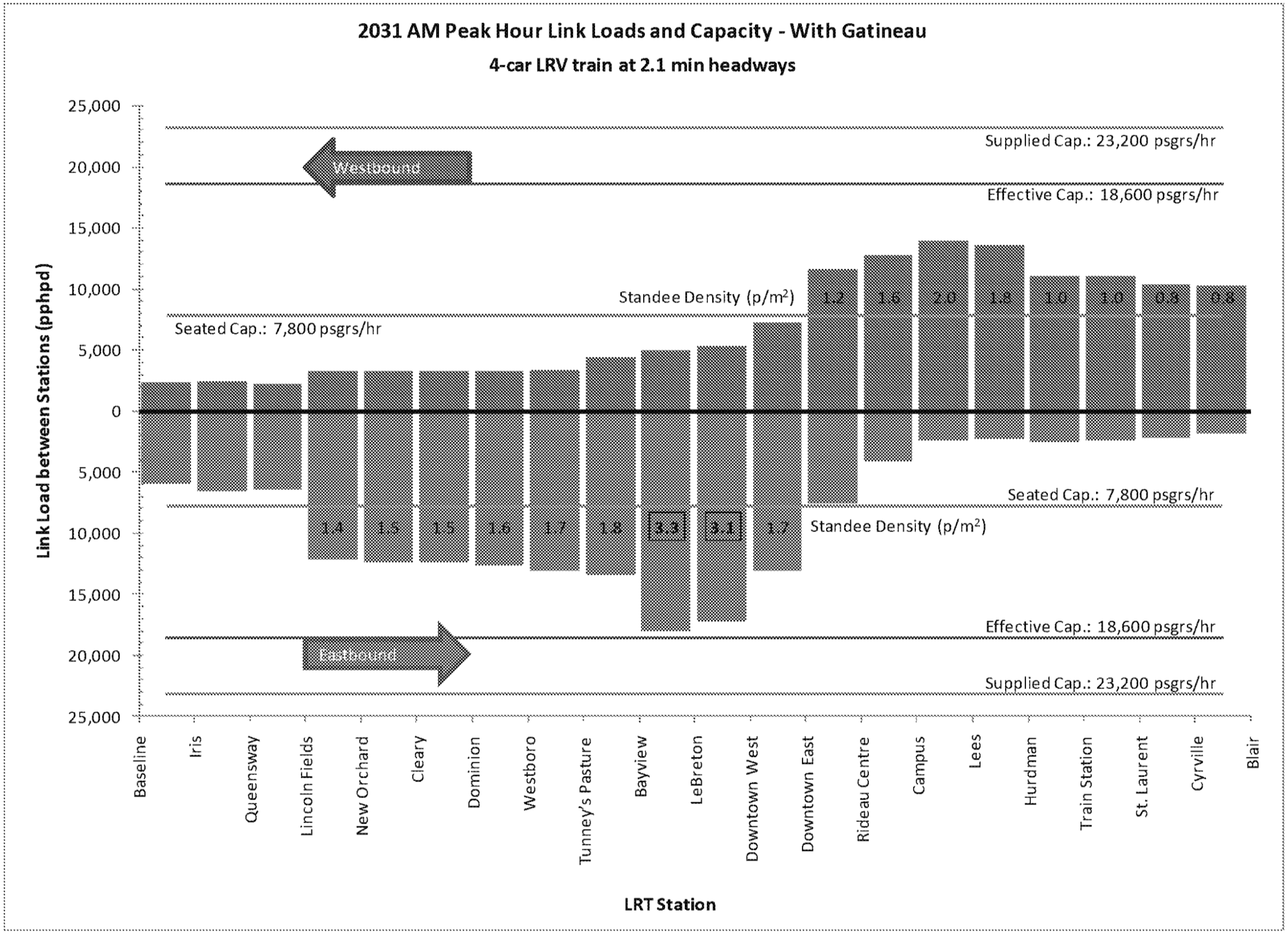

Figure 3-3: 2031 Peak Link Loads and Capacities – With Gatineau Transfers

3.2.1 Peak Fleet Requirements

The fleet sizes required to support these peak service level were also estimated. Based on early simulation efforts, minimum cycle time was estimated as the round trip run time of 48 minutes (24 minutes in each direction) plus a layover at each terminal of 1.5 times the headway:

Cycle Time = 48 min + 2(1.5*headway)*

Using this estimate of cycle time, 18 4-car trains would be required in peak service in 2021 for the service between Tunney's Pasture and Blair, as shown in Table 3-4. At an assumed spare ratio of 10%, this results in a fleet of 80 vehicles. An equivalent value for 2031 would require about 26 trains resulting in a fleet of 115 vehicles; however, this value is incomplete as it only reflects the fleet required to operate over the initial portion of the system between Tunney's Pasture and Blair. The operating assumption in 2031 anticipates an extension beyond Tunney's Pasture which will require additional vehicles to travel a longer route.

For consistency the peak fleet requirements are again based on the conservative assumption of a typical 30-metre, double-ended LRV fleet.

Table 3-4: Peak Vehicle Demand

	2021	2031	Beyond 2031
Peak Period Headway	3.25 min	2.10 min	2.00 min
Number of Cars in Consist	4	4	5
Cycle time	58 min	54 min	54 min
Number of Trains in Peak Service	18	26	27
Peak Vehicle Demand	**72**	**104**	**135**
Total Fleet (with 10% Spares)	**80**	**115**	**149**

3.3 Operational Analysis and Simulation

This section documents the analysis and simulation of train operations on the proposed OLRT system as developed throughout the PE phase including run times, dwell times, terminal capacity and line capacity (throughput). This analysis informed and helped to optimize the design of track and terminals in order to support the operational requirements. The operational analysis was performed in parallel with the development and refinement of track, station, and systems design. Several revisions to the track alignment, station and terminal design beginning with the EPR design and concluding with the final PE alignment resulted in multiple performance analyses. Unless otherwise indicated, the results presented in this section reflect the final PE design as included elsewhere in the reference documents. Initial analyses were based on Manual Train Operation (MTO). During the course of PE, Automatic Train Operation (ATO) capabilities were added to the system design in order to enhance operating consistency and reliability (See also "*Recommendation for Automatic Train Operation (ATO) Capability on Opening Day*" in Appendix B). Both MTO and ATO will be possible on the system and the final operational analysis was performed for both modes of operation.

3.3.1 Operations Simulation

CTP performed a computer model simulation of the proposed LRT operation based on the alignment design and signal system criteria available during this phase, starting with the initial CTP alignment design, which was based largely on the EPR alignment. The simulation was undertaken to estimate run times, identify infrastructure deficiencies that negatively affect operations, and to validate the capability of the system to support the proposed operations through 2031. The simulation was carried out assuming nominal peak operating headways of 3 minutes in 2021 and 2 minutes in 2031 for both ATO and MTO operation. Manual operations were simulated by introducing randomized underperformance of individual trains as well as a lower braking rate into stations. Simulation results are incorporated in the subsequent sections. Greater detail including inputs and assumptions is provided in the *Rail Operations Simulation and Analysis Report* in Appendix C.

3.3.2 Dwell Time Estimates

As part of the simulation work, dwell times estimates were developed for each station stop using the projected peak hour passenger flows discussed in Section 3.1. These projections were applied to a dwell time model that is based on dwell time observations of a high ridership light rail line with a downtown central subway -- the MBTA Green Line in Boston.

At each station stop, the model uses a fixed base dwell time of 15 seconds to account for activity before and after passenger movement (door opening and closing, related system checks, etc.) The model adds time for boarding and alighting based on an average passenger flow of 30 people per minute per train door; for a 4-car train and 4 doors per car, 480 passengers can board or alight per minute. Resulting dwell times applied as nominal values for the simulation are presented in Table 3-5.

Table 3-5: Nominal Station Dwell Times (seconds)

LRT Station	Year 2021		Year 2031	
	Eastbound	Westbound	Eastbound	Westbound
Tunney's Pasture	-	-	22	21
Bayview	19	19	37	19
LeBreton	19	18	20	18
Downtown West	34	37	35	37
Downtown East	42	46	42	40
Rideau Centre	39	38	30	37
Campus	28	27	26	24
Lees	18	19	18	18
Hurdman	28	38	29	37
Train Station	16	16	16	15
St. Laurent	22	23	22	23
Cyrville	17	17	17	16
Blair	-	-	-	-

Note: Layover time at terminals includes dwell time for loading & unloading of passengers

Randomized variations were applied to these nominal dwell times in the simulation. Additional detail about dwell time variation is provided in Appendix C.

3.3.3 Run Time Estimates

End to end run times between Tunney's Pasture and Blair vary depending on the operator performance, the route (diverging vs. straight moves), as well as the amount of train interaction when train headways are very short, as is the case in the Peak periods in 2031 with a 2-minute headway. The effect of train interaction occurs primarily for MTO operations. The run time estimates provided in Table 3-6 below reflect the actual anticipated run times under peak period operating conditions and include the randomization of operator performance (for MTO) and station dwell times. These values reflect median values that are suitable for purposes of developing an operating plan and estimating fleet requirements. For ATO, run times are approximately 23 minutes in each direction. MTO run times are approximately 24 minutes and 24.3 minutes for 3-min and 2-min headways, respectively. The directional differences and crossover effects are minimal when compared to the performance variation by different operators. Table 3-6 shows the approximate station to station run times, including station dwell times that are conservatively based on the passenger flows occurring during the peak period.

Table 3-6: Median Station to Station Run Times

Automatic Train Operation (ATO) – 2031, 2-minute operation

Station	Eastbound			Westbound		
	Run Time	Departure to Departure Time	Cumulative Run Time	Run Time	Departure to Departure Time	Cumulative Run Time
Tunney's Pasture						
	01:22	01:42	01:42	01:20	01:20	22:55
Bayview						
	01:11	01:31	03:13	01:10	01:31	21:35
LeBreton						
	01:29	02:05	05:18	01:34	01:52	20:05
Downtown West						
	00:45	01:28	06:46	00:45	01:24	18:12
Downtown East						
	00:52	01:32	08:18	00:52	01:39	16:49
Rideau						
	01:48	02:17	10:36	01:49	02:28	15:10
Campus						
	01:24	01:44	12:19	01:10	01:38	12:42
Lees						
	01:21	01:50	14:09	01:23	01:42	11:04
Hurdman						
	01:53	02:09	16:18	01:52	02:31	09:22
Train						
	02:11	02:35	18:53	02:09	02:25	06:51
St Laurent						
	01:26	01:44	20:36	01:25	01:48	04:26
Cyrville						
	02:24	02:24	23:00	02:20	02:38	02:38
Blair						

Manual Train Operation (MTO) – 2031, 2-minute operation

Station	Eastbound			Westbound		
	Run Time	Departure to Departure Time	Cumulative Run Time	Run Time	Departure to Departure Time	Cumulative Run Time
Tunney's Pasture						
	01:28	01:47	01:47	01:26	01:26	24:22
Bayview						
	01:16	01:36	03:24	01:16	01:37	22:56
LeBreton						
	01:36	02:12	05:35	01:41	02:00	21:19
Downtown West						
	00:48	01:31	07:07	00:49	01:27	19:19
Downtown East						
	00:56	01:36	08:43	00:56	01:43	17:52
Rideau						
	01:55	02:25	11:08	01:58	02:37	16:09
Campus						
	01:30	01:50	12:58	01:16	01:44	13:32
Lees						
	01:27	01:56	14:54	01:29	01:49	11:49
Hurdman						
	02:01	02:17	17:11	02:01	02:40	10:00
Train						
	02:21	02:44	19:55	02:19	02:35	07:20
St Laurent						
	01:32	01:50	21:45	01:32	01:55	04:44
Cyrville						
	02:34	02:34	24:19	02:31	02:49	02:49
Blair						

3.3.4 Capacity / Throughput

3.3.4.1 Terminal Capacity

CTP performed a discrete analysis of the terminal capacity based on the terminal configurations at the outset of the operations analysis. This showed that the original configuration of the terminals with no, or insufficient track beyond the station platform resulted in extremely slow movements into the terminal due to the safe braking requirements. This resulted in long terminal headways indicating that the required headways could not be supported by the terminals. Appendix D provides additional detail on the discrete terminal capacity analysis results.

In order to support the 2-minute operational headways, the track design was modified to provide additional track beyond the platforms such that the safe braking model limitations would not be more restrictive than the normal speed profile of a train stopping at the terminal. This was done in concert with the maximum protected platform length being reduced to 150 metres. Extending the tracks beyond the terminal station platforms was essential to reducing the minimum headway that the terminals could support. As part of a separate PE design refinement, the Blair terminal station was relocated to fall within the existing Transitway. This adversely affected the terminal capacity by creating a reverse curve in front of the station resulting in the terminal crossover being located more than 200 m from the platform. In order to minimize the headway impact of this, the crossover was upgraded to higher speed turnouts in order to maintain nominal line speeds in this section for diverging moves into and out of the terminal. The same upgrade to higher speed turnouts was applied at Tunney's Pasture and also at the Hurdman Pocket track to facilitate higher speed diverging moves into the pocket for possible turnback operations in the future.

The above design revisions are reflected in the final PE track design with minor revisions.[3] The final PE design forms the basis of the Network Operations Simulation documented in Appendix C. The simulation demonstrates that the Blair terminal can support a 2-minute headway under typical operating conditions even with the perturbations introduced by the randomized performance of manual operation. It is noted, however, that more significant delays of trains than those anticipated under normal operations will be difficult to recover at the terminal as the terminal time is projected to be only 2 to 2¼ minutes on average for ATO and MTO, respectively. A significant amount of this time is required for passenger exchange leaving little recovery time. Future design advancement must carefully consider and integrate the terminal track configuration, train control system, passenger platforms, vertical circulation elements and station facilities for operating personnel to support the frequent service and maximize terminal capacity.

3.3.4.2 Line (Way) Capacity

The operations simulation evaluated the line capacity of the proposed system – the minimum headway that can theoretically be achieved on the line between the terminals. Concerns for line capacity include: the longer dwell times anticipated during the peak period at the downtown stations; the limitations imposed by the signal system due to safe braking requirements with several locations of steep grades; and the tunnel ventilation restrictions, which limit one train to each tunnel vent zone.

The simulation of the proposed peak period operating headway of 2 minutes shows that the line configuration can adequately support this level of service, under typical operating conditions, including during MTO operations. While some amount of train interaction occurred where following trains receive temporary speed downgrades primarily due to variations in operator performance, no trains had to come to a stop and the resulting delays to trains were manageable and did not propagate.

To assess the theoretical Line Capacity, a "stress test" was performed on the line such that trains were dispatched as close as possible under ideal performance conditions (i.e. no randomized variations in performance or dwell time), as discussed further in the Simulation Report in Appendix C. This was done to obtain a preliminary estimate of the amount of operating margin in the system; the system cannot actually achieve this theoretical headway. The resulting minimum theoretical headway under ideal conditions is 1:42 minutes in both directions. These results are highly dependent on the type and layout of the signal system and are, therefore, preliminary and subject to design advancement and the selection of specific train

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[3] The pocket track behind Blair was subsequently removed due to potential space constraints in the Busway under Blair Road. Additional enhancement of the Blair Terminal configuration to provide improved means of recovery from major disruptions and capacity to hold an inoperable train are recommended.

control technology. Based on the these preliminary findings, there would be approximately 18 seconds of operating margin at a 2-minute headway operation to allow for variations in train performance and dwell time. In simple terms, a train can experience an 18 second delay before causing any delay to a following train. In summary, the line and terminal capacities appear adequate to support the projected operations under typical operating conditions. Additional modifications should be pursued to enhance the Blair terminal's ability to absorb more significant train delays as can be expected at times including extending tail tracks at Blair such that they are capable of temporarily holding an in-service or out of service train, without reducing the approach speed into the terminal for trains in normal operation.

3.3.4.3 Integration with Plans for Future Extensions

Based on findings of the operations review of the current core system, it is noted that the operational considerations and design basis of the initial core system are dependent to a significant extent on the outcome of the Western Extension study as well as other regional expansion projects. This relates to physical elements including the location of yard facilities, the allocation of fleet and, even more so, to the operational implications of the decisions of these studies. The route selection of the Western Extension, for example, could introduce street running elements and/or the need for two branches operating on the trunk system that must be accounted for in the operations simulation. Depending on the combination of elements, changes to the design of the core system currently being prepared could be required, or in the worst case scenario, an infeasible condition could be presented. It is recommended, therefore, that further operational investigations are coordinated to the maximum extent possible and that the outcomes of the other studies are informed by the operational limitations of the core system.

3.3.5 Single Tracking Analysis

As part of CTP's operational review and design refinement of the OLRT, the ability of the system to operate during planned track outages for maintenance was investigated. The available overnight maintenance window of less than four hours is narrow for conducting regular infrastructure maintenance and inspection, so the ability to close portions of track for maintenance while continuing to provide service during the late night hours is desirable. CTP recommended that the targeted maximum headway for maintaining service via single track operations be set to 15 minutes, which is a typical reasonable minimum service level for late night operations during maintenance track outages. It is desirable to provide for this service for any single-tracking segment along the line.

A preliminary analysis examined what service levels could be achieved for single track operations given the original alignment plans and recommended improvements to the alignment to support single track operations at the desired 15-minute headway. These recommendations included the modification and addition of some crossovers relative to the original EPR alignment, including the addition of a crossover between Campus and the eastern tunnel portal, and the upgrade of the west yard lead single crossover to a double crossover. The resulting configuration of crossovers as incorporated into the PE track plans is shown in Figure 3-4.

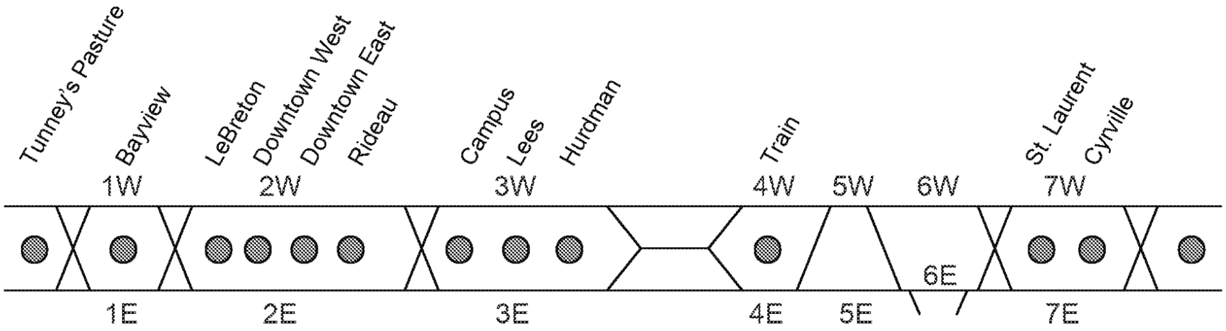

Figure 3-4: PE Alignment and Single Track Segments

Using the PE operations simulation results, the minimum sustainable headway for each potential single track outage (1E, 1W, 2E, and so on) was estimated to analyze the ability of the current track configuration to achieve a 15-minute headway for single track maintenance. The run time through each identified bypass route was calculated and was increased to account for reduced speeds through crossovers, signal clearance time and time to accelerate from a stop if the single track has not yet cleared on approach (worst case scenario). The resulting adjusted travel times in each direction were used to estimate the minimum sustainable headway for each potential outage. Table 3-7 summarizes the results of this analysis.

Table 3-7: Single Track Operations

Segment with Outage	Bypass Route	Minimum Headway
1E	1W	06:36
1W	1E	06:36
2E	2W	16:26
2W	2E	16:26
3E	3W-Pocket	11:19
3W	Pocket-3E	11:19
4E	Pocket-4W-5W	06:10
4W	4E-Pocket	06:50
5E	5W	02:15
5W	6E-5E-4E-Pocket	07:34
6E	5W-6W	03:39
6W	6E	03:39
7E	7W	11:17
7W	7E	11:17

According to these results, outages within the tunnel portion of the alignment from the LeBreton Crossover to the Campus Crossover (segments 2E and 2W) would be the critical outages at an approximate single-track headway of 16.5 minutes. This is the only section that appears not to support a 15-minute headway. Many other sections would support single tracking at much lower headways.

As the design is advanced, all track outages should be simulated to determine the minimum sustainable headway and operating strategy. Potential design refinements, including relocating the LeBreton crossover east of the station, or adding a crossover within the cut-and-cover portion of the tunnel immediately adjacent to Downtown West or Downtown East, should be considered. Such refinements would improve the minimum headway that can be sustained through this critical tunnel section, and for the case of a adding a crossover in the tunnel, would significantly improve the overall operating flexibility of the system for conducting maintenance.

Additionally, after it is verified that the desired headway for maintenance activities can be supported by the track design, a set of specific operating timetables supporting all the potential single track outages to be used during the planned maintenance should be developed, with service levels set to 15 minute headways. CTP recommends that these timetables be incorporated into the regular service plan for late evening service as much as possible such that maintenance activities can be programmed under normally scheduled operations without temporary or special timetables.

The design of the system should also be coordinated with the intent of performing certain maintenance activities via single-track operations. For example, frequent access point may need to be provided along the alignment to allow maintenance activities to occur within an isolated segment.

4. PRELIMINARY SERVICE PLAN DEVELOPMENT FOR RFP

As the RFP was developed, CTP worked with the City of Ottawa and OC Transpo to develop a Preliminary Service Plan, with the understanding that elements of the plan may be updated as the related forecasts and analyses were refined. This section discusses the development of the service periods and service headways that comprise the Preliminary Service Plan.

4.1 Service Periods and Service Levels

OC Transpo established service periods throughout the day for both weekday and weekend/holiday service. The periods are based on current OC Transpo service patterns including the need for later transit service on Fridays and Saturdays. OC Transpo targets service levels based on projected customer demand during peak periods. Off-peak headways throughout the remaining portions of the day and on the weekends were established as a matter of policy by OC Transpo to provide a high-quality service at all times. These are also expected to essentially remain the same over the 30 year term. Consideration was also given to the need for Night headways of 15 minutes to allow for fixed asset maintenance to occur alongside revenue service by introducing single track operations on portions of the OLRT System. Table 4-1 summarizes the anticipated service durations, periods, and non-peak service levels (policy-driven service). Peak service levels are discussed in Section 4.2 below.

Table 4-1: Service Periods and Non-Peak Service Levels

Period		From	To	Headway (min)
Weekdays				
Early Morning		5:00	6:30	8
Morning Peak		6:30	9:00	*varies*
Midday		9:00	14:45	5
Afternoon Peak		14:45	18:00	*varies*
Early Evening		18:00	21:30	5
Late Evening		21:30	23:00	8
Night	Mon – Thurs	23:00	1:00	15
	Friday	23:00	2:00	15
Weekends & Holidays				
Base		6:00	19:00	5
Evening	Saturday	19:00	2:00	8
	Sunday / Holiday	19:00	23:00	10

4.2 Peak Period Service

4.2.1 Peak Period Demand Targets (2018-2048)

The 2021 and 2031 peak hour loads were used in combination with OC Transpo's long term organic growth expectations to develop peak hour demand profile for the Project Term from 2018 to 2048. The peak hour loads were extrapolated back to 2018 and forward to 2048, providing the Peak Hour Load values shown in Table 4-2below.

Table 4-2: Ridership Demand Profile (2018-2048) - Peak Hour Loads

Year	Pk Hr Load (pphpd)	Year	Pk Hr Load (pphpd)	Year	Pk Hr Load (pphpd)
2018*	9,356	2028	16,036	2038	19,341
2019	10,024	2029	16,704	2039	19,535
2020	10,692	2030	17,372	2040	19,730
2021	**11,360**	**2031**	**18,040**	2041	19,927
2022	12,028	2032	18,220	2042	20,127
2023	12,696	2033	18,403	2043	20,328
2024	13,364	2034	18,587	2044	20,531
2025	14,032	2035	18,772	2045	20,737
2026	14,700	2036	18,960	2046	20,944
2027	15,368	2037	19150	2047	21,153
				2048*	21,365

* Note: Term will begin 2018 and terminate on the same date in 2048 (30 year term)

4.2.2 Peak Headways and Capacity Targets

In establishing the peak portion of the Preliminary Service Plan, peak headways and consist lengths were set to provide an effective capacity larger than the projected Peak Hour Demand over three to four year periods. This methodology produces a step function that balances the need to scale peak service levels to demand with a desire to minimize the number of service changes during the Project Term while ensuring that the load standard is not exceeded.

Effective peak hour capacity is calculated as: *Train consist capacity x Number of Trains per Hour.* OC Transpo established total train consist capacities of approximately 632 passengers for a nominal 120-metre consist, and approximately 790 passengers for a nominal 150-metre consist. These capacities were estimated based on a peak hour loading standard of 3.3 standees per square metre established by OC Transpo.

To generate peak service levels over the Project Term, peak headways were reduced incrementally to increase the peak hour capacity to meet or exceeded the peak hour demand for each period. However, headways could only be reduced as low as the Minimum Operational Headway of two minutes that was established based upon the results of the Simulation Analysis (see discussion in Section 3.3.4). When the Peak Hour Demand exceeds the Effective Capacity of a 120-metre consist operating a 2-minute headways (around 2035), train consists would need to be lengthened to 150 metres to increase the capacity provided by each train. Table 4-3 summarizes the results of these calculations.

Table 4-3: Peak Headways and Effective Capacity (2018-2048)

Years	Max Pk Hr Load (pphpd)	Peak Headway (min)	Consist Length	Effective Capacity (pphpd)
2018-2021	11,360	3.25	120-metre	11,668
2022-2024	13,364	2.80	120-metre	13,543
2025-2027	15,368	2.45	120-metre	15,478
2028-2030	17,372	2.15	120-metre	17,637
2031-2035	18,772	2.00	120-metre	18,960
2036-2040	19,730	2.40	150-metre	19,750
2041-2045	20,737	2.25	150-metre	21,067
2046-2048	21,365	2.20	150-metre	21,545

4.2.3 Peak Service Plan

The fleet sizes required to support these peak service level were also estimated. Minimum cycle time was estimated as the round trip run time of 48 minutes (24 minutes in each direction) plus the layover time. Layover time at each terminal was defined by the terminal capacity or by a policy layover as follows:

- Terminal Capacity: Maximum sustainable layover defined as twice the headway minus the travel time to enter and exit the terminal from the terminal crossover. Based on simulation results, the combined travel time to enter and exit the Blair terminal was 2 minutes.

- Policy Layover: 10% of the one-way run time (at each terminal)

Using this estimate of cycle time, the Number of Trains in Peak Service for each headway and consist scenario was calculated, as shown in Table 4-4.

Table 4-4: Peak Period Service Plan

	2018-21	2022-24	2025-27	2028-30	2031-35	2036-40	2041-45	2046-48
Peak Headway (min)	3.25	2.80	2.45	2.15	2.00	2.40	2.25	2.20
Consist Length	120-m	120-m	120-m	120-m	120-m	150-m	150-m	150-m
Cycle time (min)	55.25	53.20	53.90	51.60	52.00	52.80	54.00	52.80
Trains in Peak Service	**17**	**19**	**22**	**24**	**26**	**22**	**24**	**24**

4.2.4 Baseline Preliminary Service Plan

The service period, peak and non-peak service levels, and the long term demand growth were incorporated into a Preliminary Service Plan which provides the Baseline Service Plan for purposes of the RFP. A model was developed for estimating revenue service quantities in terms of train and vehicle kilometers over the term of the contract that allows for easy manipulation of service levels and other assumptions for updating the service quantities. A summary table of the service plan and operating quantities as generated from the model is included in Appendix E. It should be noted that for purposes of estimating revenue service quantities, the daily service periods were adjusted to account for trains operating beyond the actual hours of service to allow passengers to board up to the end of the operating period and complete their trip. Additionally, the model and results assume a full consist, as used during the peak period, to be operating during all periods.

Refinements to the service plan including potential variations in train consists, based on additional information of the travel demand during non-peak periods, should be made as this information becomes available. Additionally, the specific expectations for the start and end of revenue service and the ability of passengers to travel on the system at these boundaries should be refined further.

A more detailed operating plan including a full timetable, yard pull outs and pull ins, and consist assignments should be prepared in coordination with OC Transpo in the future.

APPENDIX A

PROPOSED LIGHT RAIL STATION LENGTHS OF 120 METERS WITH PROVISION FOR EXPANSION TO 150 METERS

Ottawa Light Rail

CAPITAL TRANSIT PARTNERS

RECOMMENDATION

Proposed Light Rail Station Lengths of 120 meters with Provisions for Expansion to 150 meters

Ottawa, ON

Presented to:

Gary Craig

Chief, Rail Engineer & Maintenance

Rail Implementation Office

160 Elgin Street, Suite 2103
Ottawa, ON

Date: 18 FEBRUARY 2011

Introduction

Capital Transit Partner's (CTP) contract tasks us to refine the Ottawa Light Rail Transit functional design concept expressed in the Environmental Project Report (EPR).

Terms of Reference, Section 1.4: Refinements to the Alignment

The alignment outlined in the DOTT Recommended Plan is preliminary in nature. Refinements in the horizontal and/or vertical alignment shall continue in subsequent stages of preliminary and detailed design in order to:

- *Improve operating characteristics*
- *Reduce future maintenance requirements*
- *Minimize construction related impacts*
- *Reduce capital and operating costs*
- *Minimize impacts to adjacent properties*

Refinements to the recommended plan alignment shall be subject to the commitments and amending procedures to be outlined in the environmental assessment report for the Project.

The EPR Functional Design Concept for Light Rail Stations

The EPR and the Downtown Ottawa Transit Tunnel (DOTT) Recommended Plan identifies a functional design concept that designs station platform lengths to 120-meters for operational service through 2031, while designing and incorporating protected areas at each station that will allow stations to be expanded to 180-meters beyond 2031 (page 9-3 of the EPR).

Other portions of the EPR and DOTT relevant to this issue include (***emphasis added***):

From page 4 of the DOTT Recommended Plan:

The line has been planned and designed to accommodate 6-car (180 m) trains, although it is likely that operation will commence using 3 or 4-car trains (90 and 120 m respectively).

From page 52 of the DOTT Recommended Plan:

Based on current ridership forecasts it is expected that 3 or 4-car LRT trains will be required to operate on the line at the following headways:

- *Early Morning – 10 minute service (**opening day and 2031**)*
- *Shoulder – morning peak – 5-minute service (**opening day and 2031**)*
- *Morning peak – 3-minute service opening day, 2-minute service in 2031*
- *Midday – 5-minute service (**opening day and 2031**)*
- *Afternoon peak – 3-minute service opening day, 2-minute service in 2031*
- *Early Evening – 5-minute service (**opening day and 2031**)*
- *Late Evening – 10-mimute service (**opening day and 2031**)*

From Page 6-2 of the Environmental Project Report

*Additional volumes of passengers emanating from the future extension of LRT to South Keys, and Société de transport de l'Outaouais (STO) routes from Gatineau could increase potential volumes to 20,000 pphpd should any future interprovincial rapid transit link feed into the planned TMP network west of the downtown. Based on this, and to provide an adequate spare capacity to accommodate future growth beyond 2031, **for the purposes of the technology selection the ultimate capacity is considered to be 24,000 pphpd. It should be noted that for reasons of geographical and development constraints in this area, the core may not increase beyond this ridership capacity**.*

From the Environmental Project Report, Appendix H, The Maintenance & Storage Facility Site Selection Report:

*The initial fleet size has been assumed to be 120 LRV's, consisting of 30, 4-car trains. **Operation of 6-car trains is being assumed, to accommodate expected ridership beyond the 2031 planning horizon in Ottawa's current Transportation Master Plan.***

Reaction to the EPR Functional Design Concept for Light Rail Stations

The Functional Design Concept for Station Platform lengths is notable on several fronts.

The Functional Design Standard calls for stations to be built with platforms that are operational to 120-meters in length while designing future platform expansions to 180-meters in length. That is practical to do at above ground stations, but the only practical way to have underground stations that can accommodate future expansion to 180-meters is to build them to that length for opening day. It would be prohibitively expensive and disruptive to future light rail passengers to expand the underground stations after opening day.

The EPR recognizes three factors (light rail technology limitations, geographical and development constraints) that limit the ultimate passenger carrying requirements to no more than 24,000 pphpd beyond 2031.

Recommended Refinement to the EPR Functional Design Concept for Maximum Station Length

For the opening day through 2031 planning horizon, CTP is recommending that the maximum station length be reduced from 180-meters to 150-meters for underground stations and to 120-meters for above ground stations. Above ground stations will be designed in a manner that anticipates the possible expansion to 150-meters beyond 2031.

Table 1 demonstrates a 120-meter light rail train's ability to meet and exceed the OLRT ridership forecast through 2031, and the ability of 150-meter trains to meet higher forecasts beyond 2031. Figure 1 and Figure 2 below provide additional detail on the relationship of the ridership projections (peak period link loads) and the provided seated and total capacities in 2021 and 2031, respectively.

Table 1 – Capacity for 120m and 150m Train Length

	Capacity through 2031		Capacity beyond 2031	
	120 m Train Length		150 m Train Length	
Consist	4 double-ended 30-m LRVs		5 double-ended 30-m LRVs	
Peak Period Headway (min)	**3.25**	**2.10**	**2.25**	**2.00**
Vehicle Capacity *	203	203	203	203
Train Capacity	812	812	1015	1015
Supplied Capacity (spc/hour/direction)	15,000	23,200	27,100	30,500
Effective Passenger Capacity (PPHPD) (PHF=0.80)	**12,000**	**18,600**	**21,700**	**24,400**
Peak Vehicle Requirement	72	104	125	135
Total Fleet (with 10% spares)	**80**	**115**	**138**	**149**

** Based on industry-recommended peak loading levels (TCRP Report 100 - Transit Capacity and Quality of Service Manual, 2nd Edition)*

The analysis above is based on the following assumptions.

A passenger loading level for the peak 15 minutes that is equivalent to a fully seated load plus 5 standees per square meter was utilized. This is based on recommendations for the design of new North American rail systems as documented in the *Transit Capacity and*

Quality of Service Manual, 2nd Edition (TCRP Report 100). This results in a single car capacity of 203 passengers, or 812 passengers per 120-m train.

The passenger capacity value used in our analysis is based on four 30-meter double-ended LRVs. This represents a *worst case scenario* for maximizing passenger capacity in that 30-meter double-ended LRVs have a significant amount of non-passenger space due to unoccupied operator cabs and coupler areas[1]. It also assumes conventional 2+2 seating arrangements. The light rail vehicle concept for Ottawa must be optimized to meet the high ridership forecast (possibly including the use of married-pairs and/or 2+1 seating arrangements). As an example, a married pair configuration of 30-meter cars will increase the capacity of a 120-m train by 40 passengers to 852.

Other LRV car lengths are not excluded from potential consideration by our use of the 30-meter LRV in our analysis. It is possible that a future DBOM consortium could propose 37-meter LRVs. We have intentionally focused on overall train length instead of individual LRV car length to foster competitiveness and innovation during the procurement process.

Consistent with TCRP-recommendations, a Peak Hour Factor (PHF) is applied to the ***supplied capacity*** in the table to obtain the ***effective passenger capacity (PPHPD)***. The PHF accounts for demand variations during the peak hour and is defined as the peak hour load divided by four times the peak 15-minute load. A PHF of 0.80 is recommended for this system based on similar high frequency operations. Stated simply, this means that a higher passenger capacity will be provided to carry the forecasted demand.

As a result, the average vehicle load over **the peak hour** will be well below the established **15-minute "peak of the peak"** load standard of 5 passengers per square meter. For example, based on the ridership forecasts for the the opening year the average load per car over the AM peak hour at the peak load point would be approximately 154. This is equivalent to a loading of 3.2 standees per square meter on opening day on a 3.25 minute headway. In 2031, the peak hour will have a loading of approximately 3.3 standees per square meter on a 2.1 minute headway.

The City's Transportation Demand Management initiatives, along with Sustainability focused programs, could be utilized to spread peak period ridership even further to reduce "peak of the peak" crowding which will effectively increase the carrying capacity of the system. For instance, OC Transpo currently experiences approximately 50% of their AM peak period demand in a one hour period, but only 33% of their PM peak period demand in a one hour

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[1] A 30-meter LRV with Operator cabs at each end results in a passenger compartment of approximately 25.5 meters.

period. Spreading the AM peak period demand even slightly will help alleviate the potential for "peak of the peak" crowding.

The minimum headway used in our analysis is 2-minutes. Headways below 2-minutes have not been considered as they are difficult to achieve reliably without significant additional infrastructure and control system investment. Ongoing operations analysis will verify the capability of the system to support headways as low as 2 minutes, and identify necessary design refinements.

Figure 1 - AM Peak Link Load and Capacity - 2021 without Gatineau

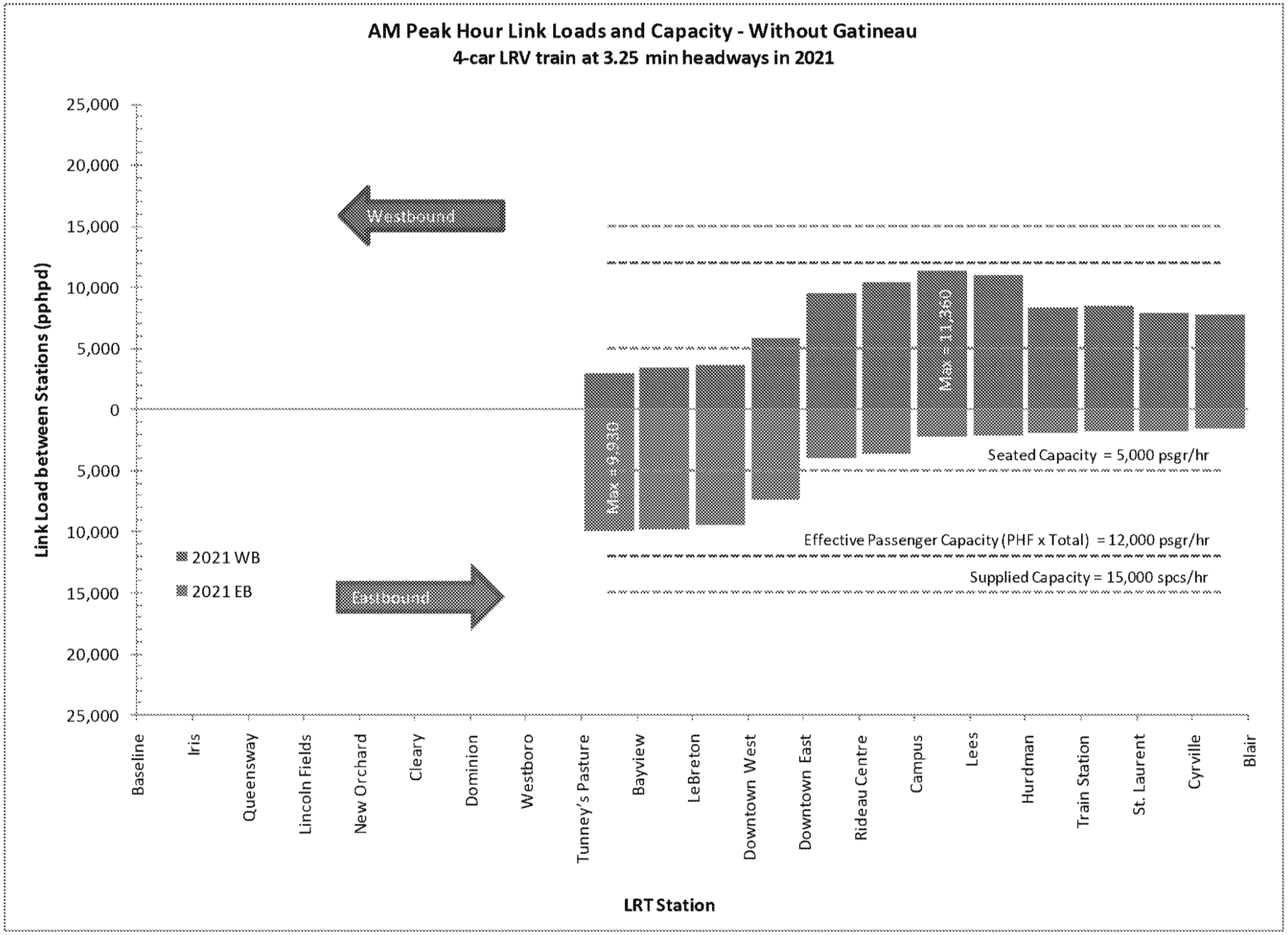
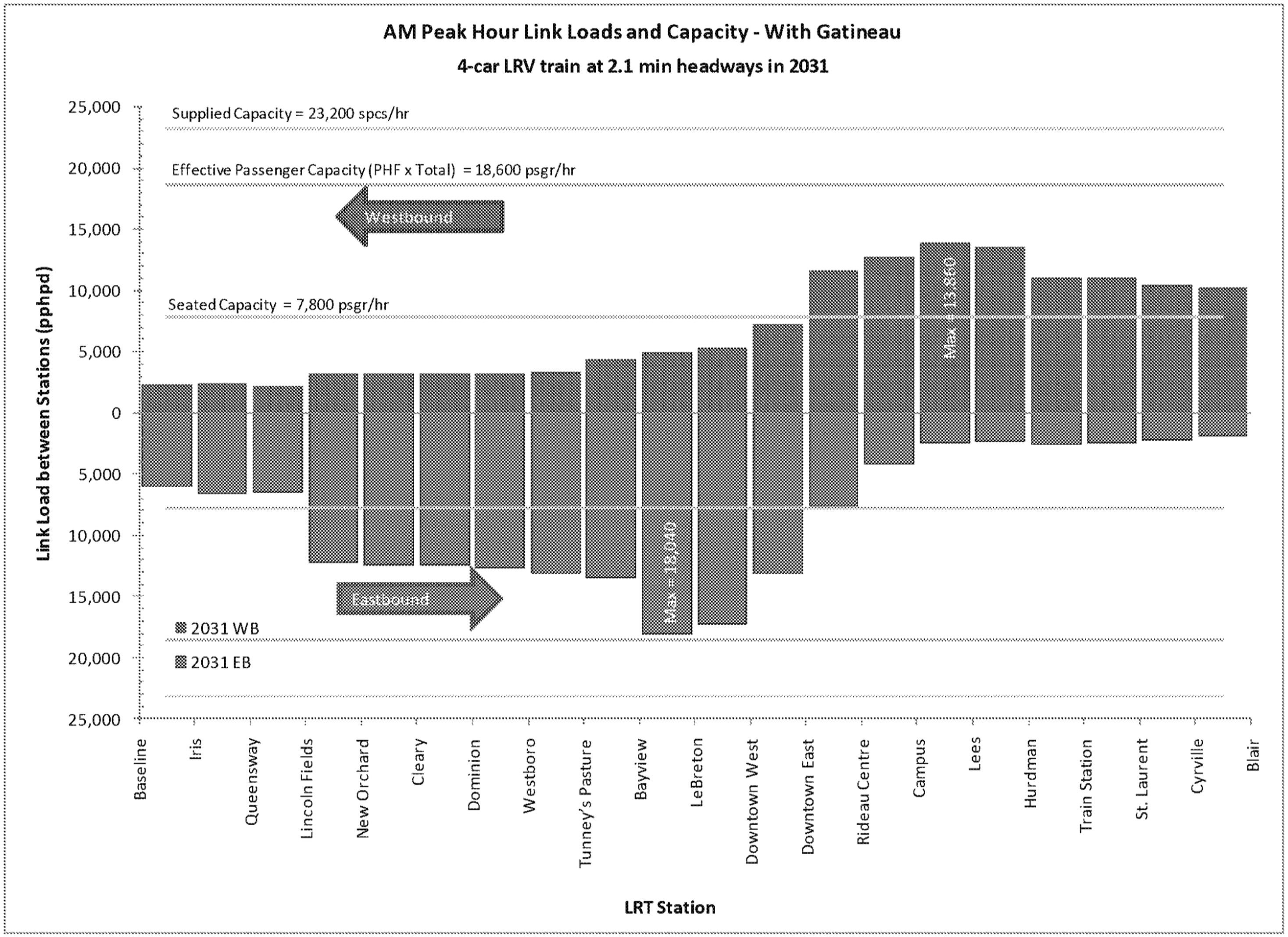


Figure 2 - AM Peak Link Load and Capacity - 2031 with Gatineau



Conclusion:

The Functional Design Concept calls for station platforms to be designed and built to an operational length of 120-meters from opening day through the 2031 planning horizon, with a protected future expansion of 180-meters designed for the period beyond 2031.

Our vehicle capacity and ridership forecast analysis reveals that all ridership forecasts from opening day up through 2031 can be met and exceeded with stations and light rail trains that do not exceed 120-meters in length. Additonally, ridership forecasts beyond 2031, up to the ultimate maximum capacity of 24,000 ppphpd, can be accommodated with stations and light rail trains no more than 150-meters in length.

This presents an opportunity to reduce the underground stations from an opening day build-out of 180-meters to 150-meters.

This recommendation will contribute to containing design, construction and operating costs.

END OF DOCUMENT

APPENDIX B

RECOMMENDATION FOR AUTOMATIC TRAIN OPERATION (ATO) CAPABILITY ON OPENING DAY

REPORT

Recommendation for Automatic Train Operation (ATO) Capability on Opening Day

Ottawa, Ontario

Presented to:

Gary Craig
Chief, Rail Engineer & Maintenance

Rail Implementation Office
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Work Package ID: WP1.3-184

ORP_STV_IN_TRAINCTRLWHITEPAPER

29 July 2011

Capital Transit Partners | 160 Elgin Street, Suite 2403, Ottawa, ON K2P 2P7 Canada

1. EXECUTIVE SUMMARY

CTP is making a recommendation to change the Environmental Project Report's (ERP) Functional Design Concept for signaling and train control. The EPR design concept envisioned that opening day operations would be supported by manually operated LRVs utilizing conventional signaling and train control systems with some form of automated operations being added at a later date when demand approached 20,000 passengers per hour per direction (PPHPD).

CTP is recommending that the OLRT system open with a signal and train control system that provides Driver Assisted Automated Train Operation (ATO) capabilities on opening day including provisions for full manual operations.

CTP is recommending Driver Assisted ATO operations on opening day due to:

- The revised opening day and 2031 ridership forecast provided by the City on January 27, 2011 which indicates that ridership will approach 20,000 PPHPD sooner than originally forecasted.
- The results of network modeling and simulation results indicating a high degree of interaction and operating variability between manually operated trains on 3 and 2 minute peak period headways.
- The avoidance of future disruptions and additional costs associated with a future transition to ATO operations.
- Conformity with EPR guidance that Light Rail Vehicles should be capable of full manual operation on future non-segregated, lower passenger demand extensions of the OLRT project.

The potential exists to combine Automatic Train Supervision with ATO operations to derive benefits related to headway reliability, energy optimization and better control of dwell times. The cost of adding Driver Assisted ATO functionality to the signal system is very small compared to the basic vital signal infrastructure for a base ATP system. CTP has estimated that the cost differential in the range of approximately15 percent.

CTP has concluded that the potential increase in capital costs associated with implementing a Driver Assisted ATO operation on opening day are offset by significant increases in operational performance, service reliability, and in potential reductions in traction power favorably impacting the cost to operate.

2. BACKGROUND

The Environmental Project Report (EPR) for the Ottawa Light Rail Transit (OLRT) Project thoroughly discusses the evaluation of the transit technology chosen for the project. These discussions appear both in the Transit Technology chapter (Chapter 6) of the EPR and in the Transit Technology Choice Report (Appendix G to the EPR). This document will focus on the operations side of the technology evaluation process, especially the potential need for automated operations.

The Transit Technology Choice Report examined the benefits and drawbacks of both Light Metro and Light Rail Transit (LRT) technologies, and concluded that while both technologies would be appropriate for the downtown segment of the OLRT, only LRT would provide the balance between high capacity operation downtown and the lower capacity, potentially less segregated, extensions into the city's surrounding communities.

The EPR projected in Section 6.3 that "ridership through the downtown of Ottawa would reach 14,400 persons per hour per direction (pphpd)" by 2031, and that incorporating demand from the wider region could drive projected ridership demands above 20,000 pphpd after 2031. Providing sufficient capacity on the LRT system to meet these ridership levels in the core would require operating trains at very short headways, which would "necessitate some development of automated operations." Providing the systems and infrastructure for an automated operation in the core has advantages, as "the main core segregation costs have already been largely accommodated by the existing Transitway," as the Transit Technology Choice Report explains in Section 3.12.2.

However, the EPR also recognized that a fully-automated system would introduce higher costs than necessary into the potential future extensions. Providing full segregation comparable to the Transitway along the suburban corridors would be a very expensive endeavor; Section 3.12.2 of the Transit Technology Choice Report notes that "even the costs to implement a limited number of local road grade separations can be very expensive." Given the differing capital needs between the downtown core and the suburban extensions, the EPR recommended the choice of LRT technology, as the vehicle design is flexible enough to accommodate both automated and manual operations in different areas.

The EPR established the timing of the driving mode choice (manually operated or automatically operated) in the Executive Summary of Appendix G: Transit Technology Choice Report on page EX-2.

"The LRT system provides capacity for the main core, but will necessitate some development of automatic operation to maintain operational efficiency at the end of the planning period and beyond."

CTP and RIO have interpreted the sentence above to be a clear statement that automation was to be deferred until passenger capacity demands grew beyond the 14,400 pphpd forecast for 2031.

3. LEVEL OF AUTOMATION

Signaling and train control systems can have various levels of automation from simple automatic train protection (ATP), to Driver Assisted ATO, to driverless and unattended train operation (DTO or UTO).

3.1 Simple ATP

The basic ATP system provides a vital enforcement of speed limits and train separation. Based upon movement authority received from wayside controllers and upon a data base of civil and temporary speed restrictions the signaling and train control system's vital ATP function generates and enforces a speed profile. When a train is within 2 or 3 seconds of crossing the speed profile the ATP function sounds an alarm, when the train is 2 km/hr below the speed profile the ATP system applies full service braking until the train drops below the 2 km/hr curve. However depending on operator request for power at the time the brake request is made the train may not slow down in time and the speed profile may be violated. In this case the emergency brakes are immediately applied.

There is considerable variation in the ability of operators to drive close to the speed profile without exceeding it. As a result there is considerable variation in run times between stations. The operator is also completely in control of opening and closing doors so dwell times are also quite variable.

3.2 Driver Assisted ATO

Driver Assisted ATO is the next level of automation. With this system the driver closes the doors at each station, presses a button and the train is automatically controlled to move to the next station within the speed profile allowed by the Automatic Train Protection system (ATP). When the train stops at the next station, the doors are automatically opened. The ATO system may tell the operator when to close the doors or it may directly control door closing with operator override. Driver Assisted ATO offers greater operational consistency and allows the trains to move closer to the maximum speed allowed by the ATP system than drivers can do manually. It also prevents emergency brake applications that occur when drivers accidentally violate the ATP speed profile.

With Driver Assisted ATO in place, commands from a central Automatic Train Supervision (ATS) system can be processed to adjust train speeds and dwell times to maintain headways. This function is particularly helpful in managing junctions on systems with branch lines. ATS also allows management of train acceleration, speeds and braking to minimize energy usage. Typically headway management is given priority at rush hours and energy conservation during off peak hours.

Driver Assisted ATO has been used with Light Rail systems but so far only in areas where there are high station platforms, notably, Los Angeles Green Line and San Francisco Muni. With low station platforms it is easy for passengers to step into the right of way as a train is approaching or entering a station. However, accommodations can be made in the implementation of Driver Assisted ATO to deal with this hazard by giving the driver a more intuitive means to immediately take complete and fine grained control of propulsion and all forms of braking. One example would be to set up the ATO controls so that if the driver puts the master controller in a position calling for a more restrictive acceleration or braking than the ATO system, the train control defaults to the driver's request.

One of the most difficult tasks in implementing Automatic Train Operation is calibrating the automatic station stopping function to deal with inclement weather. In this situation rail adhesion becomes extremely variable and optimizing station stopping is a difficult process. Providing the train operator with the ability to take over control of station stopping as necessary would allow ATO operation to begin while the station stopping algorithms are refined.

3.3 DTO and UTO requirements

The DTO (train attendant but no driver) and UTO (no driver or attendant) options provide all the same functions as Driver Assisted ATO without any driver required at all. Automatic coupling and uncoupling of vehicles in a train may also be provided, allowing train size to be more easily adjusted to passenger demand. With regards to the train control system, the additional cost for driverless or unattended operation is not significantly higher. However the cost of securing the wayside and preparing the vehicle for DTO or UTO can easily be 2 or more times the cost of the entire train control system.

UTO and DTO systems offer some savings in driver labor costs but most authorities have found that overall DTO or UTO labor savings are not very significant. While driver labor may be lower, with UTO and DTO, there are added costs of maintaining the intrusion prevention systems. With UTO, crews must be available to access and move disabled trains. Where station platform doors are used, as would be necessary in Ottawa, station doors become a reliability issue.

Due to nature of the OLRT's growth plans and the capital costs of securing the central corridor, driverless or unattended operation is not recommended.

4. OPENING DAY RECOMMENDATION

CTP recommends that the OLRT system be designed and constructed in a manner to allow for a Driver Assisted ATO system on opening day. The alignment and systems should be designed to allow for trains to operate automatically without driver intervention from station to station. However, vehicles should be designed with a fully-functional cab, so that a train may be operated in manual mode as necessary—whether in case of emergency or for regular operations on future suburban extensions along partially-separated alignments as called for by the EPR's functional design concept.

Driver Assisted ATO systems have been implemented across many systems, including metro systems like BART in California, PATCO in Philadelphia, and Scarborough Rapid Transit in Toronto. Driver Assisted ATO is less common on light rail systems, but has been implemented on fully-separated lines, like the Green Line LRT in Los Angeles or on the segregated underground portions of the San Francisco Muni light rail system. In both these cities the Light Rail System uses high platforms in the areas with ATO. In all of these systems, train movements are controlled centrally, but an operator is present on trains at all times and is able to manually operate the train at any time, as needed.

For the Ottawa application of Driver Assisted ATO, special consideration should be given to the safety implications of low platforms and alignment characteristics that are less separated than other ATO systems. As passenger trespass into the right-of-way is relatively easy, it is recommended that the ATO system be designed in a way that allows the operator to take control of the train quickly and intuitively and to remain continuously alert. The operator should be able to stop the train not only by hitting the Emergency Stop Button but also by pulling back on the master controller to provide an operator controlled braking effort. A dead man control could be applied even in ATO mode to ensure operator alertness.

5. SUPPORTING REASONS

5.1 Revised Ridership Forecast

Originally, the EPR projected in Section 6.3 that “ridership through the downtown of Ottawa would reach 14,400 persons per hour per direction (pphpd)” by 2031. Although initial forecasts predicted that the 20,000 pphpd point would not be reached until well after 2031, more recent forecasts have increased projections. Ridership demand forecasts from January 2011 now predict that 18,000 pphpd could be expected through downtown Ottawa by 2031. Considering the potential impact of even higher ridership from region-wide travelers including from Gatineau, the new OLRT system could potentially see more than 20,000 pphpd before 2031. With these high ridership forecasts for the first years of operation of the system, the need to provide service as very close headways will occur much sooner than originally planned. It will likely be necessary, therefore, to implement some automation sooner rather than later on the OLRT.

5.2 Network simulation results

The results of a network simulation performed by CTP indicate that as peak headways decrease from 3 minutes to 2 minutes over time, there is enough variation in train performance under manual operation to negatively impact system reliability. The variations in train performance trigger interactions such as following trains receiving downgrades in speed. These perturbations in train movements result in minor delays which, accumulated over the length of a run, can amount to a significant delay and can lead to service consistency issues.

CTP performed the network simulation analysis of the proposed service at nominal 3-minute and 2-minute peak period headways assumed in 2021 and 2031, respectively. The simulation reflected manual operation by introducing nominal randomized variability in driver performance; dwell times were also randomized based on industry experience. The result of these simulations indicate that at shorter headways, variation in train performance increases, as does the occurrence of train movement interactions that negatively impact operations. This effect is particularly noticeable in the downtown tunnel segment where station spacing is very close.

The physical layout of the terminals provides a limited amount of time for delay recovery. Therefore, measures that minimize the potential for train delays to develop are highly valuable to support a reliable operation and maintain a consistent headway, especially during the peak period.

The use of Driver Assisted ATO eliminates the majority of train performance variation introduced by operators. Train performance between stations would be nearly uniform and thereby assist in maintaining uniform headways and minimizing train movement interference. The use of ATO will provide a service consistency benefit on opening day which will continue to increase as demand increases and headways decrease over time.

5.3 Other Benefits of Automation from the Start

5.3.1 Limiting construction disruptions

In Section 6.2.8 of the Transit Technology Choice Report, it was noted that "a level of automation could be phased in at a later stage of the project, but it is normal to implement from the initial installation in order to minimize disruption to an essential service." Adding the systems and infrastructure necessary for automated operations to an active transit system is a complex and disruptive undertaking even when it is planned for in the initial design phase. Complex challenges can be expected involving cut-in and testing, commissioning and training. Additionally, with the date when ridership demand will necessitate automation moving closer to opening day, implementing automation at the outset of operation would eliminate these future disruptions.

5.3.2 Automatic Train Supervision (ATS)

The inclusion of automation on the system allows for an Automatic Train Supervision (ATS) system to potentially be implemented. ATS systems centrally control the performance of each vehicle on the system to maintain the planned headways and scheduled. If a train becomes delayed, the central ATS system can alter train performance across the network, slightly speeding or slowing trains as necessary to maintain the schedule and/or consistent headways.

5.3.3 Energy Savings

Importantly, the combination of Driver Assisted ATO and ATS allows alteration of train performance and schedules to optimize energy savings. Train control can be optimized for different goals at different time of the day, for example headway management during rush hours and energy savings off peak.

5.3.4 Consistent boarding locations

Automated operations would allow for trains to stop more consistently at the same location on each platform, a task that can be difficult under manual operation. Consistent stopping allows boarding locations to be identified on the platform, encouraging organized queuing by passengers and decreasing dwell times.

5.3.5 Controlling dwell times

Dwell times can a significant source of delay and headway variability. Incorporating door opening and announcements signaling pending closing of doors into the automated system allows for dwell times to be more closely controlled. Dwells could be programmed by station and by time of day based on anticipated and experienced loads, with manual override by the operator, limiting excessive dwells and helping to maintain service in line with the established schedule.

6. COST CONSIDERATIONS

The ATO function of the recommended Driver Assisted ATO system is a non vital function run on top of the vital ATP function. The major cost of such a signal and train control system is the vital hardware and software required to support the ATP function. Adding the Driver Assisted ATO function is a minimal cost, In fact some signal and train control suppliers build this function into their basic system and it is just a matter of enabling the function. There is, of course, additional testing that must be done in commissioning the system, but the overall cost increase for ATO is no more than 5% to 15% of the base cost of ATP only.

While some budgetary uncertainty is to be expected with cutting-edge technologies, the overall cost of signaling and train control is expected to remain at fractional levels compared to the overall project budget. For instance, the EPR budget estimate of $2.1 billion included $18.4 million for signaling and train control representing less than 1 percent of the total budget. If the cost of signaling and train control doubles, it still represents only 1.8 percent of the total budget or approximately $36.8 million.

The exact amount of the increase is not known at this time, however, by making this decision early in the procurement phase we allow the maximum opportunity for cost control by allowing supply-side innovations to occur early in the project.

END OF DOCUMENT

APPENDIX C

RAIL OPERATIONS SIMULATION AND ANALYSIS REPORT

LTK Engineering Services

Ottawa Light Rail Transit Project Rail Operations Simulation and Analysis

Final Report

by:

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20 W. Park St.,
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November 3, 2011

Ottawa Light Rail Transit Project
Rail Operations Simulation and Analysis

REVISION HISTORY

Revision No.	Date	Description of Revision
0	Sept. 30, 2011	Initial Release
1	Nov. 3, 2011	Revisions address CPT comments/edits

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FINAL REPORT

Ottawa Light Rail Transit Project
Rail Operations Simulation and Analysis

This report provides the results of simulations analyses of train operations on the planned light rail system for the City of Ottawa. This assignment was performed by LTK Engineering Services under subcontract to the Capital Transit Partnership, the joint venture General Engineering Consultants for the light rail project. The project is currently in the preliminary engineering phase. The simulation work was performed at a time when the civil alignment was undergoing a series of revisions. This report focuses on presenting the findings and conclusions for the latest alignment which includes the new cut/cover tunnel section under Queen Street in downtown Ottawa.

ASSIGNMENT SCOPE

The objectives of the simulation assignment were as follows:

- Calculate anticipated terminal-to-terminal run times for train operations in each direction
- Determine the ability of the system to support the weekday service levels planned for two periods in the system life cycle:
    - the initial year of 2021
    - the design horizon of 2031
- Examine the impacts of civil design on train throughput, in particular in the following areas:
    - The terminals at Blair Street and Tunney's Pasture, both of which will be used for turning back trains at their two-track platforms
    - The underground section through downtown, through which additional train separation restrictions will be imposed to satisfy fire/life safety standards
    - The yard leads, which will enter the mainline via track connections that include at-grade track crossings
- Provide the theoretical maximum throughput of trains that can be achieved in each direction (i.e. "line" or "way" capacity), identifying potential bottlenecks along the line.
- For each of the tasks above, perform the analyses assuming that train control will be one of two methods of train operation:
    - Automatic Train Operation, in which train propulsion and braking is computer controlled
    - Manual Train Operation, in which a human train operator utilizes propulsion and braking controls to manage train speed in response to cab signals

SUMMARY OF FINDINGS AND CONCLUSIONS

A summary of LTK findings are identified below and discussed in greater detail in subsequent sections of this report:

- The initial line of the Ottawa light rail system, as developed during the PE phase, is capable of supporting train schedules of 3-minute headway in 2021 and 2-minute headway in 2031. Under routine everyday operating conditions which include variation in adherence to schedule, trains may experience minor delays with enforced speed reductions due to congestion ahead. However, trains can be expected to depart the terminals according to schedule and no cascading service disruptions are anticipated under routine circumstances.
- For 2021 service, simulations confirm that a desired cycle time of 54 minutes is achievable, which will require 18 train sets to provide service at 3-minute headway. One-way times are 23 minutes for automatic train operation (ATO) and 24 minutes for manual train operation (MTO). This leaves a combined turn time at the two terminals of 8 minutes and 6 minutes for ATO and MTO operations, respectively.
- For 2031 service, simulations show that continued MTO with service operated at 2-minute headway will increase expected delays along the line, adding approximately one-half minute to the one-way run times on average. Service provided with ATO will not experience an increase in operations delays to the same extent and thus will not see an increase in run times. Simulations indicate that to support 2-minute headway without significant delays at Blair terminal and the terminal interlocking, terminal layovers of train sets may need to be limited to 2¼ minutes for ATO and 2 minutes for MTO.
- A simulation exercise to estimate the maximum theoretical line capacity indicates that the system can support a throughput in each direction of one train every 1 minute 42 seconds. This is considered a preliminary estimate; a more accurate value will be possible as signal system design progresses. It should be noted that the actual system capacity is limited by the terminal capacity and other factors. The above value is useful in assessing the amount of operating margin for the proposed minimum operational headway.

SIMULATION SOFTWARE TOOLS

To perform these analyses, LTK used specialized rail network simulation software called OnTrack. OnTrack is a powerful and flexible software suite that is a valuable tool for planning and design during all phases of a rail transit project. A number of its features made this software a superior tool for the Ottawa assignment, including the following:

- Graphic display of train movement and signal system operation during the simulation process, enabling the user to observe performance of individual trains and the system overall, to quickly identify bottlenecks warranting further analysis

- "Self-signaling" functionality, which can create and simulate a signal system for operations analysis of run times, headway and capacity during conceptual and preliminary engineering phases when only basic information about the signal system is available.
- Interactive functionality which enables the user to modify train and signal system operation during simulation execution. The feature can be used to test failure management scenarios and follow system recovery during simulation execution. During the final engineering phase, the user can input and test the final design of the signal system and rail vehicle.
- Generation of detailed simulation results in both tabular and graphical forms, including detailed logs, summary extracts, speed profiles (speed vs. location) and train charts (location vs. time)

OnTrack supports the following types of analysis:

- Determining the requirements for a railway network's infrastructure (track configurations),
- Analyzing the capacity of lines and stations,
- Examining the operating impacts of alternative characteristics of the rail vehicle (for example, changes in maximum operating speed, tractive effort/acceleration, service brake rate, safe braking distance/design brake rate),
- Testing service plans and timetables to ensure the service can be reliably operated, with and without the effects of random variances in departure times, dwell times, acceleration/braking, top speeds),
- Analyzing the placement of emergency crossovers and pocket tracks and the level of service that can be supported with the temporary loss of one track,
- Analyzing the effects of system failures and delays, including the ability of the system to quickly recover from a service disruption and the performance of alternative failure management responses, and
- Analyzing various signaling systems including automatic train operation (ATO) and manual operations with cab signals.

OnTrack is capable of simulating any of a number of different types of rail signal systems, rights of way, and vehicle types. It has been licensed to a number of transit agencies for their on-going needs.

SYSTEM DESCRIPTION

The following describes the system configuration and other assumptions that form the basis of the simulation and analysis effort.

A schematic of the initial segment of the Ottawa Light Rail Line as simulated is shown in Figure 1. The line has the following characteristics:

- Right-of-Way: 12.5-kilometers, all double-tracked, generally following the rights-of-way of the transit Busway corridors east and west of downtown Ottawa. Exclusive right-of-way primarily at-grade, with a tunnel section through downtown Ottawa.

- Stations: 13 stations, including the terminals at Blair Street and Tunney's Pasture. Two platform tracks at each station, generally 120m long to accommodate 4-car trains, and designed for future extension to 150m. The three underground stations will be constructed with 150m platforms. Each station will have either side platforms or a center platform; all boarding and alighting will occur on one side of the train.
- Special Trackwork: Both terminal stations will include scissor crossovers on approach to the station, using No.12 turnouts for higher speed (40km/h) during diverging moves. Trains will turn back while laying over at the platform. For purposes of simulation, trackage beyond the terminal platforms will be limited to lengths supporting safe braking distance at terminal entry speeds. Additional crossovers have been placed along the mainline to enable trains to run-around track that is out-of-service due to failure or maintenance.
- Yard Leads: Yard lead turnouts and mainline crossovers will enable trains to be dispatched and recovered in either direction of travel. The at-grade configuration of both the east and west yard lead interlockings will require westbound trains entering and leaving the yard to cross the eastbound mainline track, potentially disrupting eastbound service in the vicinity.
- Signal System: For purposes of simulation, the signal system design is based on audio-frequency fixed block technology. Car-borne train control equipment receives signals from track circuits along the right-of-way indicating the permissible speed in response to conditions ahead. For automatic train operation (ATO), this car-borne equipment directly controls propulsion and braking. For a manually-operated train, an illuminated cab signal on the operator's cab console notifies the operator of the allowable speed. If the operator fails to quickly respond to a reduced speed command, the train automatically brakes. The signal system logic utilizes a limited number of discrete speed codes; typically, eight codes are provided in the commercially-available products used on modern North American rail transit systems. In the preliminary engineering phase, the eight speed codes identified for the Ottawa system, in km/h, are: 0 (positive stop), 8, 15, 25, 40, 55, 65 and 80.
- Underground Train Separation: Fire/Life Safety design standards being applied to the light rail transit project require that no more than one train is able to occupy an emergency ventilation section at any time. As illustrated in Figure 2, an emergency ventilation section is either an underground train station or the tunnel segment between two stations or between a tunnel portal and adjacent station. This standard enforces a more restrictive degree of train separation than the signal system normally would under other circumstances. A train may not enter a tunnel section until the train ahead has completely cleared that section (either entering a station or clearing the tunnel portal), regardless of the tunnel length.
- Light Rail Vehicle: The City of Ottawa has selected light rail technology for the rail system. For purposes of simulation a vehicle with the following characteristics is utilized:

    - 30-meter, double-articulated, 70% low-floor vehicle
    - Trains of one to four cars (30-120 meters)

Figure 1. Initial Segment Track Schematic

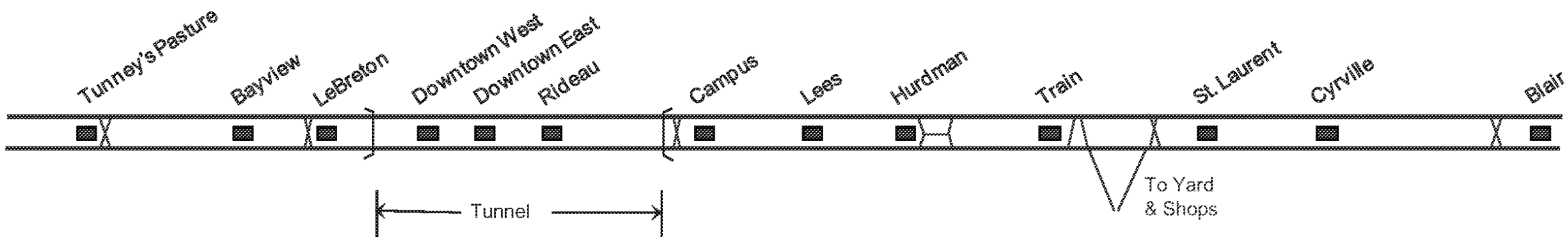
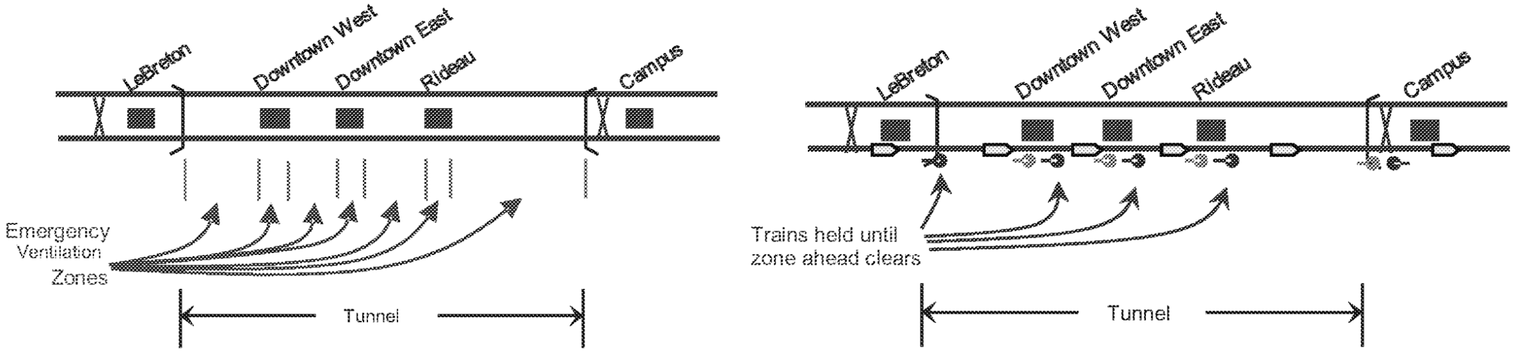


Figure 2. Emergency Ventilation and Underground Train Separation



- Seating for approximately 72 passengers in each car, with room for approximately 88 standees under a loading condition of 4 passengers per square meter (160 total passengers in each car)

The propulsion and braking performance and other characteristics of the light rail vehicle applied in the simulation are summarized in Table 1.

Table 1. Light Rail Vehicle Characteristics

Dimensions		Propulsion and Braking		LRV Weight	
Length	29.5 m	Max Operating Speed	100 km/h	AW0 – 0 psgrs	45000 kg
Width	2.7 m	Max Acceleration Rate	1.34 m/s^2	AW1 – 72 psgrs	50000 kg
Height	3.9 m	Max Brake Rate	1.34 m/s^2	AW2 – 160 psgrs	56000 kg
Axles	4 powered; 2 unpowered	Emergency Brake Rate	2.20 m/s^2	AW3- 241 psgrs	62000 kg

SIMULATED SERVICE PLAN

The City of Ottawa already has a robust and popular transit service in place, provided by local buses and by express buses on a network of exclusive busways. A small commuter rail service ("O Train" also operates). The planned initial segment of the light rail system will run along the busways that radiate east and west from downtown. Hence, initial ridership is expected to be very high. Plans for extensions of the initial segment are also under development; the next phase is expected to extend the line southwest from Tunney's Pasture terminal to Baseline. For this assignment, service characteristics simulated for analysis were as follows:

- For 2021, 4-car light rail trains operating at 3-minute headway in the peak period. All trains will operate between the terminal at Blair and Tunney's Pasture.
- By 2031, the light rail system is expected to have expanded beyond Tunney's Pasture to Baseline. At that time, ridership levels are expected to support the operation of 4-car trains at a 2-minute headway in the peak period. Trains will turn back at Blair as the eastern terminus. However, trains will continue west of Tunney's Pasture, although no data on the alignment were available for use in the simulation.

The Weekday Service Plans applied for Years 2021 and 2031 in the simulation assignment are summarized in Table 2.

Dwell times were developed for each station stop using projected peak hour ridership levels provided by the City. These projections were applied to a dwell time model that is based on dwell time observations of a high ridership light rail line with a downtown central subway -- the MBTA Green Line in Boston. At each station stop, the model uses a fixed base dwell time of 15 seconds for activity before and after passenger movement, and adds time for boarding and alighting based on an average passenger flow of 30 people per minute per train door; for a 4-car train and 4 doors per car, 480 passengers can board or alight per minute. Resulting dwell times applied as nominal values for the simulation are presented in Table 3.

Table 2. Ottawa Service Plans

Service Period	Time of Day	Service Headway (minutes)	
		Year 2021	Year 2031
Early Morning	5am – 6am	10	10
Peak Shoulder	6am – 7am	5	5
Morning Peak	**7am – 9am**	**3**	**2**
Midday	9am – 4pm	5	5
Afternoon Peak	**4pm – 6pm**	**3**	**2**
Early Evening	6pm – 9pm	5	5
Late evening	9pm – 1am	10	10

Note: 4-car trains assumed to operate at all times weekdays

Table 3. Nominal Station Dwell Times

LRT Station	Year 2021		Year 2031	
	Eastbound	Westbound	Eastbound	Westbound
Tunney's Pasture	n/a (see note)	n/a (see note)	22 sec.	21 sec.
Bayview	19 sec.	19 sec.	37	19
LeBreton	19	18	20	18
Downtown West	34	37	35	37
Downtown East	42	46	42	40
Rideau Centre	39	38	30	37
Campus	28	27	26	24
Lees	18	19	18	18
Hurdman	28	38	29	37
Train Station	16	16	16	15
St. Laurent	22	23	22	23
Cyrville	17	17	17	16
Blair	n/a (see note)	n/a (see note)	n/a (see note)	n/a (see note)

Note: layover time at terminals includes dwell time for loading & unloading of passengers

SIMULATION INPUT

Two databases are created, using OnTrack templates, as input to the simulation to define system characteristics. Two other files are created to define the service plan of train operations.

Civil Characteristics

The first, and largest, database describes the civil characteristics of the line. For the purposes of this assignment, the data required included:

- Civil Speeds: the start and end points of each stretch of restricted civil speed. For speeds through curves, the restrictions were applied to the curve itself and not to the associated spirals.

In those locations on the line where curves with restricted speeds are too close to permit more than a brief spike in acceleration, the restricted speed was maintained throughout.

- Grades: the start and end points of vertical curves and vertical tangents, and the associated grade of the vertical tangent.
- Passenger Stations: the center point and length of each platform, plus the programmed or posted stopping location of the train.
- Special Trackwork: turnouts, crossovers and pocket tracks, defined by switch type and configuration, and by wayside signals associated with each interlocking.
- Wayside signal system elements: for the signal system, those elements that are located along the right-of-way, including any type of fixed signal (interlocking, automatic, traffic) as well as block boundaries for the fixed block track circuits. Detailed definition of the signal system, such as control lines for each track circuit, were not required due to the use of the "self-signaling" feature of the OnTrack model.

Vehicle Characteristics

Data defining vehicle operating performance are entered into a separate database. For this assignment, the data included:

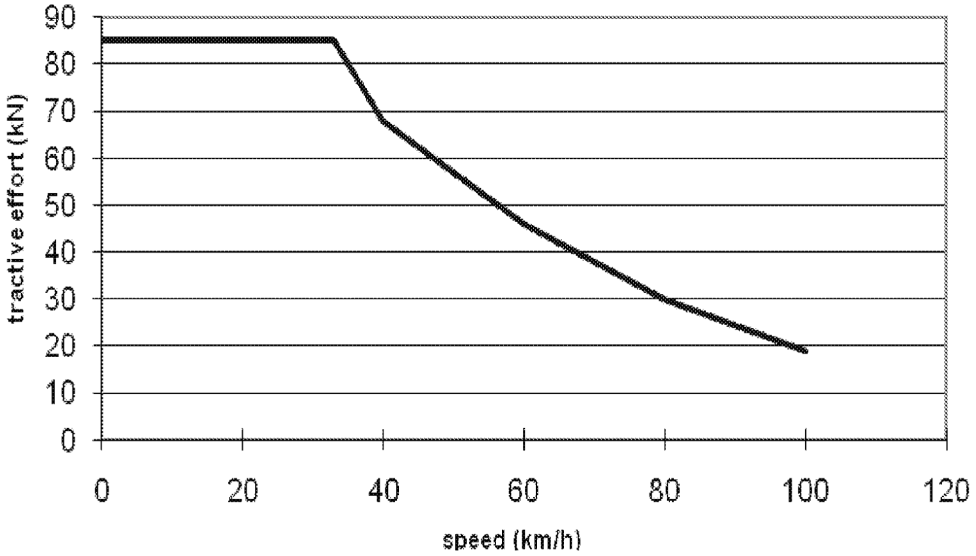
- Physical characteristics and dimensions: frontal area, length, number of axels, weight (empty and loaded)
- Propulsion: tractive effort data, maximum acceleration rate
- Braking: maximum brake rate, service brake for braking to cab signal restrictions and a separate rate for braking to a stop at a passenger station, degraded emergency (for worst case modeling of safe braking distance).
- Car-borne signal system elements: type of signal system (audio-frequency track circuits with cab signals), speed codes and associated allowable speeds

The tractive effort curve applied for the simulation is shown in Figure 3.

For the simulation, the following brake rates were used:

- Service Brake Rate for responding to changes in speed code: 0.98 m/s^2
- Station Brake Rate for ATO train berthing: 0.98 m/s^2
- Station Brake Rate for MTO station stops: 0.76 m/s^2

Figure 3. LRV Tractive Effort Curve



Operations File

This file defines the types of service that can be run on the system.

- Service templates: Each service "template" defines the route and stopping pattern or a service run. It identifies the origin and destination terminals, the station stops and associated dwell times, and the route to take through an interlocking or other set of switches.
- Randomization: For more realistic simulation of expected operations, a number of operating characteristics can be randomly varied within a configurable range of values. Randomization is achieved by applying a randomly generated number to the user-configured parameters. For analysis of Ottawa service reliability and system capacity, two parameters were randomly varied:

  - Dwell time at stations: for both ATO and MTO operations (because train operators are assumed to control the doors in both cases), dwell times were allowed to vary from the nominal times presented earlier. Half of the time, dwell times were set to the nominal value; the remainder of the time, an additional 1-7 seconds could be added.
  - Top Speed for a Speed Code: for MTO operations, the speed reached by a train was limited to 1-5 km/h below the maximum allowable speed for each speed code, reflecting the variability of manual train operators relative to the more precise operation possible with ATO.

Dispatch File

The Dispatch file provides the train service timetable, identifying each train that is to operate on the system. Each train is defined by the following:

- Train origin and destination station
- Departure time
- Service template (route and stopping pattern)
- Consist (number of cars)
- Consist source (if this train consists of vehicles already at the terminal)
- Disposition of the consist upon arrival at the destination.

SIMULATION RESULTS

Five sets of simulations were performed to support the analyses specified in the scope of work. These were as follows:

- Baseline Run Time Generation: Baseline run times were generated, using scenarios in which trains operate at full performance unaffected by the presence of a train ahead ("unimpeded"). Dispatching trains at 6-minute headway assured that trains could operate unimpeded by conditions downstream. Dwell times and top speeds were also set to the nominal levels, without any randomized variances in these parameters to slow the train from its optimal performance. For these runs, the only feature differentiating ATO and MTO was the slower station brake rate for the latter.
- Unimpeded Run Time Generation: A second set of simulations utilized the randomization feature to vary dwell times for ATO and MTO and to vary top speeds for MTO.
- Year 2021 Service Plan: A series of trains was dispatched to provide continuous train service at 3-minute headway. Randomized variances in dwell and speed were again utilized. During these simulations, the ability of the system to maintain its train schedule with on-time departures was closely examined at both terminals and at potential choke points on the line. These simulations also enabled a confirmation of earlier estimates of train cycle times and fleet size requirements.
- Year 2031 Service Plan: Similar to the Year 2021 simulations, a series of trains was dispatched to provide train service at 2-minute headway. Randomization functionality was active. For this service plan trains turned back at Blair, but not at Tunney's Pasture in line with the expectation that the line will have been extended beyond Tunney's Pasture station by 2031.
- Maximum Line Capacity: A series of simulations were performed to determine how closely together trains could be operated in each direction. The trains were dispatched and then temporarily held in a manner that resulted in the trains stacking closely together as they began their runs. Randomization was not applied in this scenario.

A summary comparison of one-way run times (terminal-to-terminal) is provided in Table 4 on the following page. The results of each set of simulation runs are discussed in greater detail in the sections that follow. For ease of reference, all graphics generated by OnTrack to illustrate speed profiles (speed by location) and train charts (location by time-of-day) are provided at the end of this report.

Baseline Run Time Generation

The baseline run times were generated using the full performance characteristics of the vehicle and no randomized variances that would delay train operation. Use of ATO for the simulation also provided a slightly higher station brake rate, an advantage in train performance and travel times.

The speed profiles plotted for these baseline simulations show that the trains do achieve the civil speed along most of the alignment in both directions. At those locations where the civil speed is not attained, potential reasons are the short length of run between stations or other speed restrictions, and the approach to a steep downgrade. The downgrade can cause the signal system to restrict speeds in order to provide sufficient safe braking distances in advance of a speed restriction further down the line.

Comparison of the baseline run times for ATO and MTO in Table 4 shows that the slightly lower station brake rate assumed for MTO train operations has a minor effect on run times.

Table 4. Summary of Simulated Run Times

		Run Times (Terminal to Terminal)			
		ATO		MTO	
Run Description	Headway	Eastbound	Westbound	Eastbound	Westbound
Full Performance	n/a	0:22:26	0:22:27	0:22:45	0:22:50
Unimpeded	6 min	0:22:46	0:22:50	0:23:58	0:23:56
Yr2021	3 min	0:22:53	0:23:00	0:23:50	0:24:01
Yr2031	2 min	0:23:00	0:22:54	0:24:19	0:24:22

		Run Time as percent of ATO Full Performance			
		ATO		MTO	
Run Description	Headway	Eastbound	Westbound	Eastbound	Westbound
Full Performance	n/a	100%	100%	101%	102%
Unimpeded	6 min	101%	102%	107%	107%
Yr2021	3 min	102%	102%	106%	107%
Yr2031	2 min	103%	102%	108%	109%

		Run Time increase over ATO Full Performance			
		ATO		MTO	
Run Description	Headway	Eastbound	Westbound	Eastbound	Westbound
Full Performance	n/a	0:00:00	0:00:00	0:00:19	0:00:23
Unimpeded	6 min	0:00:20	0:00:23	0:01:32	0:01:29
Yr2021	3 min	0:00:27	0:00:33	0:01:24	0:01:34
Yr2031	2 min	0:00:34	0:00:27	0:01:53	0:01:55

Description of Terms in Table 4:

Full Performance:	Trains operate at max allowable speed and station stops are at nominal dwell times; no randomized variations of top speed or dwell time degrade travel times.
Unimpeded:	Median value of run times of 20 trains operating with randomized variability of dwell times and, for MTO, variability of top speed for a speed code. Long headway avoids train speed being restricted by the train ahead
Yr2021:	Median value of run times resulting from a service plan dispatching trains at 3-minute headway and turning trains at both Blair and Tunney's Pasture. Randomized variations occur, as defined in "Unimpeded" above.
Yr2031	Same as for Yr2021, with the following exceptions: Service plan dispatches trains at 2-minute headway and trains are turned at Blair but not Tunney's Pasture, under the assumption that they continue on to the extension to Baseline.

Unimpeded Train Operation

Simulations were performed for both ATO and MTO train operations, in order to examine the effects on travel times of routine variations that are induced by human factors. When manually operating the train, each train operator may operate the train differently, with variations in reaction time to a change in speed code, use of the controller for acceleration and braking, and some degree of offset to the maximum allowable speed on a speed code. For MTO operations, randomized variations in the amount of top speed offset were utilized to reduce the average speed of each train by varying degrees. Random variations in dwell times were utilized for both MTO and ATO, reflecting the assumption that the train operator will operate the train doors in either case.

The results of these simulations provides a picture of the travel times achievable when trains are able to operate without encountering restrictions due to trains ahead. These travel times may be achieved during off-peak periods when there is less risk of congestion on the line. Composites of the speed profiles of twenty eastbound and twenty westbound trains are charted in Figures A1 and A2. Summary results are provided in Table 5 below.

Table 5. Unimpeded Train Operations: One-Way Run Times

	ATO		MTO	
Statistic	**Eastbound**	**Westbound**	**Eastbound**	**Westbound**
Fastest	0:22:33	0:22:29	0:23:23	0:23:29
Median	**0:22:46**	**0:22:50**	**0:23:58**	**0:23:56**
Slowest	0:22:58	0:23:03	0:24:34	0:24:14
Range	0:00:25	0:00:34	0:01:11	0:00:45
ATO Full Perf.	0:22:26	0:22:27	0:22:26	0:22:27
Median as % of ATO Full Perf.	101%	102%	107%	107%

The results show that the assumed randomized variations in top speed have a much greater effect on run times than the randomized dwell times, both in the increase in run times and in the range of run time variation.

Year 2021 Service Plan

Year 2021 train operations were simulated for the peak period to test the ability of the initial line to support 3-minute headway with reliable service and on-time performance. Of particular interest was the ability of the terminals at Blair and Tunney's Pasture to support a peak period train schedule without experiencing train movement conflicts at either of the two terminal interlockings. Of equal importance was a determination of the maximum terminal layover time that is possible at each terminal before risking cascading delays in service.

Figures A3 and A4 show the speed profiles of all eastbound and westbound trains in the peak period under the ATO scenario. Because no variance in speeds among trains is expected when operating in ATO, the composite appears as a single line except where one or more trains encounter speed restrictions due to conditions ahead. The speed profile shows that a number of eastbound trains encounter moderate speed restrictions on approach to Blair terminal. However, no train is forced to stop at the interlocking and speeds below 40 km/h are rare. Eastbound speed restrictions are also observed in the underground section approaching Downtown East and to a lesser extent Downtown West station. Westbound train operations under ATO exhibit even fewer delays than the eastbound trains. Figures A5, A6 and A7 chart train movement through the system and at the terminals. These figures show trains departing from the terminals on-time and no evidence of delays elsewhere on the line.

The multi-color effect displayed on the speed profiles of the MTO scenario, shown in Figures A8 and A9, is a result of the intentionally-randomized variations in top speed among the peak period trains. These variations in train movement through the system do not however create additional delays other than those observed in the ATO scenario. Charts of train movement at the terminals and of the system overall, presented in Figures A10, A11 and A12, show no significant delays and trains departing on-time.

The results of these simulations confirm that 3-minute headway in the peak period can be supported by 18 trains under both the ATO and MTO scenarios. In each case, a 54-minute cycle time is achieved with either 4-minute or 3-minute layovers at each terminal for the ATO and MTO scenarios, respectively. Under the circumstances (i.e., high service frequency), a 3-minute terminal equipment layover is comfortable. A summary of simulation results for the Year 2021 service plan is presented in Table 6 below.

Table 6. Year 2021 Service Plan Simulation Summary (3-min Headway)

Yr2021	Median Run Times		Median Terminal Layover		Cycle Time	Total Layover	Trains in Peak
	EB	WB	Blair	Tunney's			
ATO	0:22:53	0:23:00	0:04:08	0:04:00	0:54:00	0:08:07	18
MTO	0:23:50	0:24:01	0:03:10	0:02:59	0:54:00	0:06:09	18

Year 2031 Service Plan

Simulations of the Year 2031 service plan tested the ability of the line to support the 2-minute headway that the City anticipates to be needed to carry forecast demand. Examination of the speed profiles plotted in Figures A13 through A20 permit a comparison of performance in Years 2031 and 2021. The speed profiles for 2031 show an increase in the number of locations where congestion is likely to restrict train operating speeds. These speed restrictions increase terminal-to-terminal run times by a modest number of seconds. Trains departures from the terminals continue to occur on-time. There are no cascading delays observed during the peak two hours.

A number of simulations were performed for the 2031 service plan to test the maximum terminal layover time that could be scheduled at Blair without the occurrence of consequential delays on approach to the terminal.

The threshold for this terminal time appears to occur at approximately 2¼ minutes for ATO and 2 minutes for MTO. Train schedules that were simulated with more terminal time resulted in more delay to trains approaching and departing Blair terminal. This was evident from the speed profiles and the greater variance in run times and terminal times.

A summary of simulation results for the Year 2031 service plan is presented in Table 7 below.

Table 7. Year 2031 Service Plan Simulation Summary (2-min Headway)

	Median Run Times		Median Terminal Layover		Round Trip
Yr2031	**EB**	**WB**	**Blair**	**Tunney's**	**Time**
ATO	0:23:00	0:22:54	0:02:15	n/a	0:48:09
MTO	0:24:19	0:24:22	0:01:56	n/a	0:50:37

Maximum Line Capacity

A series of simulations was run with the objective of testing the maximum throughput of the initial line. The simulations were performed with the understanding that the OnTrack software would only provide an approximation of the capacity. More accurate estimates would require considerably more detail of signal system design.

The simulations involved the dispatch of ten trains from a terminal while holding the leader a short distance downstream. Once every train was stopped behind the train ahead, the lead train was released to proceed down the line followed by the others. The simulations were performed using ATO full performance characteristics; that is, no variations in dwell time or top speed.

In the eastbound direction, trains arrived at Blair terminal 1:42 apart. Coincidentally, westbound trains arrived at Tunney's Pasture terminal at 1:42 intervals as well.

Composite speed profiles of eastbound and westbound trains in these simulations are presented in Figures A21 and A22. They indicate the system has worked out its delays and achieved a steady state headway of 1:42 shortly after departing Campus station in the eastbound direction and after reaching the Downtown West station in the westbound direction.

It is important to note that the actual operational headway that the system can support is subject to the terminal capacity (terminal throughput) as well as other effects such as variations in dwell time. These would typically increase the minimum achievable headway. The above estimate of Maximum Line Capacity provides a basis for understanding the amount of operating margin – the "slack time" built into the operation to accommodate small irregularities in service – for a particular operational headway. For a scheduled 2-minute headway, the operating margin would be approximately 18 seconds. A train can be delayed by this amount without affecting the train behind it. As shown from the simulation results of the other scenarios, more significant delays can occur resulting in occasional delays to following trains; however, these can be adequately recovered at the terminals and do not cascade.

Figure A1. Eastbound Speed Profile of ATO Full Performance

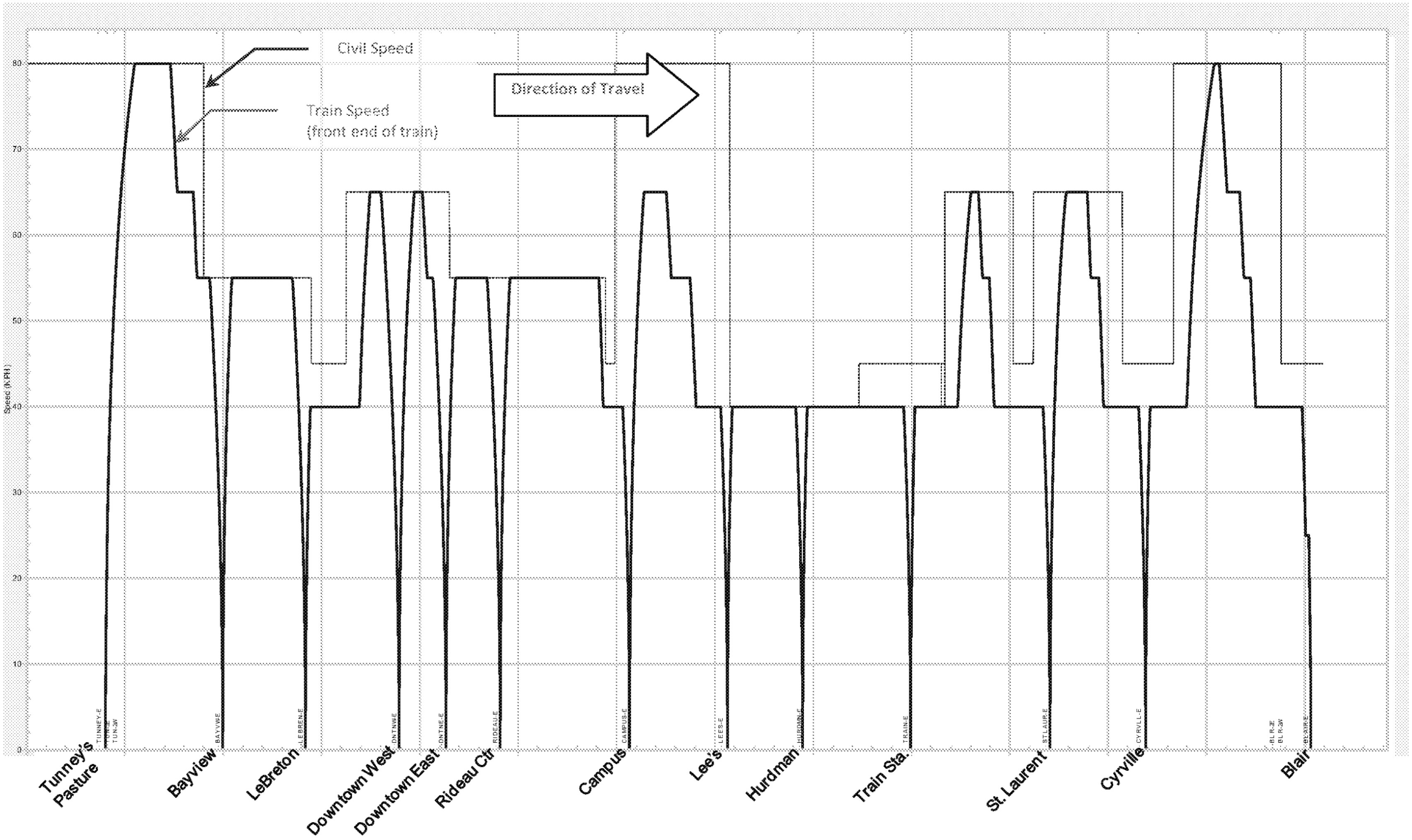


Figure A2. Westbound Speed Profile of ATO Full Performance

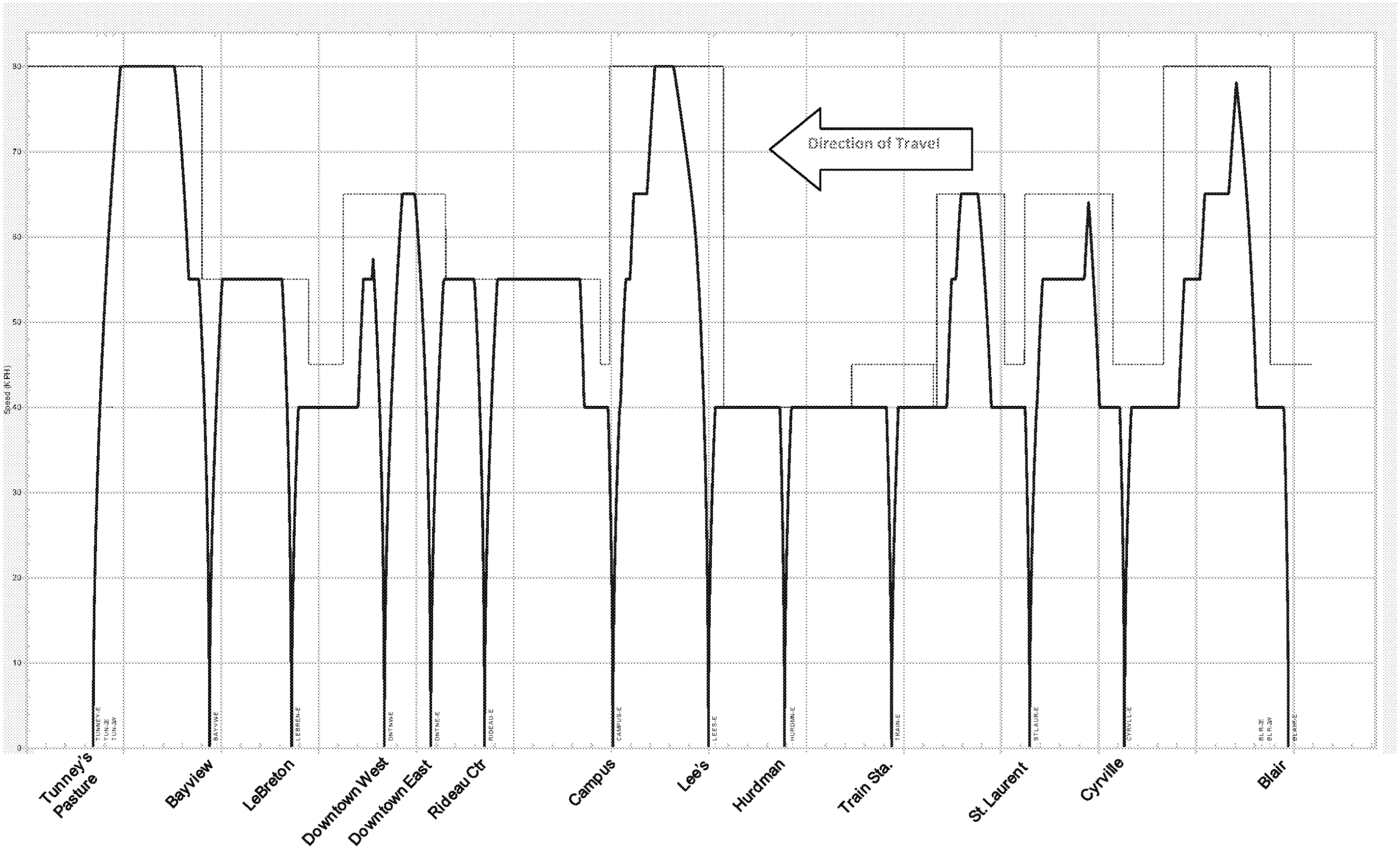


Figure A3. Year 2021 Service Plan: Composite Eastbound Speed Profile of Trains in ATO

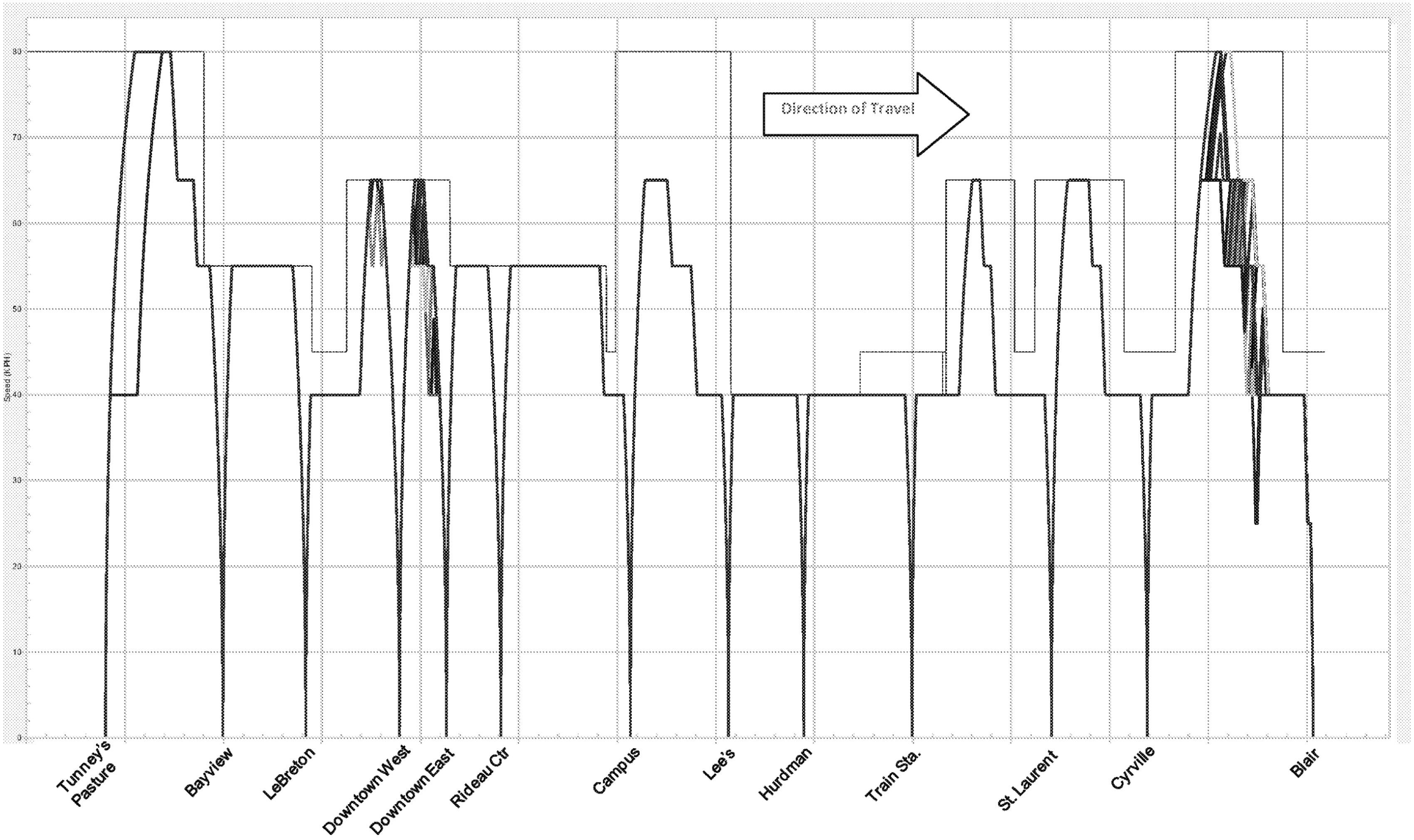


Figure A4. Year 2021 Service Plan: Composite Westbound Speed Profile of Trains in ATO

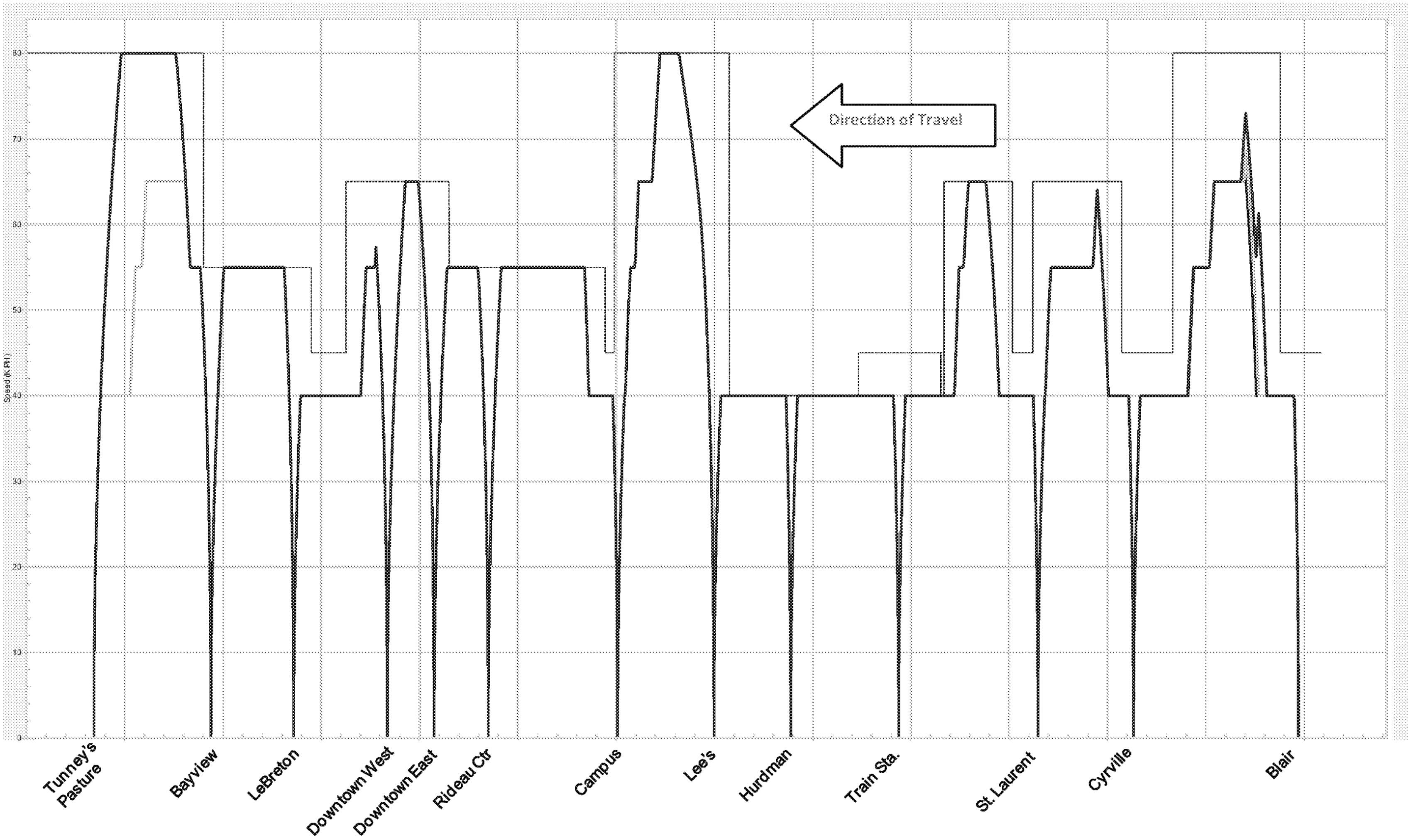


Figure A5. Year 2021 Service Plan: Peak Hour Train Movement at Blair Terminal; Trains in ATO

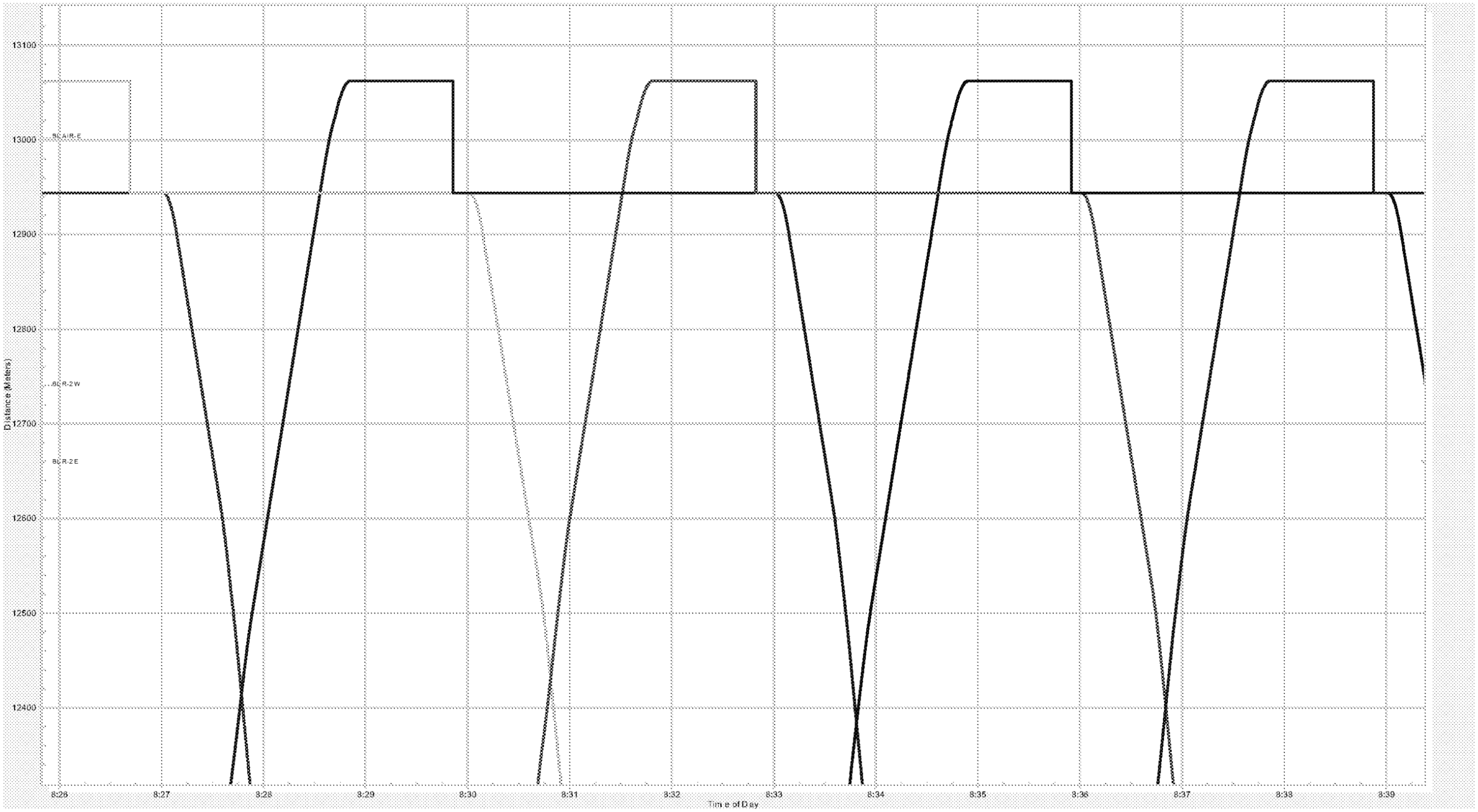


Figure A6. Year 2021 Service Plan: Peak Hour Train Movement at Tunney's Pasture Terminal; Trains in ATO

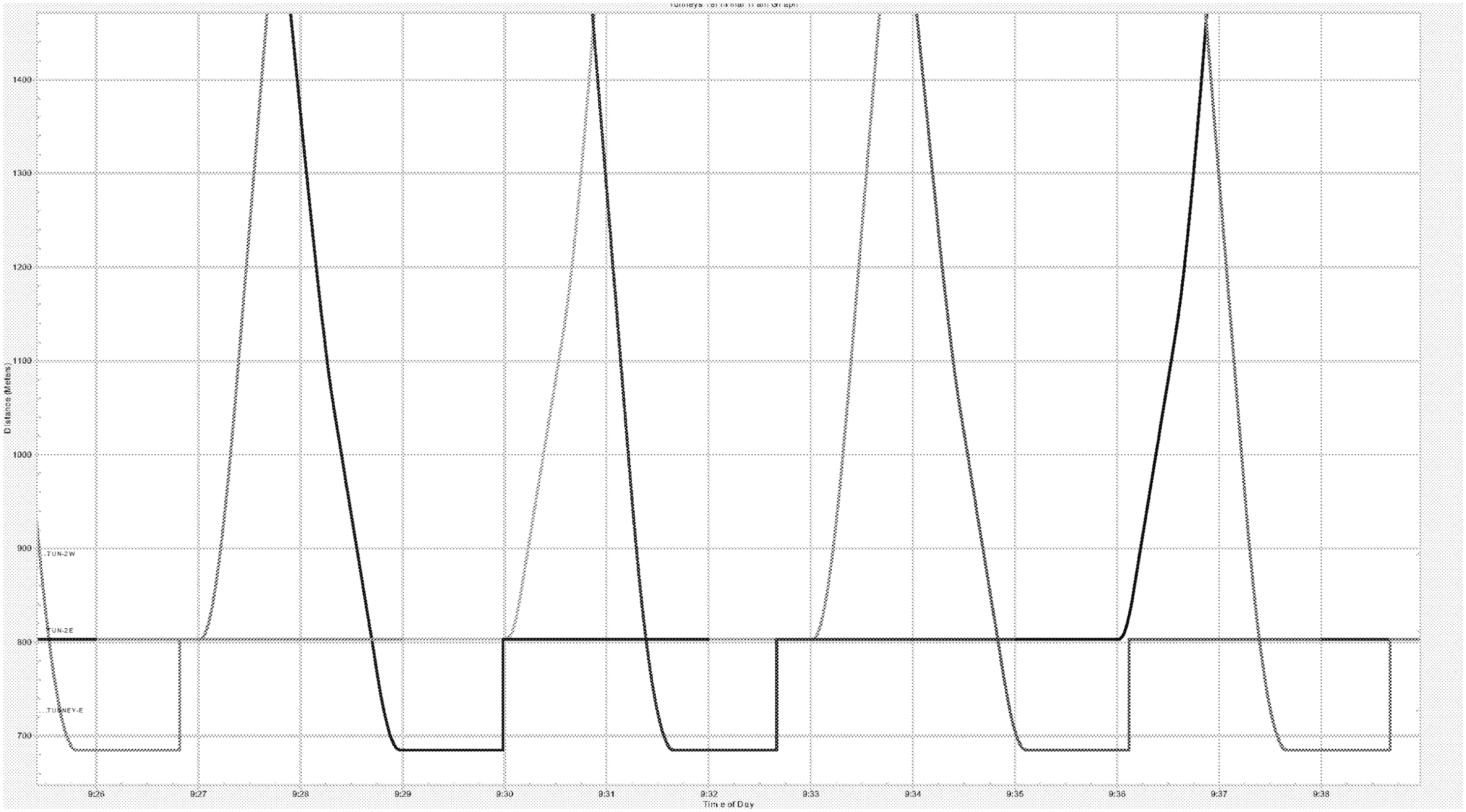


Figure A7. Year 2021 Service Plan: Peak Hour Train Movement for the Initial Segment; Trains in ATO

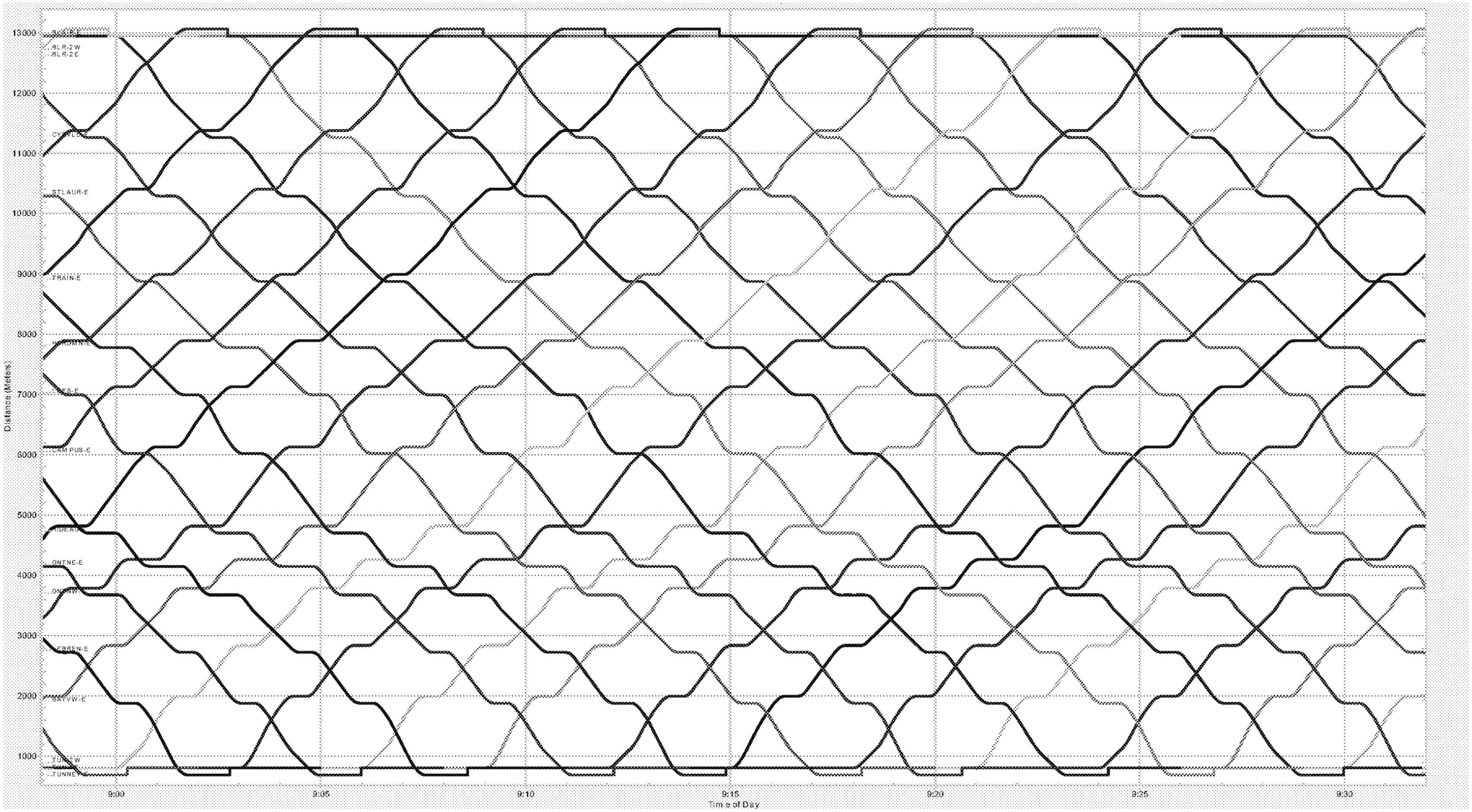


Figure A8. Year 2021 Service Plan: Composite Eastbound Speed Profile of Trains in MTO

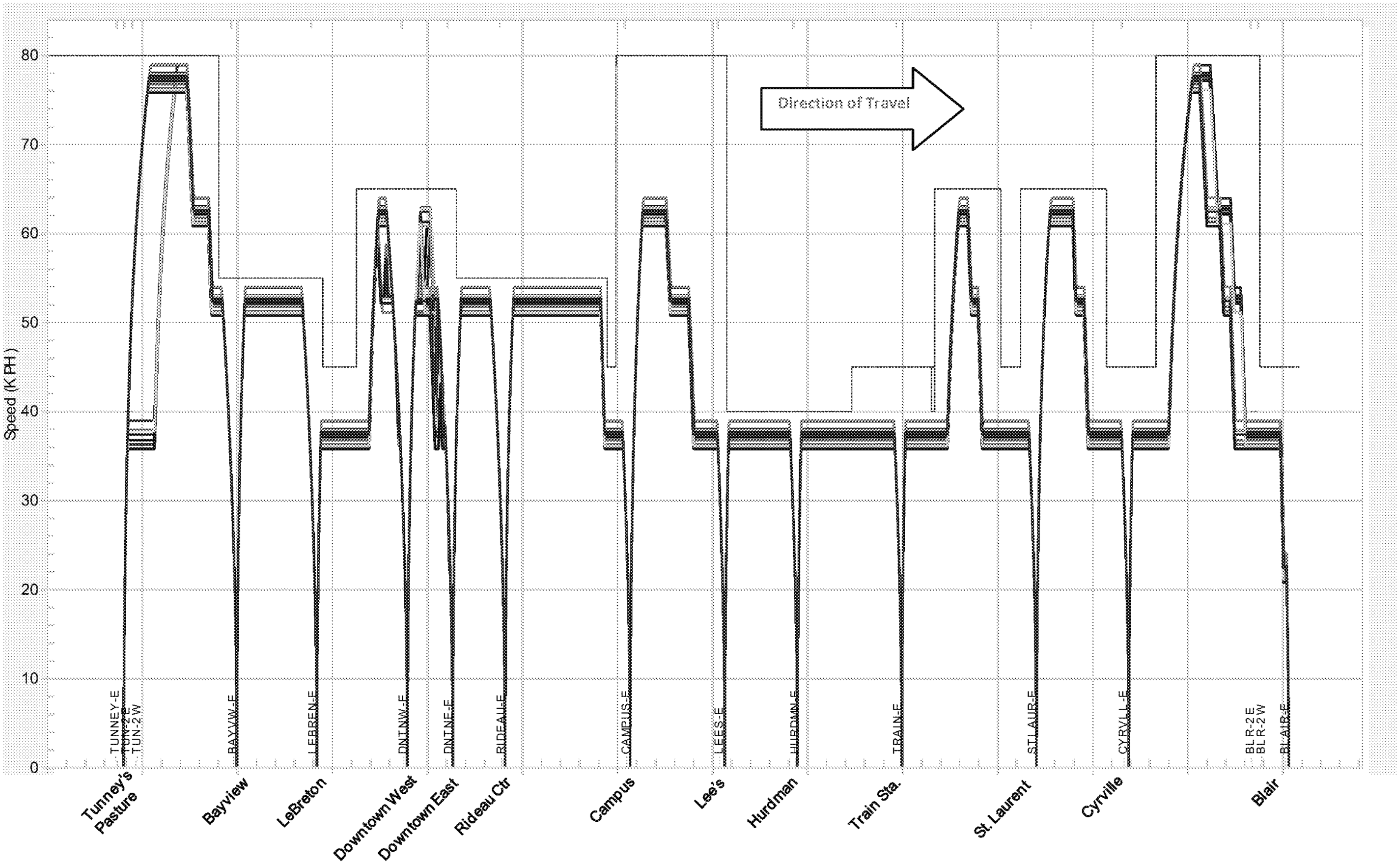


Figure A9. Year 2021 Service Plan: Composite Westbound Speed Profile of Trains in MTO

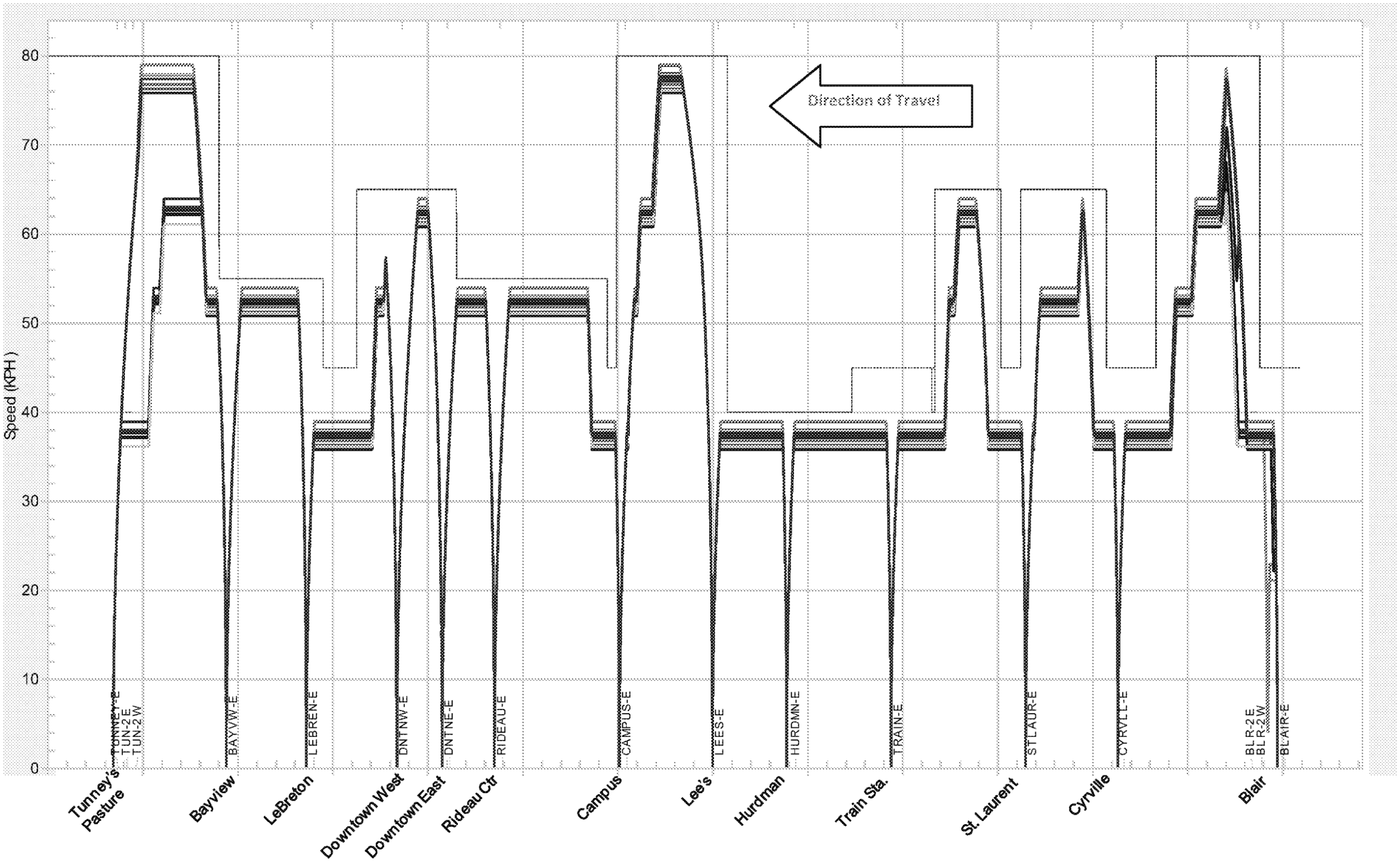


Figure A10. Year 2021 Service Plan: Peak Hour Train Movement at Blair Terminal; Trains in MTO

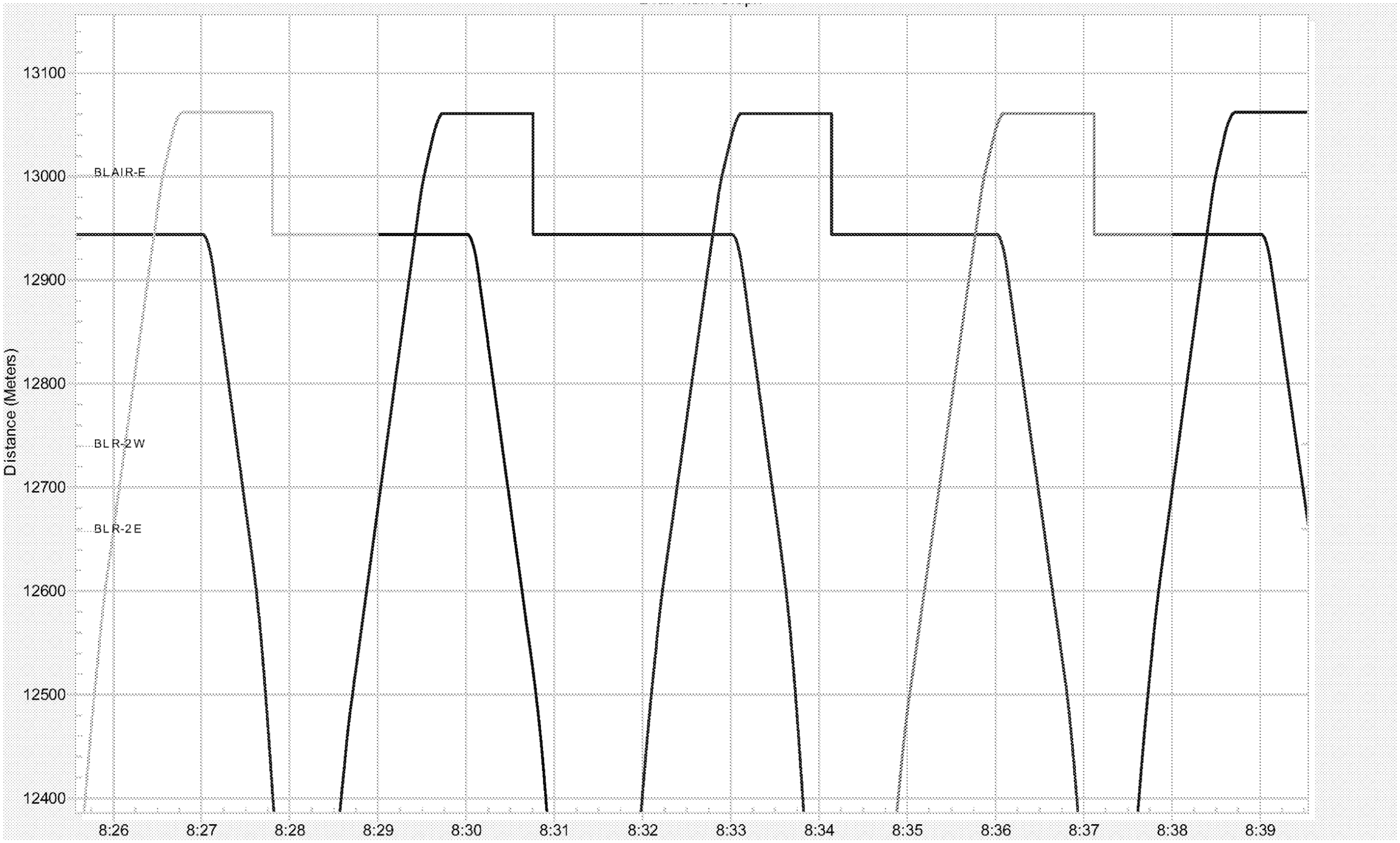


Figure A11. Year 2021 Service Plan: Peak Hour Train Movement at Tunney's Pasture Terminal; Trains in MTO

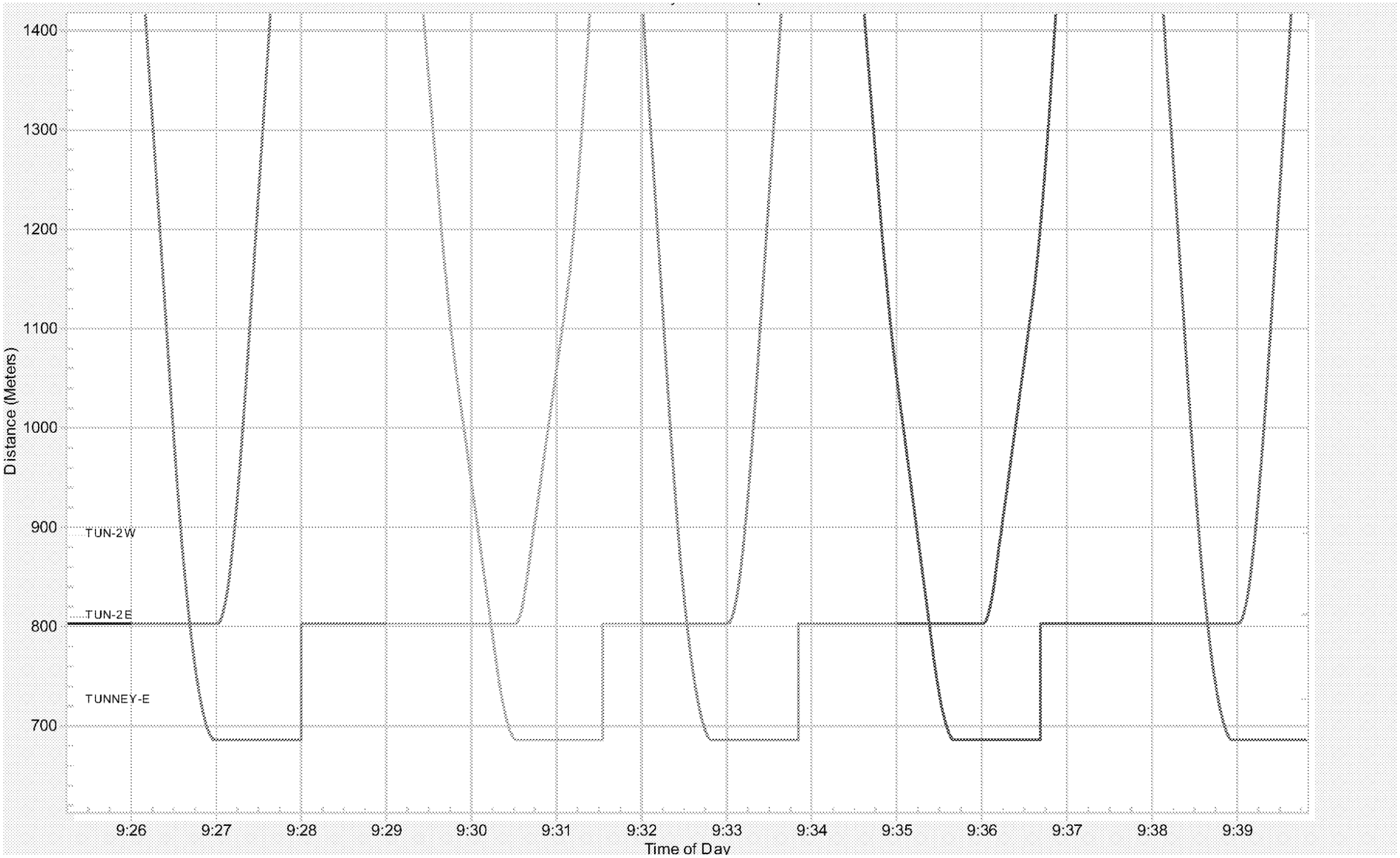


Figure A12. Year 2021 Service Plan: Peak Hour Train Movement for the Initial Segment; Trains in MTO

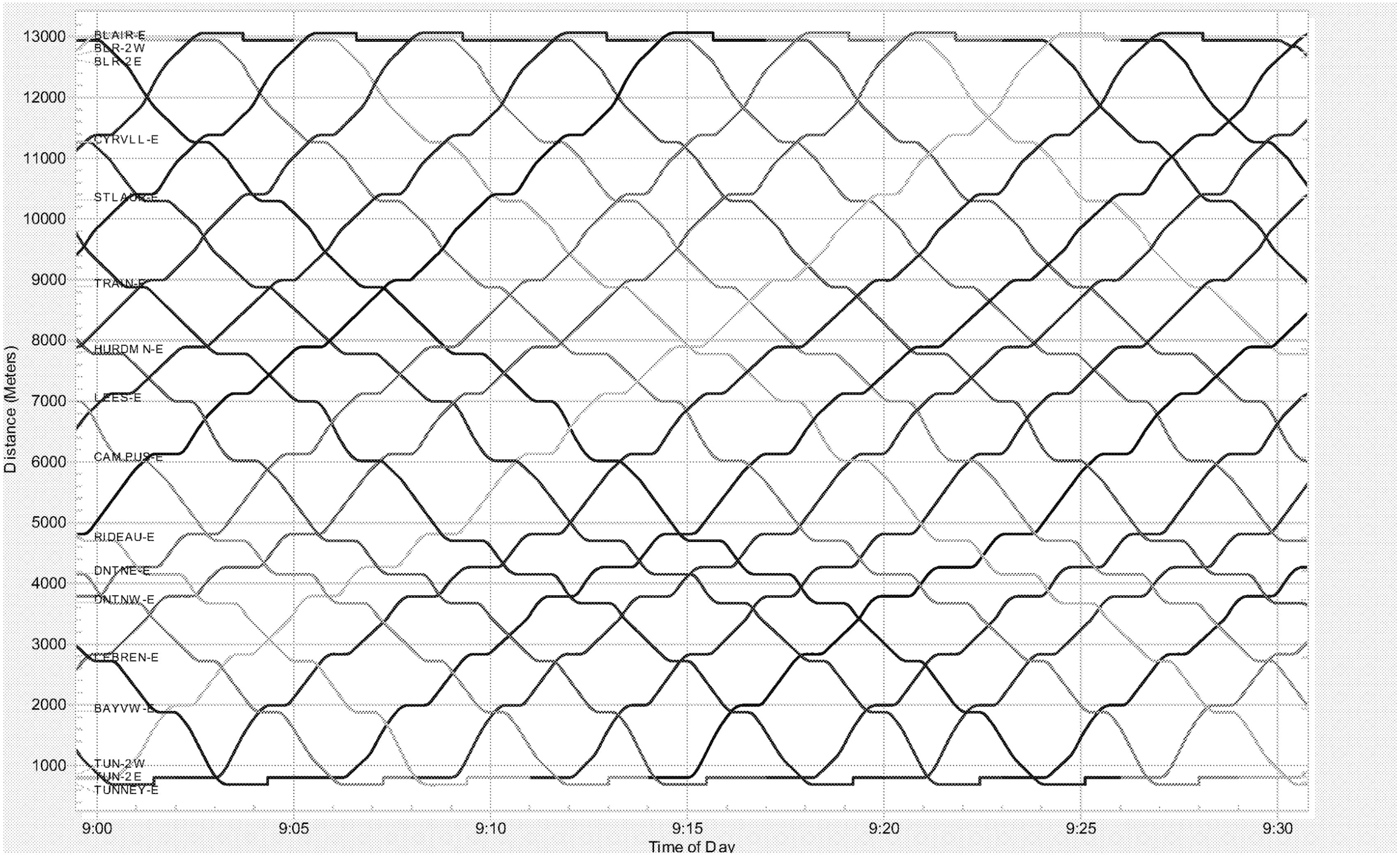


Figure A13. Year 2031 Service Plan: Composite Eastbound Speed Profile of Trains in ATO

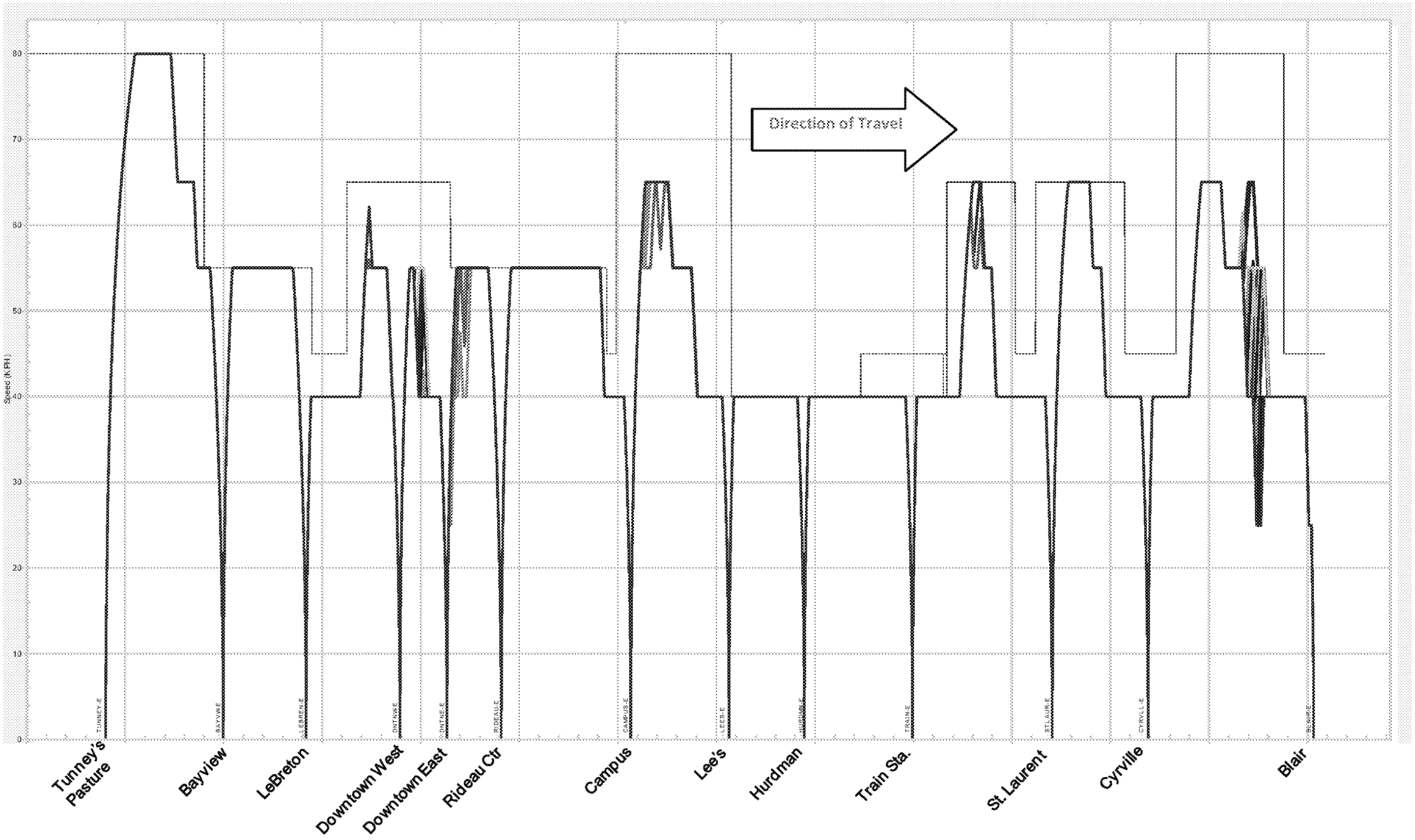


Figure A14. Year 2031 Service Plan: Composite Westbound Speed Profile of Trains in ATO

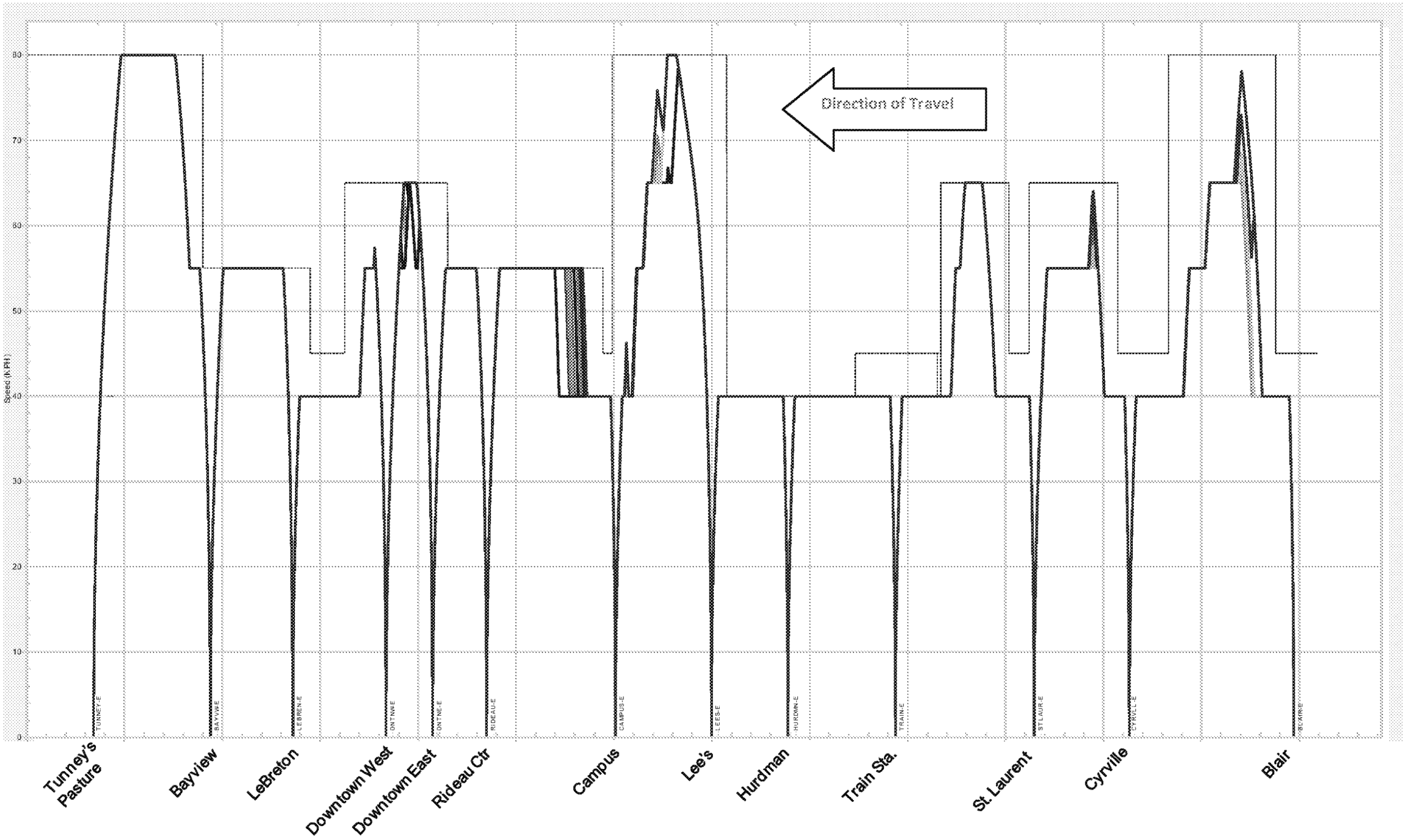


Figure A15. Year 2031 Service Plan: Peak Hour Train Movement at Blair Terminal; Trains in ATO

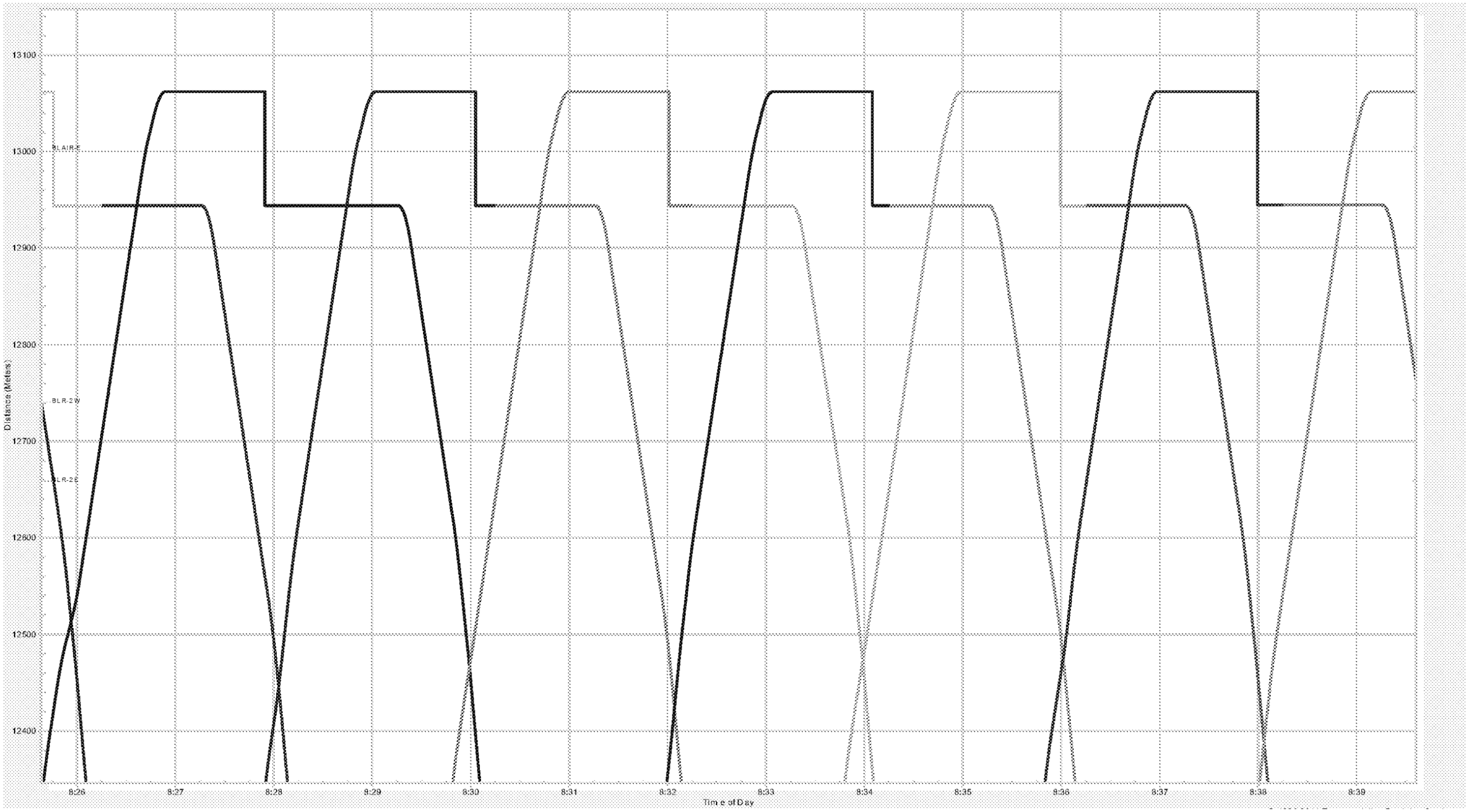


Figure A16. Year 2031 Service Plan: Peak Hour Train Movement for the Initial Segment; Trains in ATO

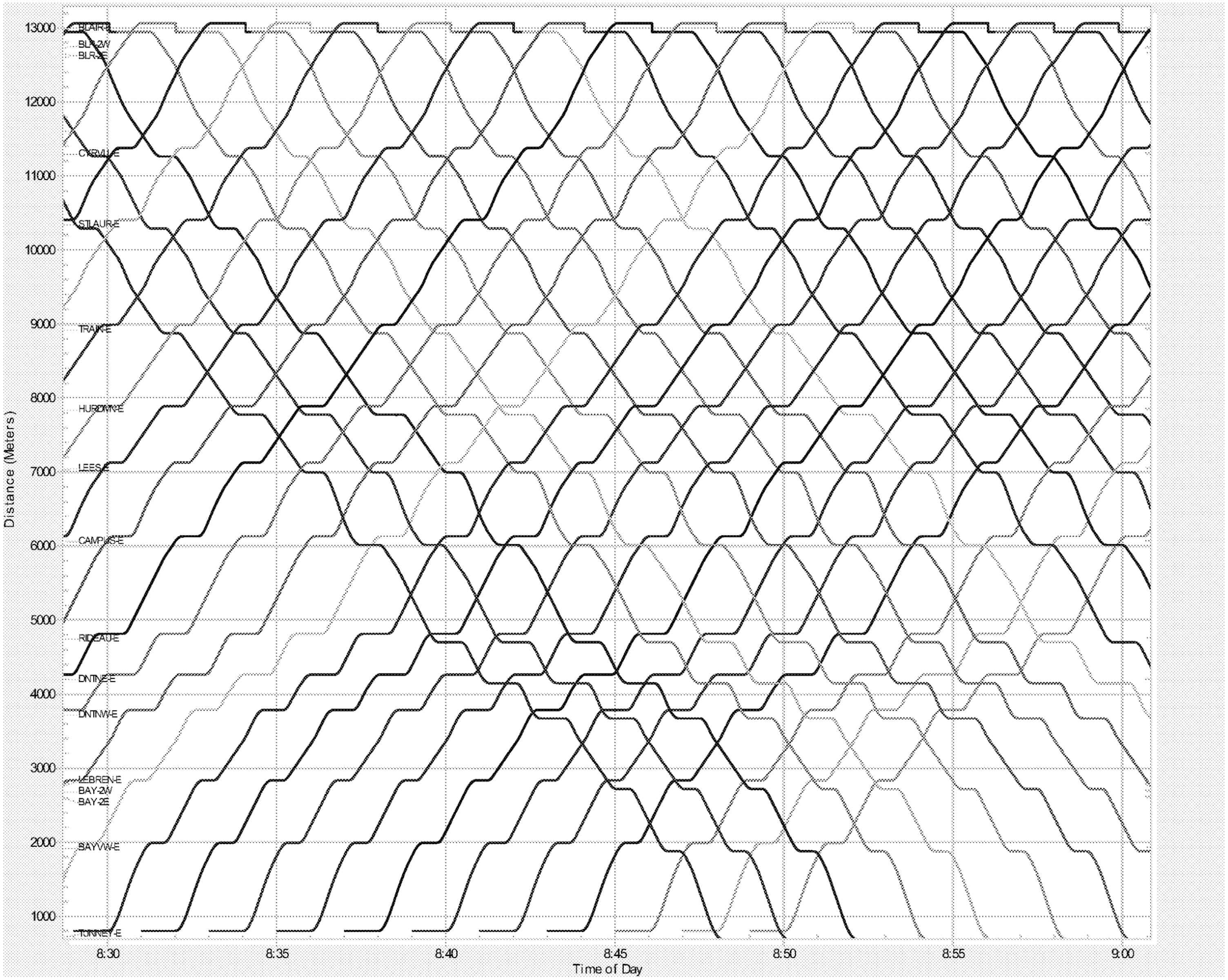


Figure A17. Year 2031 Service Plan: Composite Eastbound Speed Profile of Trains in MTO

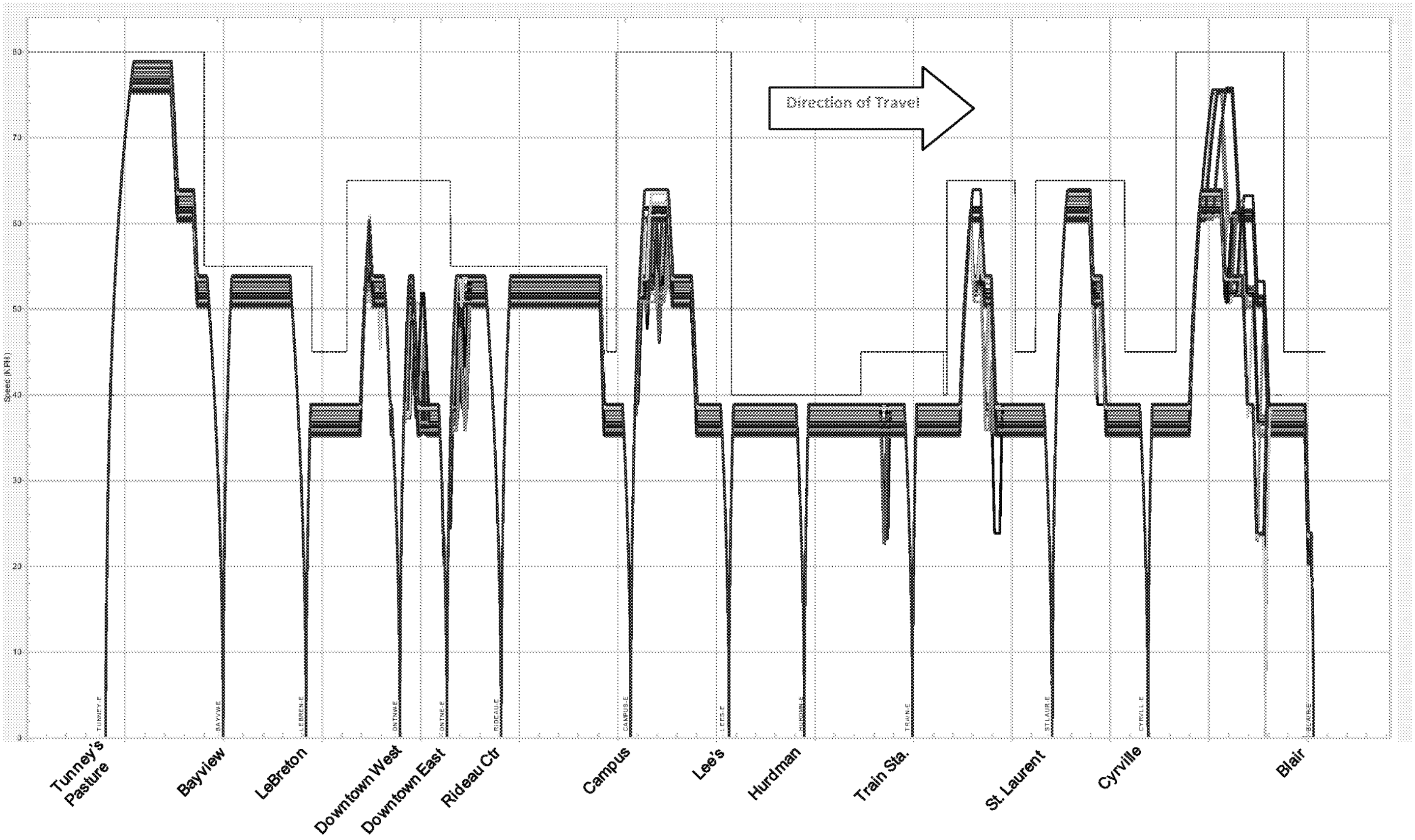


Figure A18. Year 2031 Service Plan: Composite Westbound Speed Profile of Trains in MTO

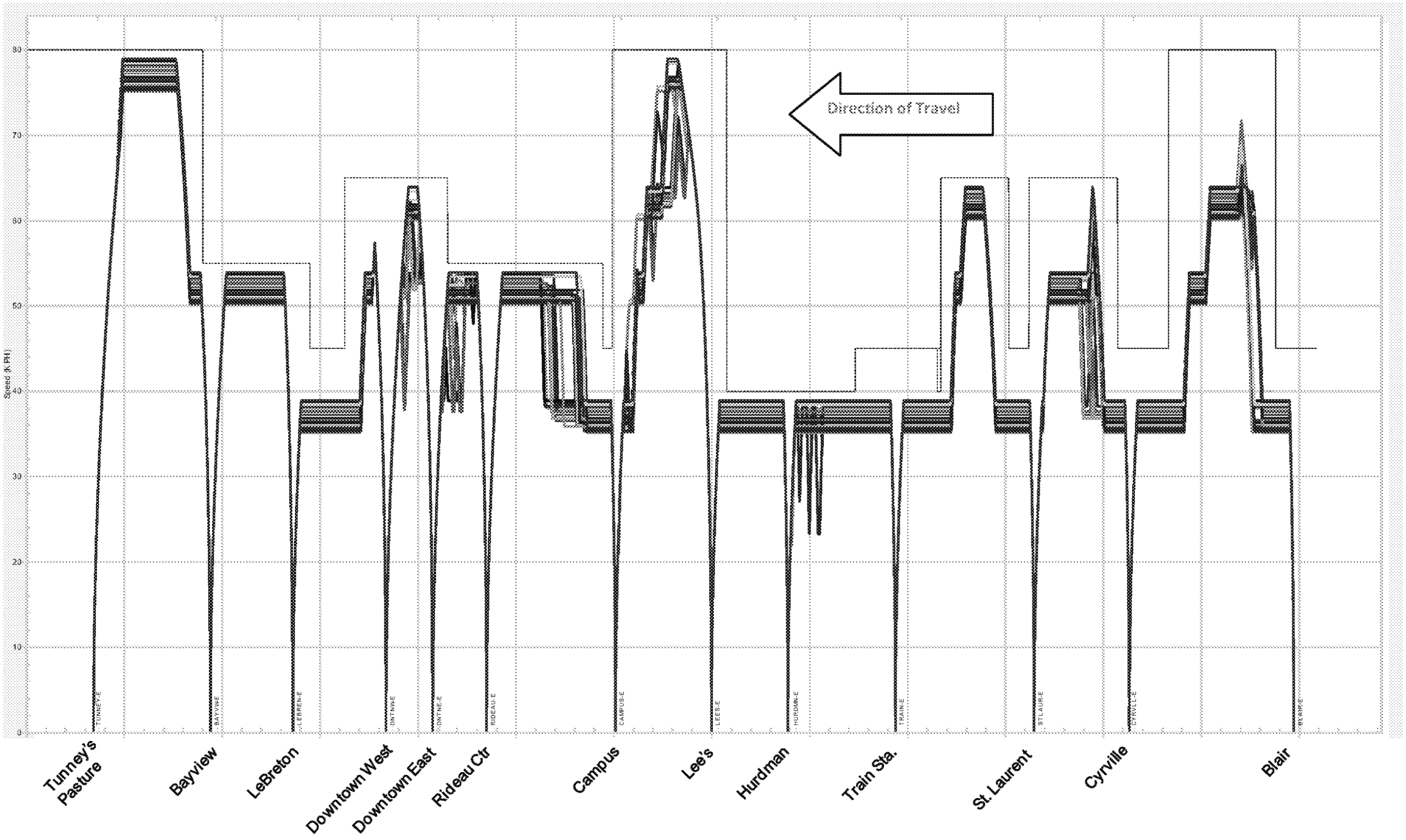


Figure A19. Year 2031 Service Plan: Peak Hour Train Movement at Blair Terminal; Trains in MTO

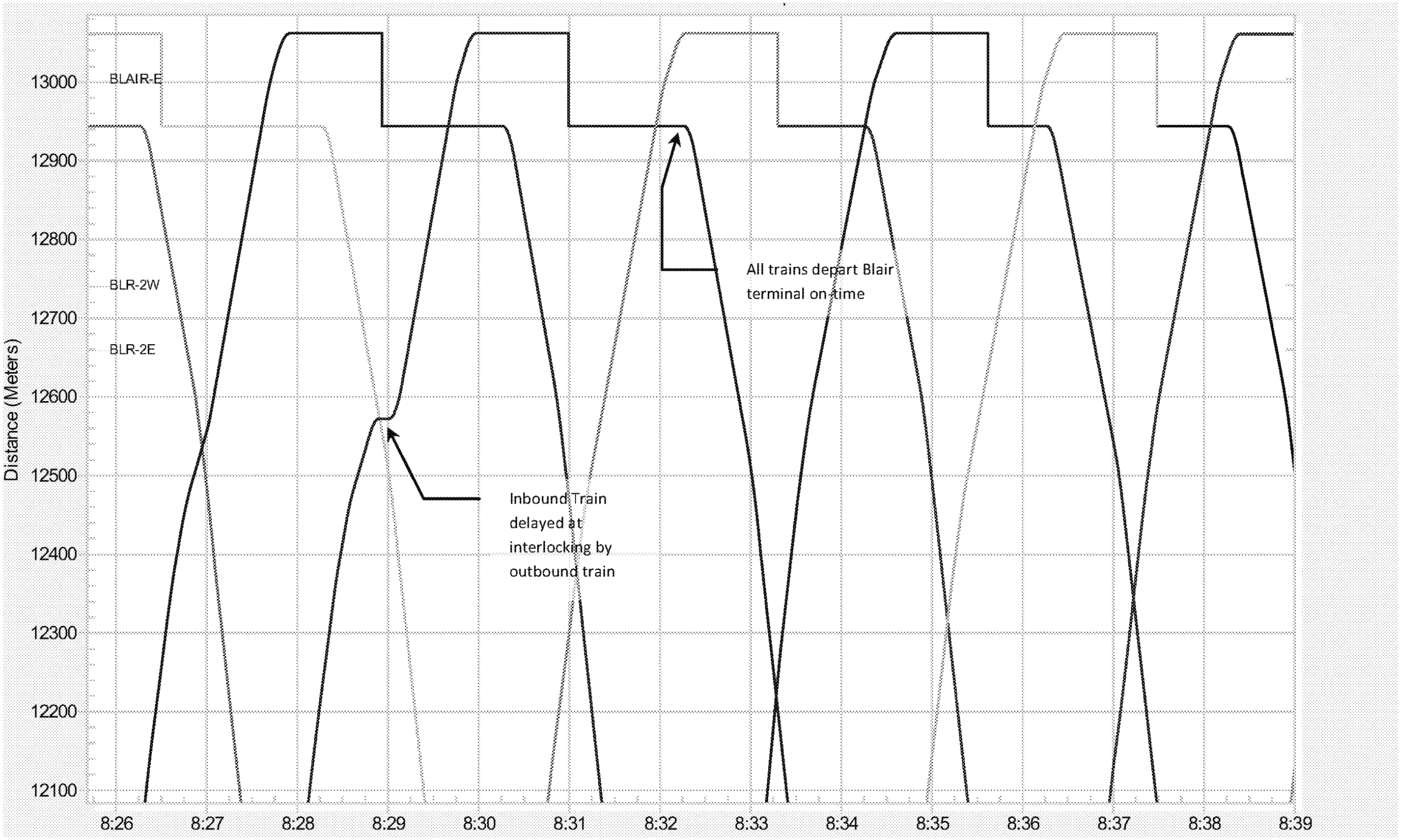


Figure A20. Year 2031 Service Plan: Peak Hour Train Movement for the Initial Segment; Trains in MTO

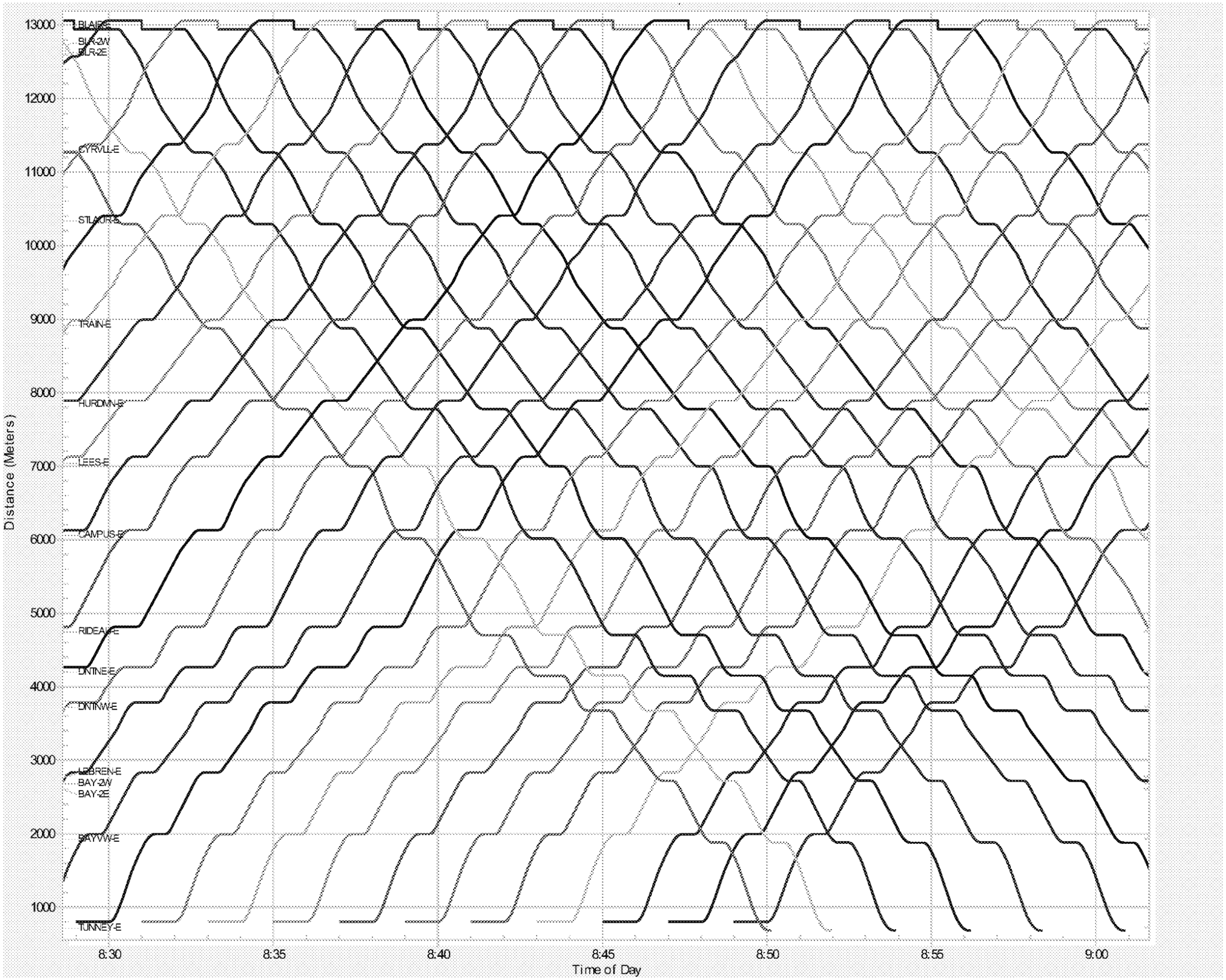
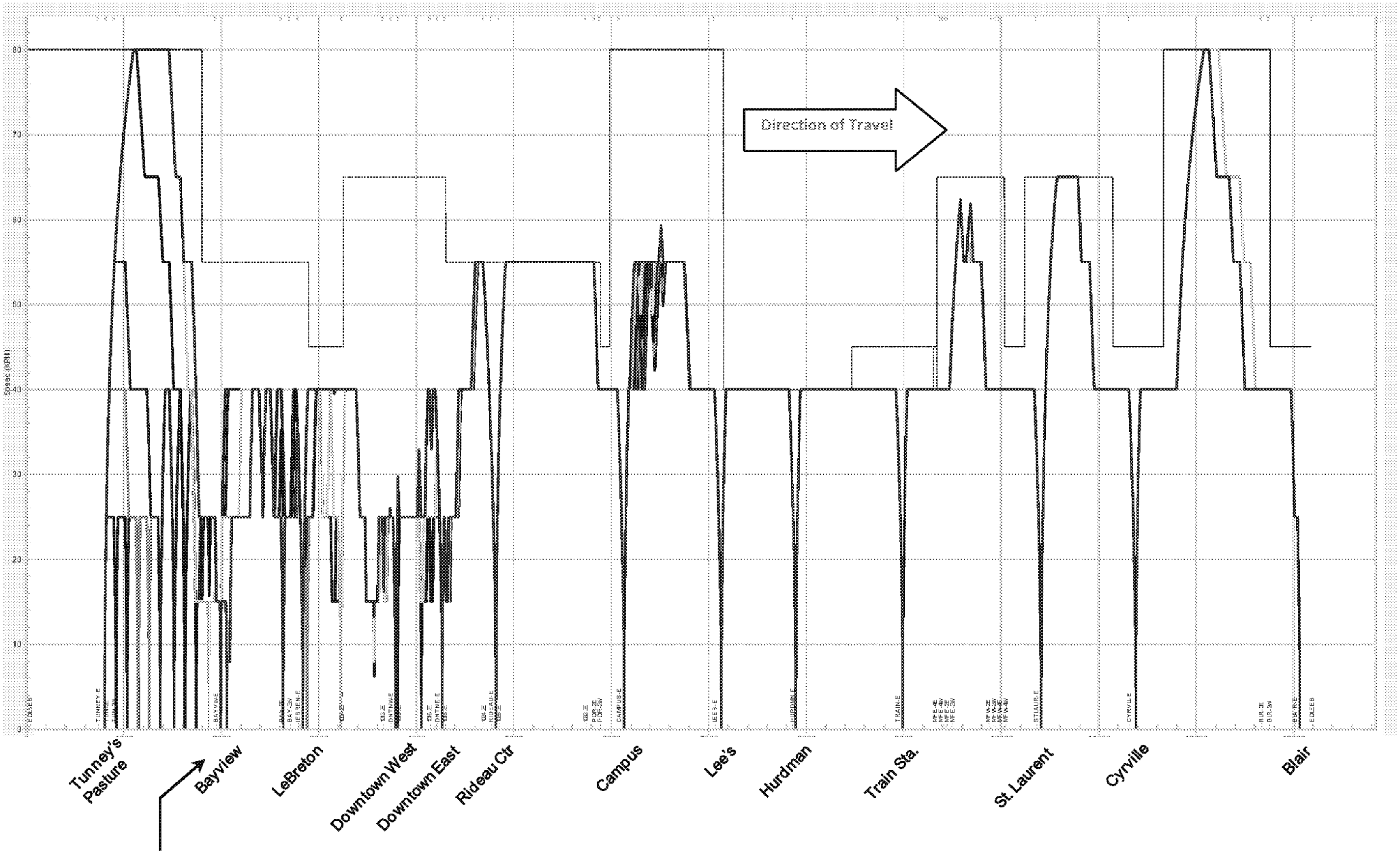
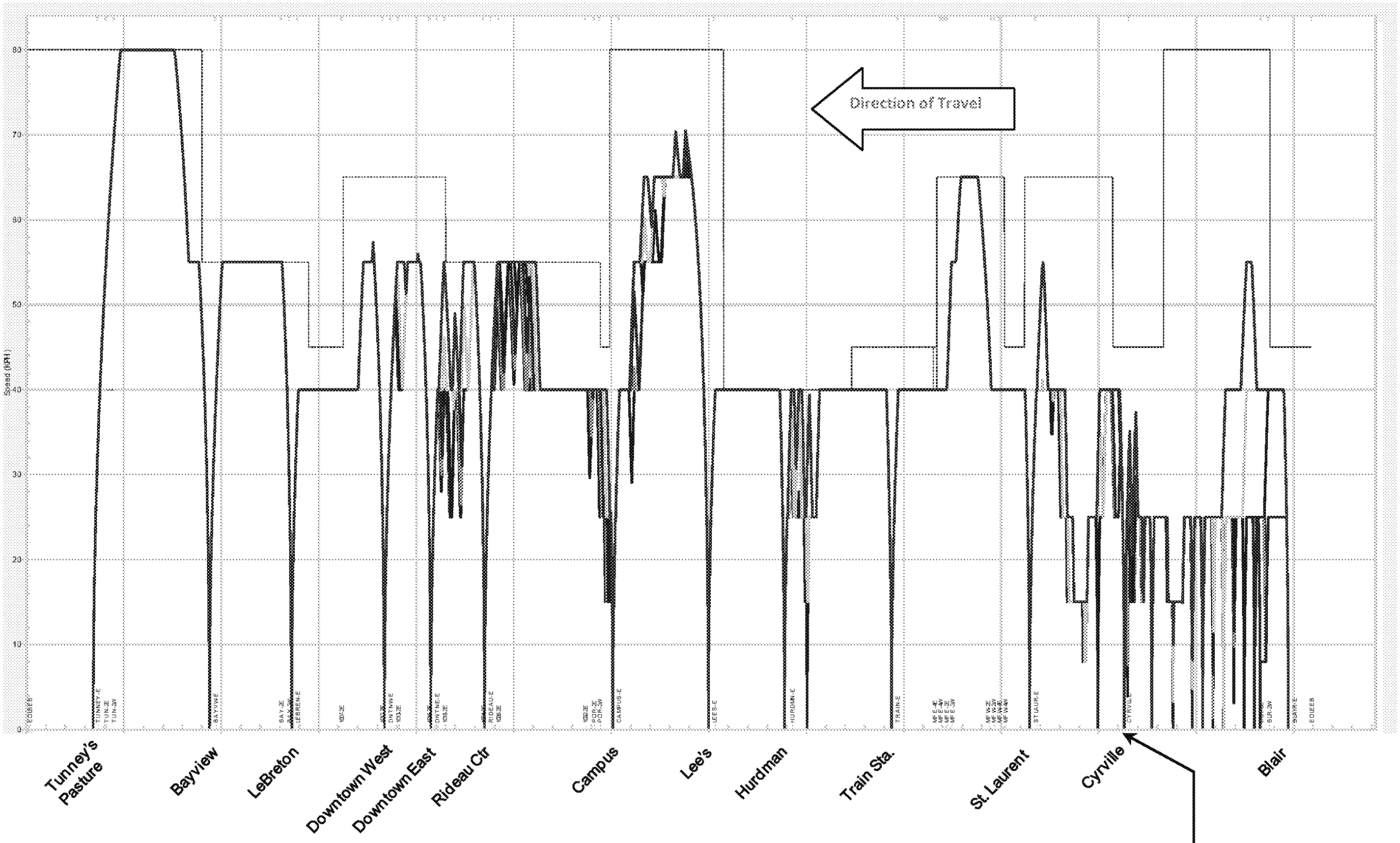


Figure A21. Composite Speed Profile of Eastbound Trains on Close Headway in ATO



Trains stack up behind lead train held at Bayview. With lead train released, trains proceed at close headway.

Figure A22. Composite Speed Profile of Westbound Trains on Close Headway in ATO



Trains stack up behind lead train held at Cyrville. With lead train released, trains proceed at close headway.

APPENDIX D

DISCRETE TERMINAL CAPACITY ANALYSIS

Ottawa's Light Rail Transit Project

Discrete Operations Analysis Update

March 9, 2011

Today's Agenda

1. Background / Purpose
2. Assumptions / Methodology
3. Tunney's Pasture Terminal (2 scenarios)
4. Blair Terminal (6 scenarios)

Background / Purpose

- Evaluate terminals and other constraining elements of EPR track design
- Focus, in particular, on minimum headway capability
- Identify and test different track and station modifications, as necessary, and quantify potential operational benefit
- Inform and coordinate with Civil and Systems groups on design refinement

Assumptions / Methodology

- Calculate minimum headway for <u>unimpeded operation</u> of successive trains under ideal performance
- Ideal train performance determined using STV’s train performance calculator (TPC)
- Use same reference vehicle as for Network Simulation
- Alignment Revision 01 as starting point; subsequent variations as shown

Assumptions / Methodology

- Utilize preliminary signal design for Safe Braking Distance (SBD) and Civil Speed restrictions
- 10 sec of signal time to set / lock next route
- 6% adjustment of TPC running time to account for manual operation
- Apply terminal dwells resulting in regular headways

Assumptions / Methodology

Unimpeded Terminal Operation

Two interactions constrain headway:

- First train cannot depart terminal (Step 3) until second train clears crossover (Step 2) [+ signal time]
- Third train can only approach terminal unimpeded (Step 4) if it maintains a sufficient distance (safe braking) from the crossover until the first train clears the crossover (Step 3) [+ signal time]

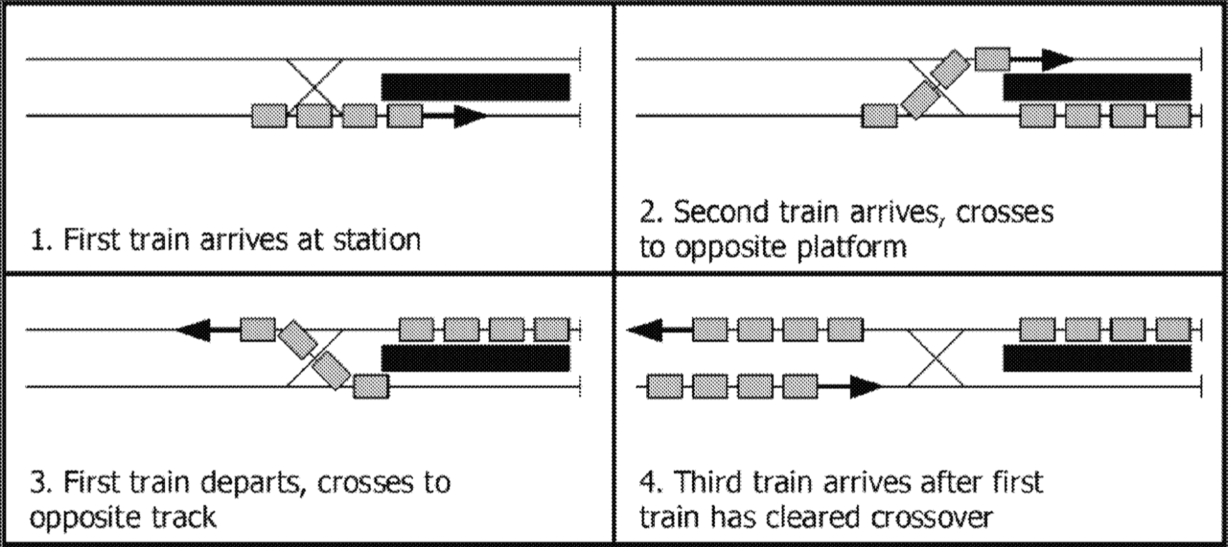


Diagram from TCRP 100 Transit Capacity and Quality of Service Manual

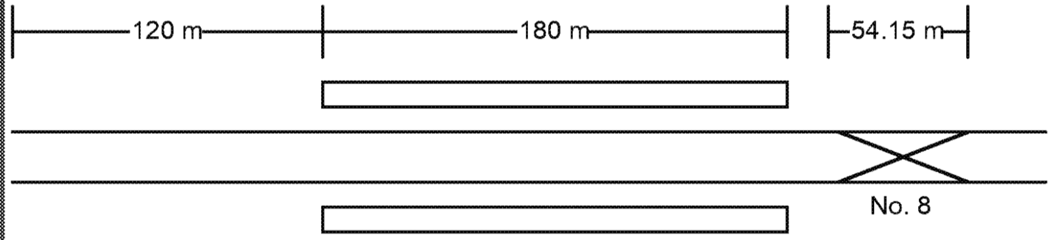
Tunney's Pasture

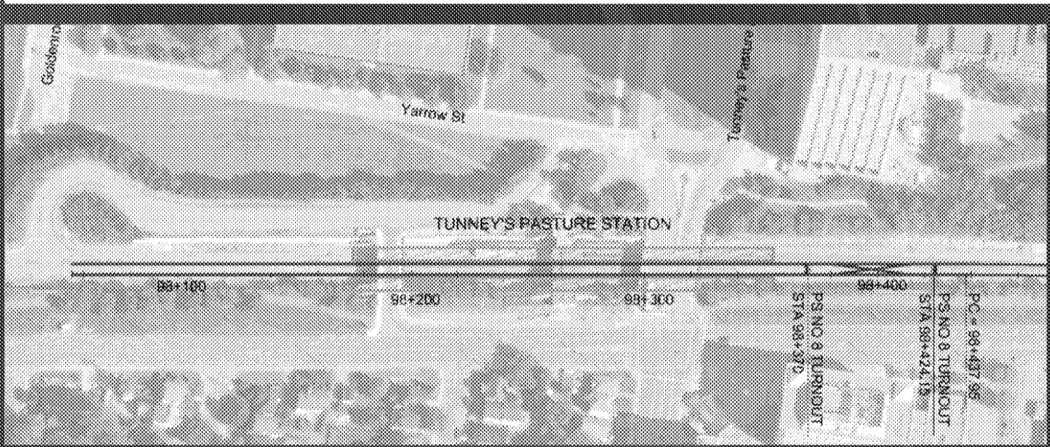
- EPR Configuration – 180m platform, 6 car train with 120m tail tracks (runoff)
- CTP refinement – 120m platform, 4-car train with 180m tail tracks (runoff)

Tunney's Pasture

180 m platform, 6-car train

- 180-meter platform with 6-car trains
- 120-meter runoff
- No. 8 crossover
  - 54.15 m long, 25 km/h civil speed restriction
  - located 15 m from end of platform

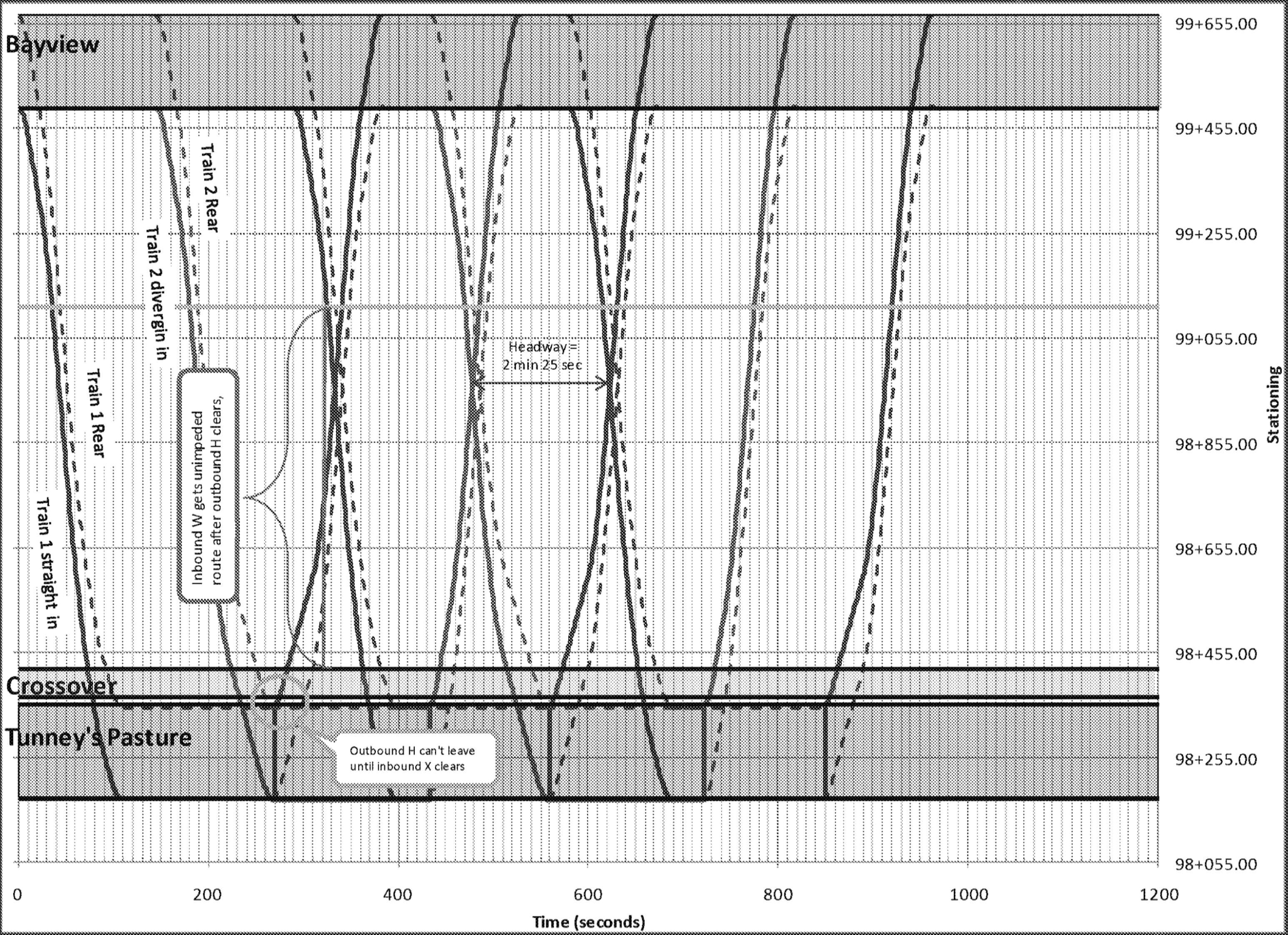




Minimum unimpeded headway = 2 min 25 sec

Terminal dwell time = 162-165 sec

Tunney's Pasture 180 m platform, 6-car train



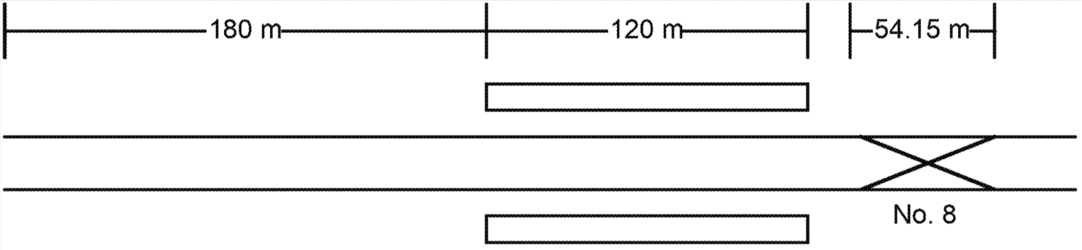
Inbound W gets unimpeded route after outbound H clears,

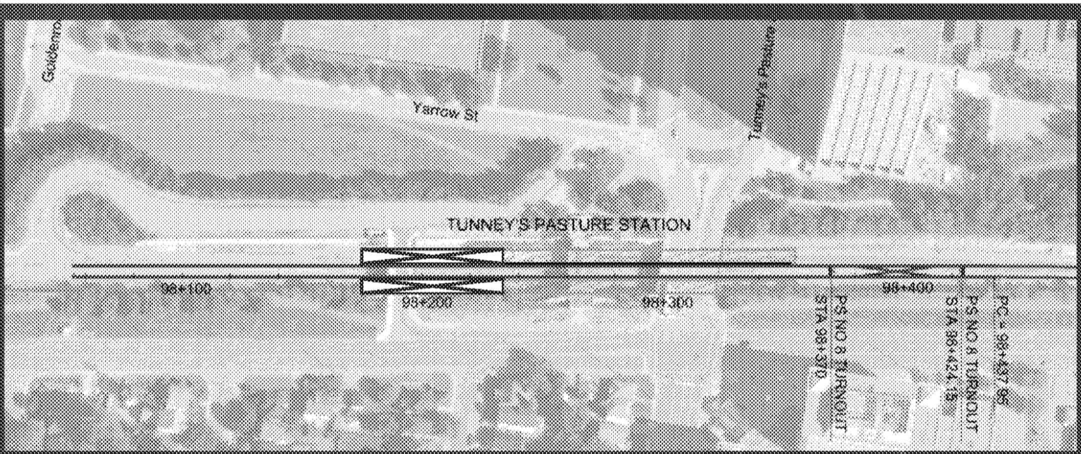
Headway = 2 min 25 sec

Outbound H can't leave until inbound X clears

Tunney's Pasture
120 m platform, 4-car train

- 120-meter platform with 4-car trains
- 180-meter runoff
- No. 8 crossover
  - 54.15 m long, 25 km/h civil speed restriction
  - located 15 m from end of platform

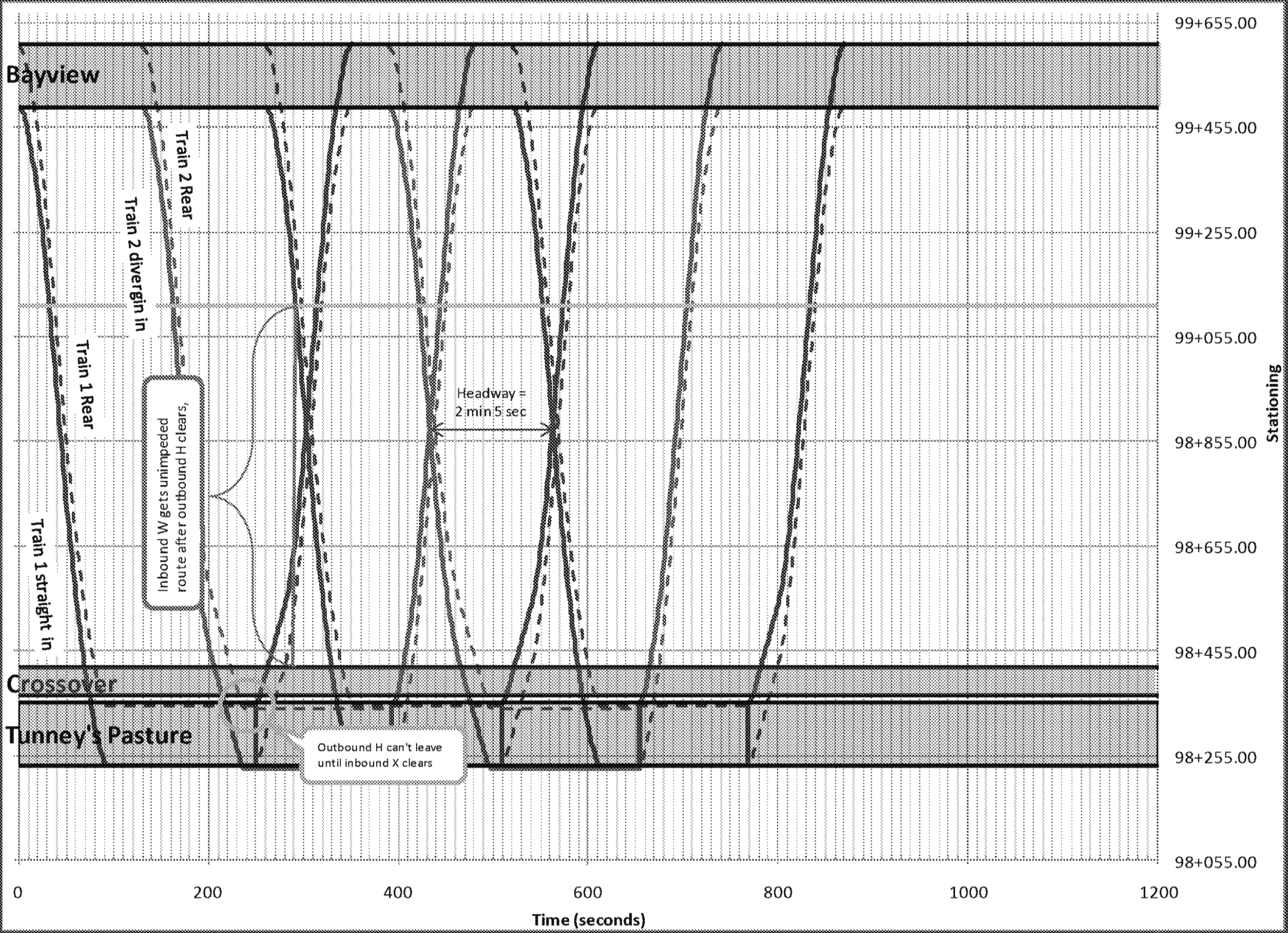




Minimum unimpeded headway = 2 min 5 sec

Terminal dwell time = 145 sec

Tunney's Pasture 120 m platform, 4-car train



Inbound W gets unimpeded route after outbound H clears,

Headway = 2 min 5 sec

Outbound H can't leave until inbound X clears

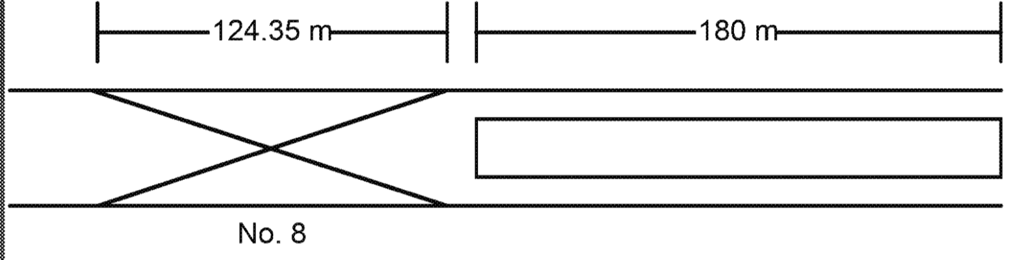
Blair

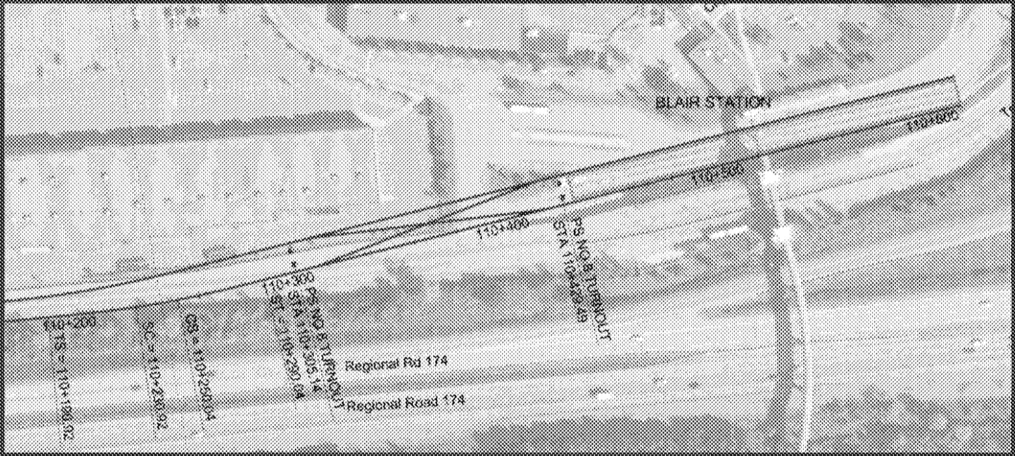
- EPR Configuration – 180m platform, 6 car train with no tail tracks (runoff)
- CTP refinement – 120m platform, 4-car train with 60m tail tracks (runoff)
- CTP alternate configuration – 120m platform, 4-car train, with single tail track. Four scenarios:
  - Safe braking if tail track is occupied: 105m runoff
  - Safe braking if tail tack is unoccupied: 295m runoff
  - Upgraded No. 15 crossover
  - Operation through tail track, no diverging moves

Blair

180 m platform, 6-car train

- 120-meter platform with 4-car trains
- No runoff
- No. 8 crossover
    - 124.35 m long, 25 km/h civil speed restriction
    - Located 5 m from end of platform

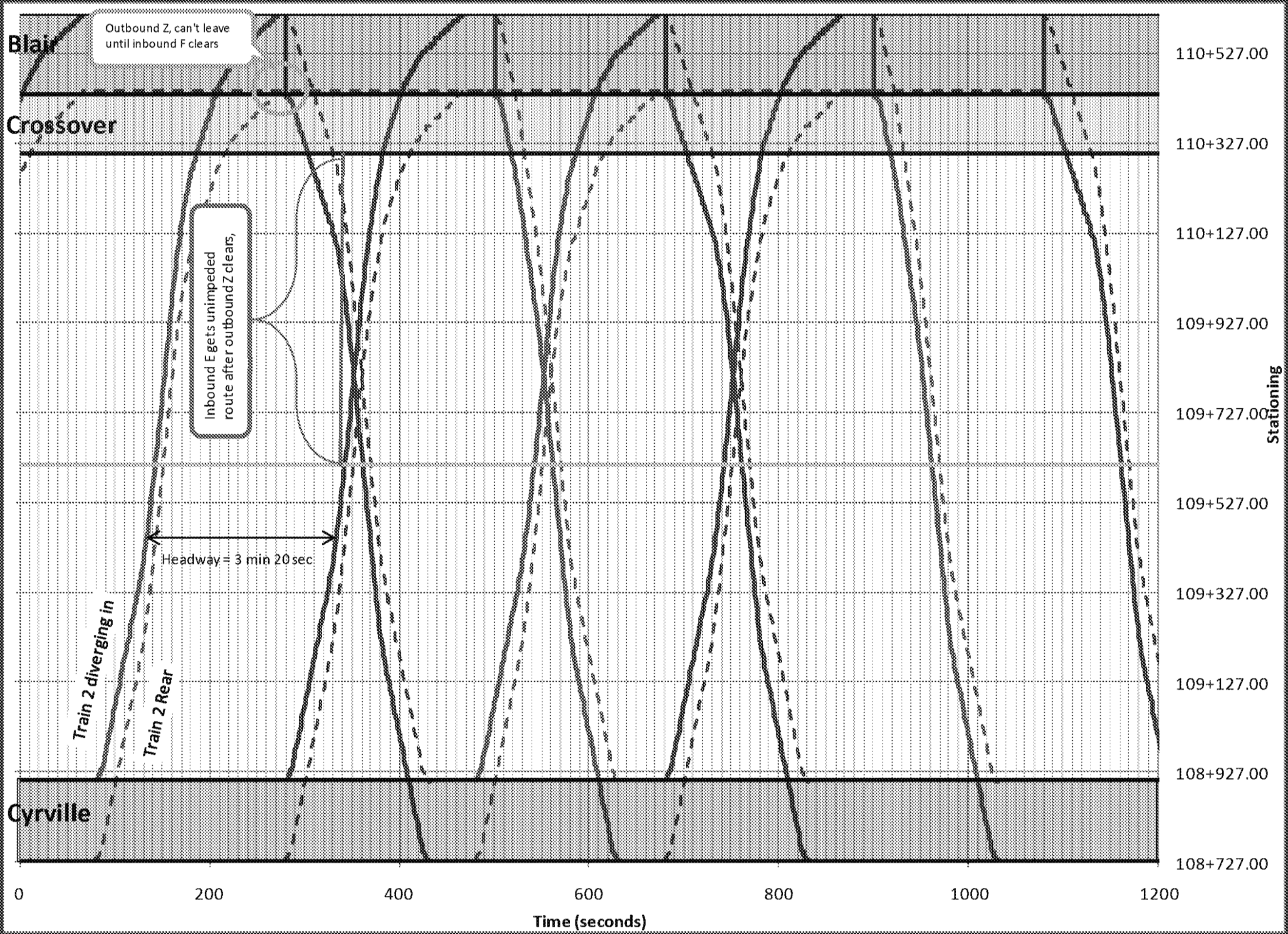




Minimum unimpeded headway = 3 min 20 sec

Terminal dwell time = 212-217 sec

Blair 180 m platform, 6-car train


Outbound Z, can't leave until inbound F clears

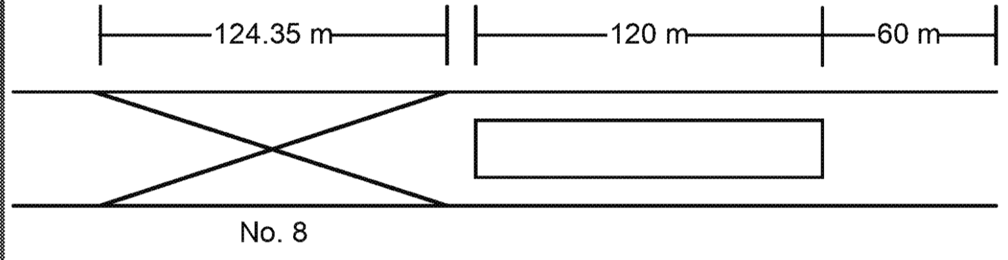
Inbound E gets unimpeded route after outbound Z clears,

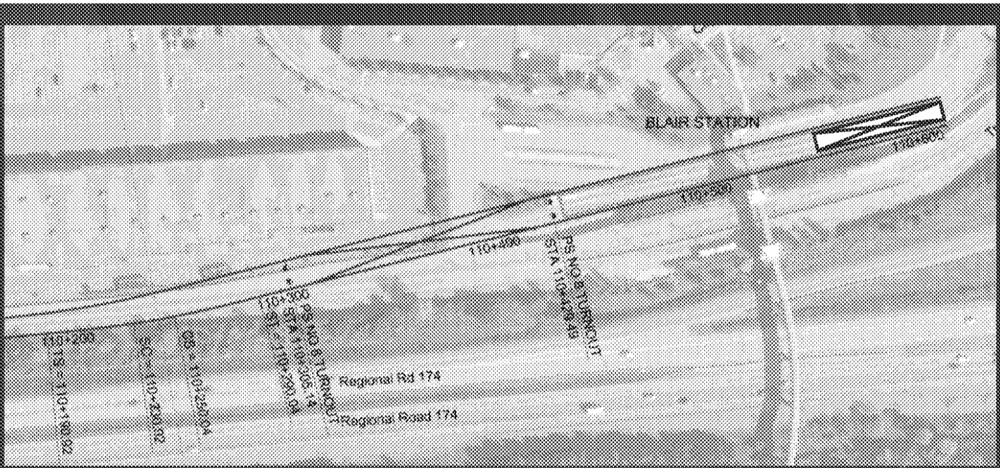
Headway = 3 min 20 sec

Blair

120 m platform, 4-car train

- 120-meter platform with 4-car trains
- 60-meter runoff
- No. 8 crossover
  - 124.35 m long, 25 km/h civil speed restriction
  - Located 5 m from end of platform

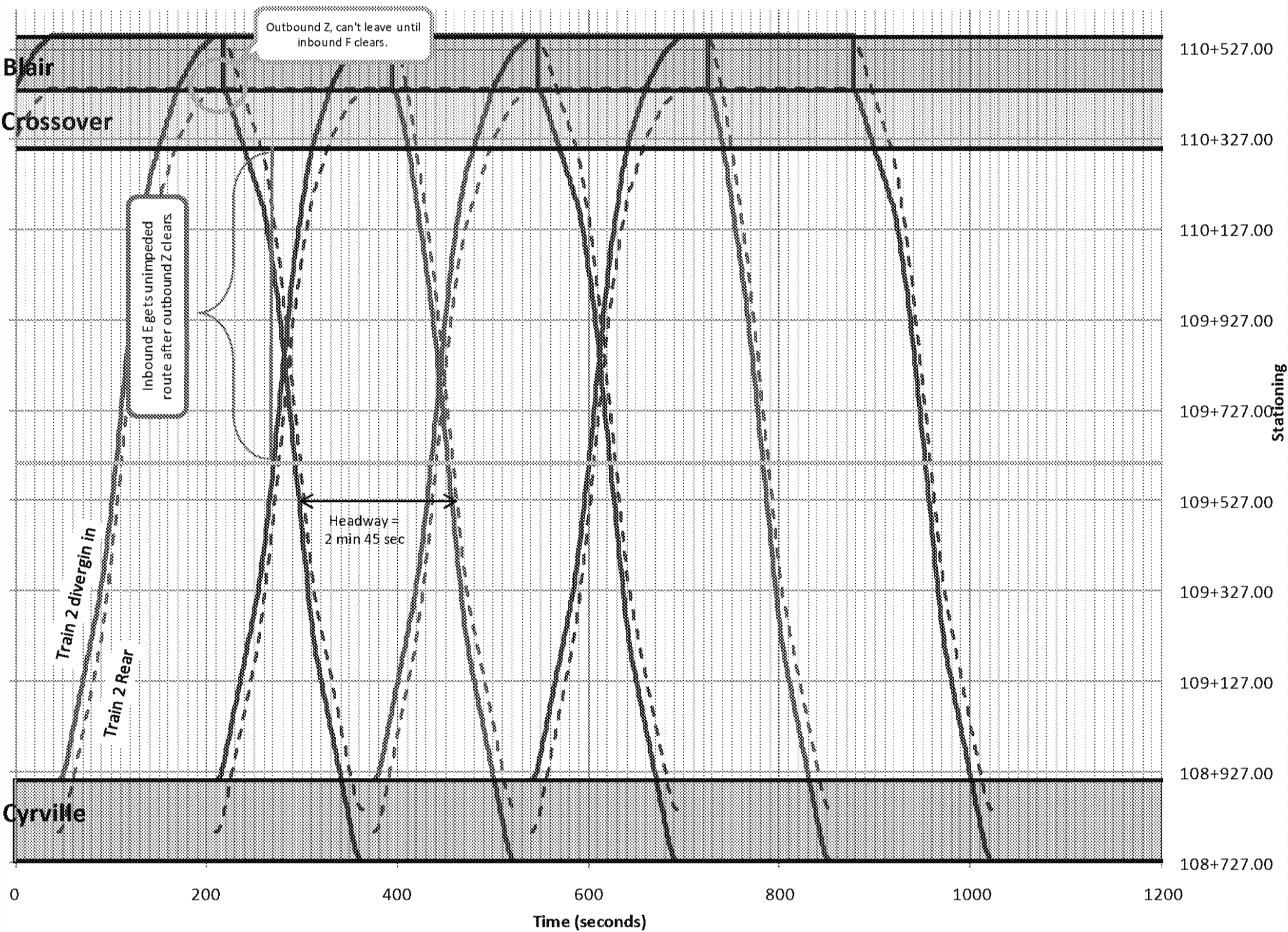




Minimum unimpeded headway = 2 min 45 sec

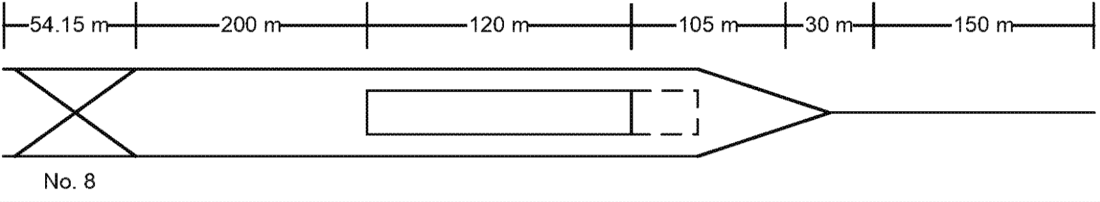
Terminal dwell time = 180-186 sec

Blair 120 m platform, 4-car train

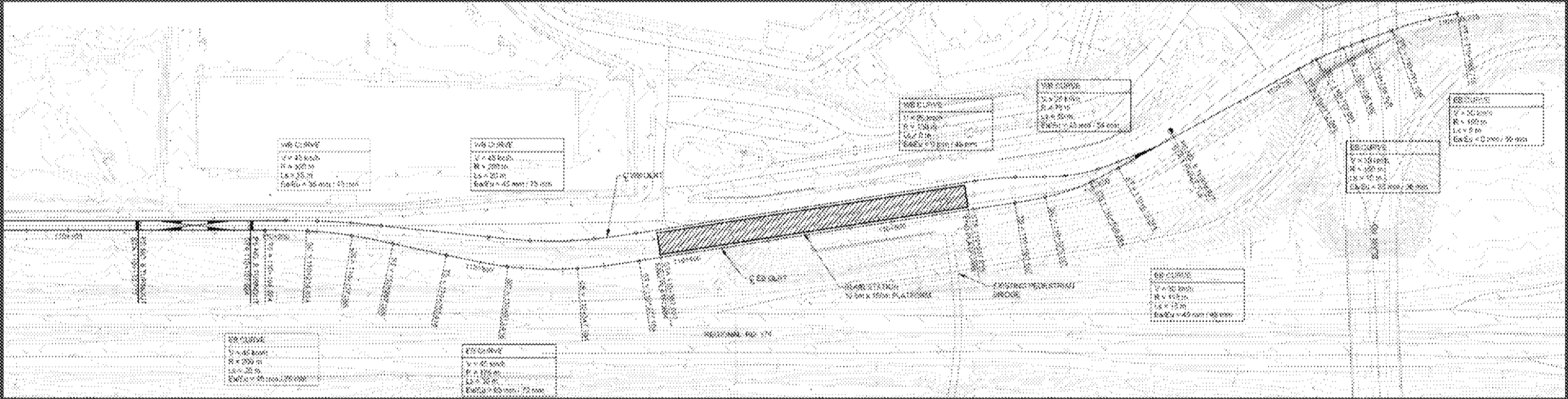


Blair - Relocated

120 m platform, 4-car train, single tail track

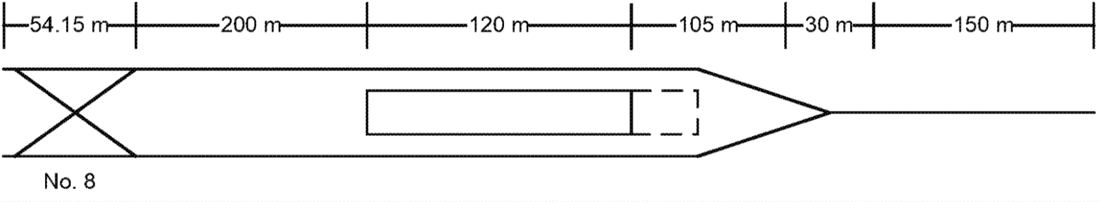


- 120-meter platform with 4-car trains (can be extended to 150m)
- 105-meter double track runoff, followed by 150-meter single tail track
- No. 8 crossover
  - 54.15 m long, 25 km/h civil speed restriction
  - located 200 m from end of platform



Blair - Relocated

120 m platform, 4-car train, single tail track



Two Operational Configurations

1) Tail track is occupied

- Safe braking measured to end of double track runoff (105-meter runoff)

Minimum unimpeded headway = 2 min 20 sec

Terminal dwell time = 130-135 sec

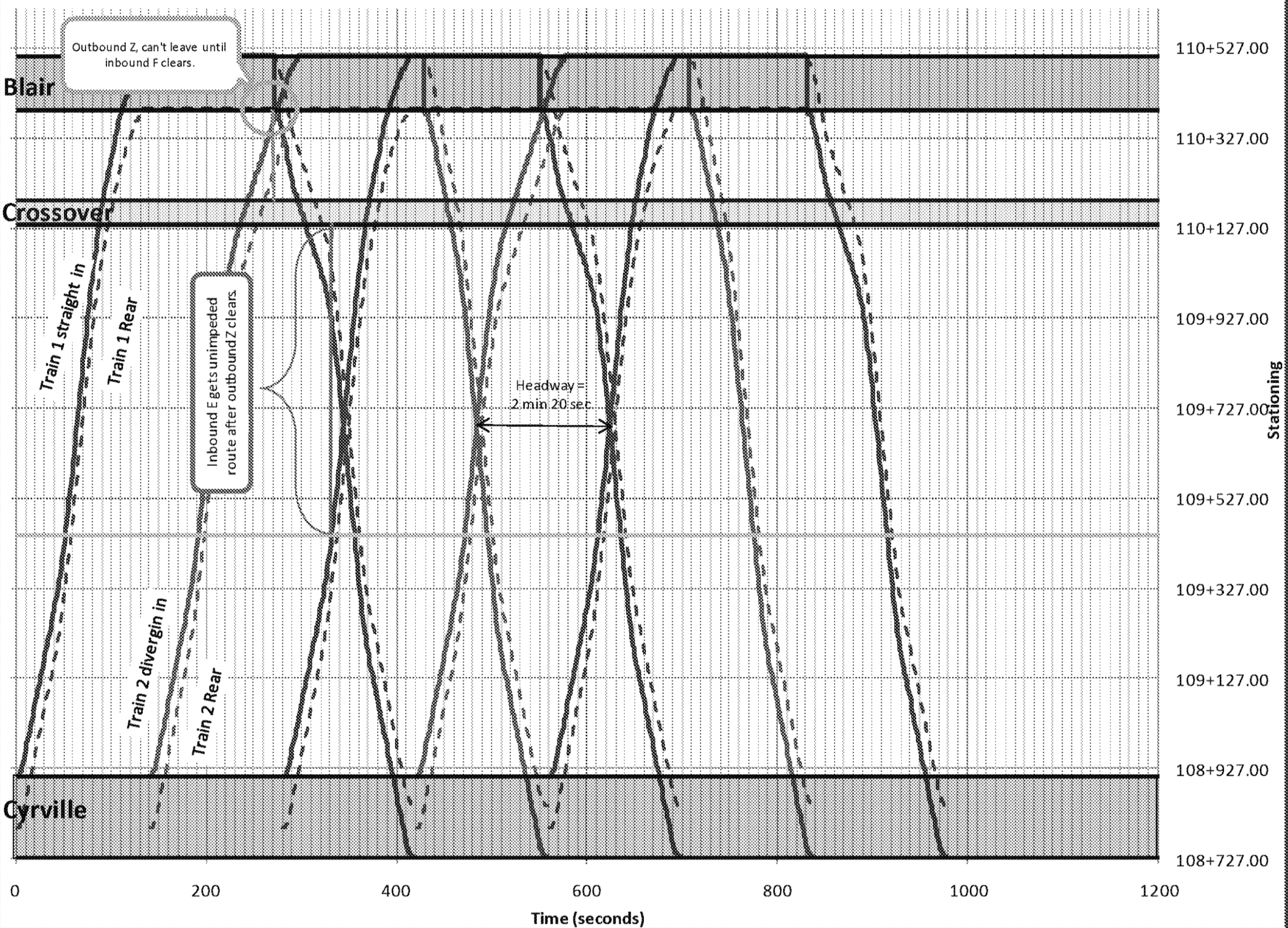
2) Tail track is unoccupied

- Safe braking measured to end of tail track (295-meter runoff)

Minimum unimpeded headway = 2 min 20 sec

Terminal dwell time = 140-145 sec

Blair 120 m platform, 4-car train
105-meter runoff

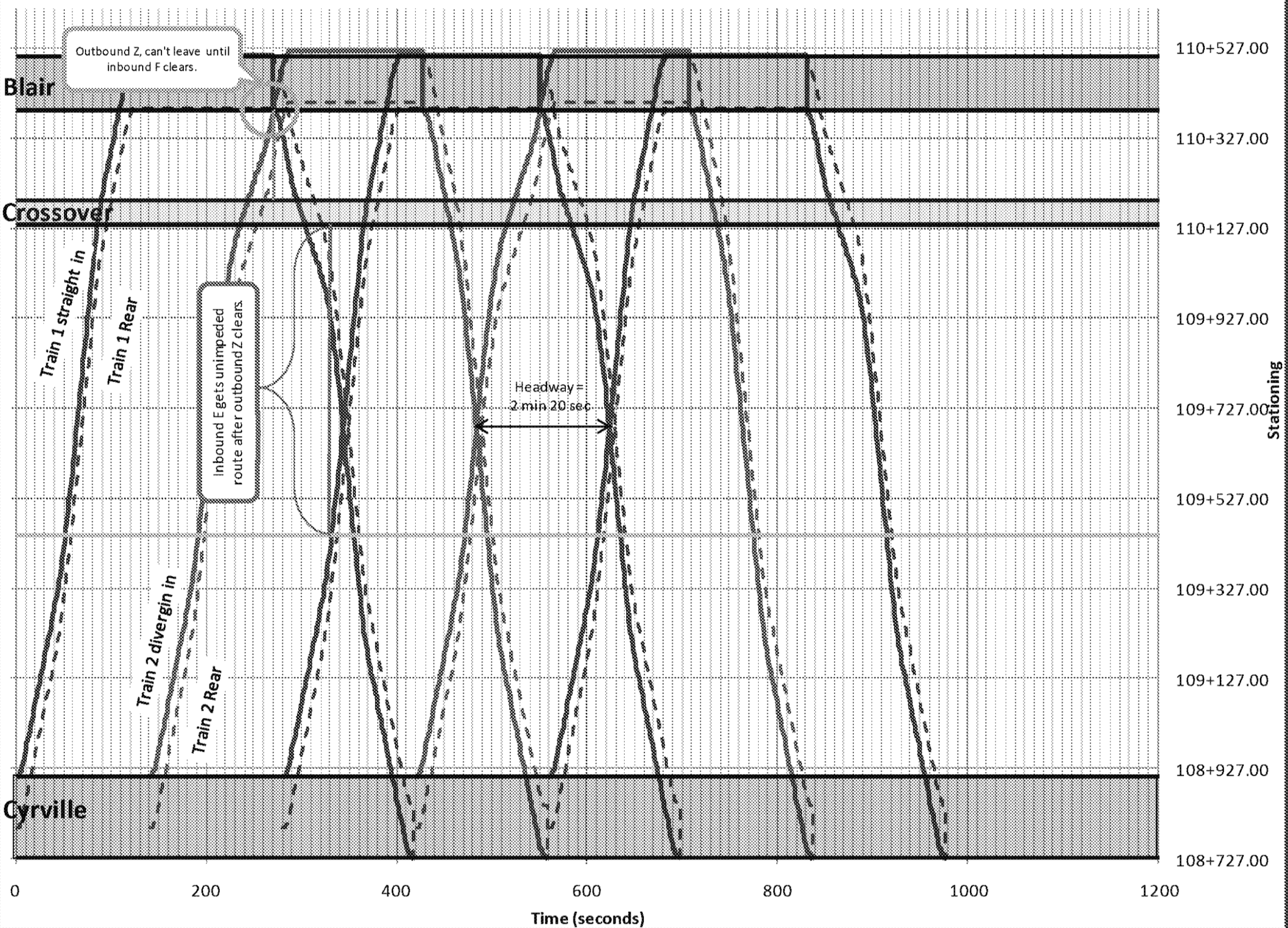


Outbound Z, can't leave until inbound F clears.

Inbound E gets unimpeded route after outbound Z clears.

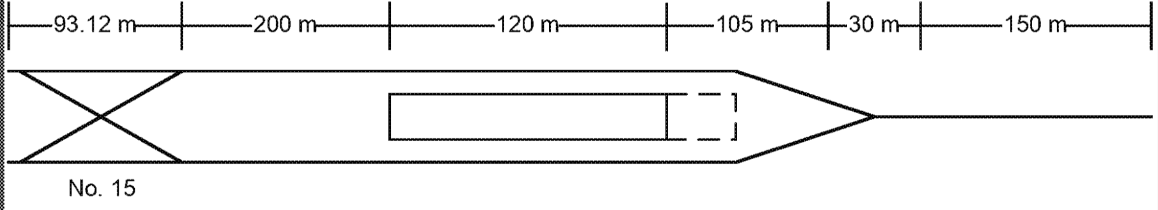
Headway = 2 min 20 sec

Blair 120 m platform, 4-car train 295-meter runoff

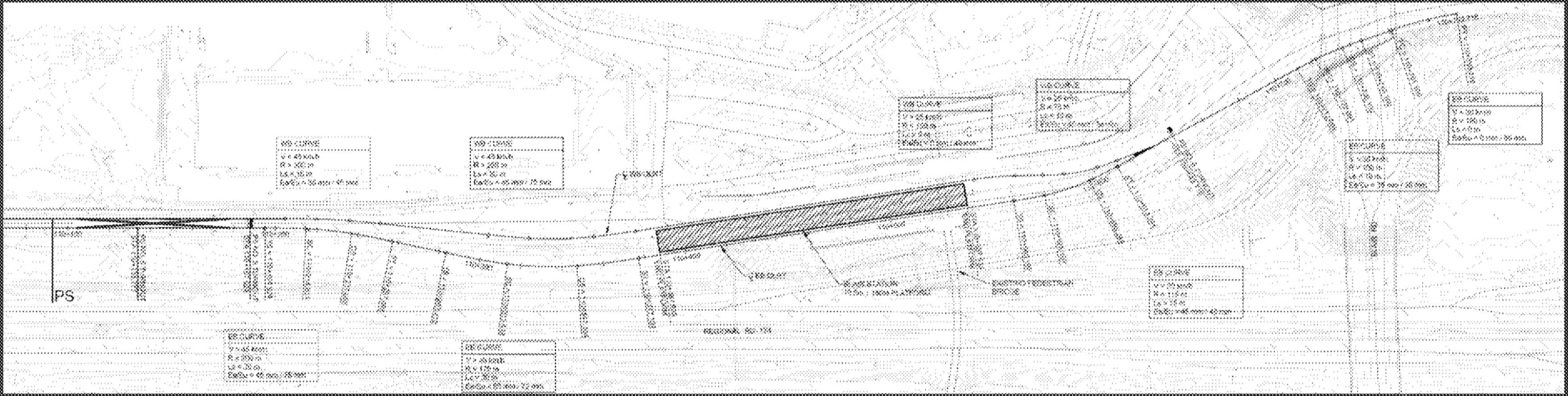


Blair - Relocated

120 m platform, 4-car train, No. 15 crossover



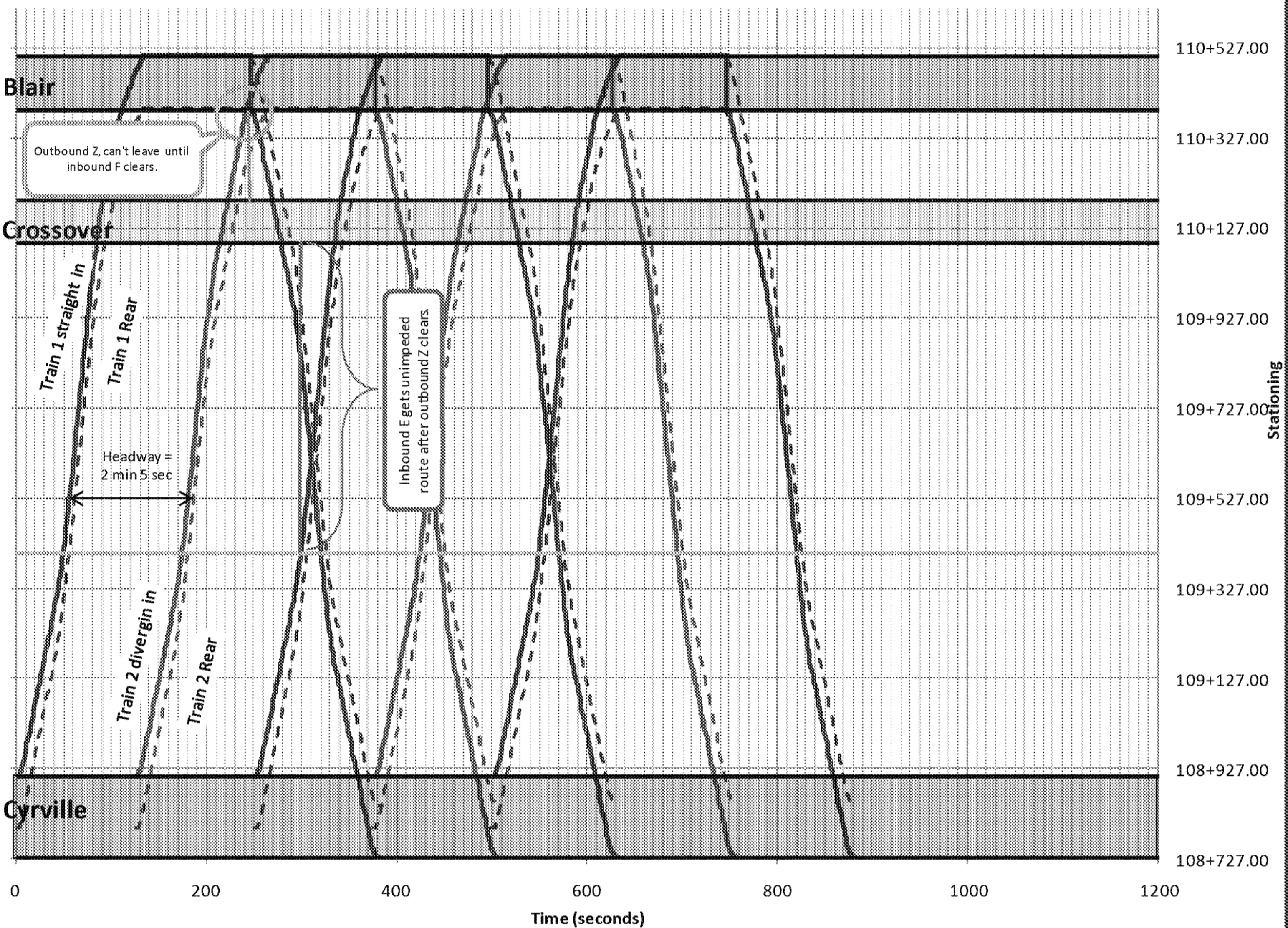
- 120-meter platform with 4-car trains (can be extended to 150m)
- 105-meter double track runoff, followed by 150-meter single tail track
- Upgraded No. 15 crossover
  - 93.2 m long, 45 km/h civil speed restriction
  - located 200 m from end of platform



Minimum unimpeded headway = 2 min 5 sec

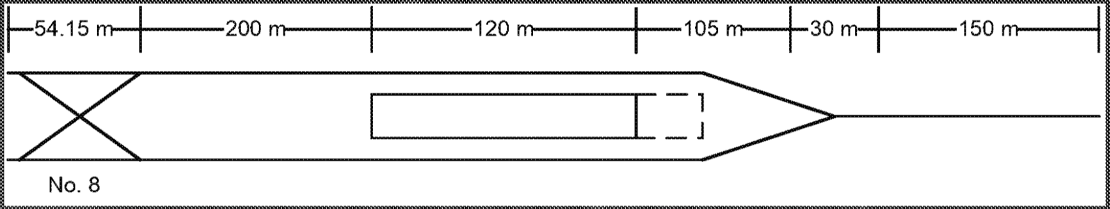
Terminal dwell time = 110 sec

Blair 120 m platform, 4-car train No. 15 Crossover



Blair – Relocated

120 m platform, 4-car train, tail track operation



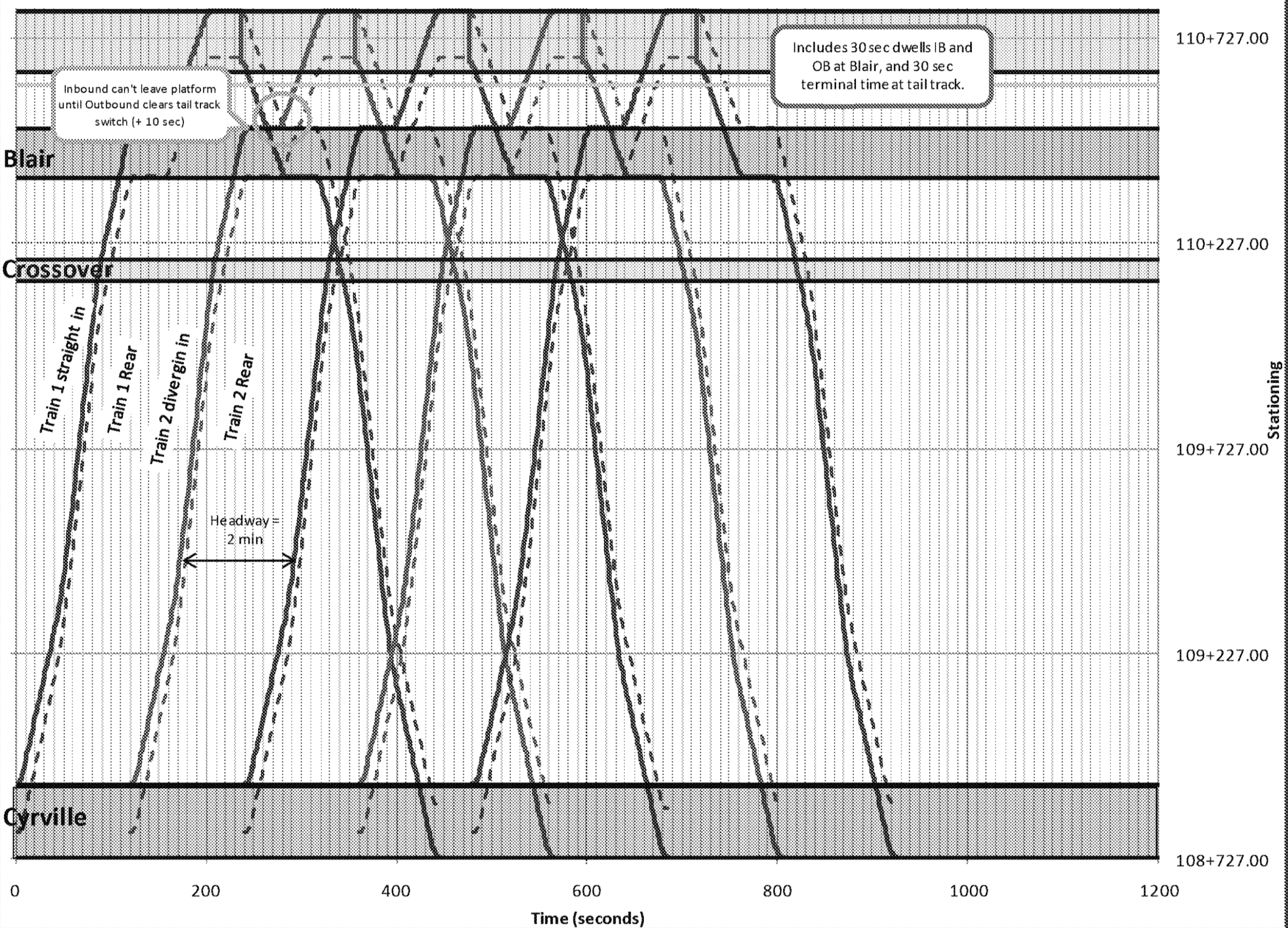
- 120-meter platform with 4-car trains (can be extended to 150m)
- 105-meter double track runoff, followed by 150-meter single tail track
- No. 8 crossover
  - 54.15 m long, 25 km/h civil speed restriction
  - located 200 m from end of platform

- Terminal operation using tail track
  - No regular use of crossover at terminal
  - Minimum headway constrained by time to travel in and out of tail track
  - Terminal dwell time to switch train direction and change operators set at 30 sec

Minimum unimpeded headway = 2 min

Terminal dwell time = 30 sec

Blair 120 m platform, 4-car train Tail track operation



Inbound can't leave platform until Outbound clears tail track switch (+ 10 sec)

Includes 30 sec dwells IB and OB at Blair, and 30 sec terminal time at tail track.

Ottawa

Summary of Results

Scenario	Minimum Headway	Dwell
Tunney's Pasture EPR 180m, 6-car	2 min 25 sec	162 – 165 sec
Tunney's Pasture CTP Refinement 120m, 4-car	2 min 5 sec	145 sec
Blair (Orig) EPR 180m, 6-car	3 min 20 sec	212 – 217 sec
Blair (Orig) CTP Refinement 120m, 4-car	2 min 45 sec	180 – 186 sec
Blair (CTP Alternate) 120m, 4-car, tail occupied	2 min 20 sec	130 – 135 sec
Blair (CTP Alternate) 120m, 4-car, 295m (tail open)	2 min 20 sec	140 – 145 sec
Blair (CTP Alternate) No. 15 crossover, 120m, 4-car	2 min 5 sec	110 sec
Blair (CTP Alternate) Pocket Track Operation	2 min *	30 sec platform, 30 sec in pocket

*Pocket Track operation inferior during normal operation, but valuable for recovery

APPENDIX E

PRELIMINARY SERVICE PLAN AND OPERATING QUANTITIES SUMMARY

Table E-1: Preliminary Service Plan

Preliminary Service Plan				2018-2021	2022-2024	2025-2027	2028-2030	2031-2035	2036-2040	2041-2045	2046-2048
Period	**Start**	**End**	**Duration (hours)**	**Headway (min)**	**Headway (min)**	**Headway (min)**	**Headway (min)**	**Headway (min)**	**Headway (min)**	**Headway (min)**	**Headway (min)**
Weekday											
Early Morning	5:00	6:30	1.5	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00
Morning Peak	6:30	9:00	2.5	3.25	2.80	2.45	2.15	2.00	2.40	2.25	2.20
Midday	9:00	14:45	5.75	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Afternoon Peak	14:45	18:00	3.25	3.25	2.80	2.45	2.15	2.00	2.40	2.25	2.20
Early Evening	18:00	21:30	3.5	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Late Evening	21:30	23:00	1.5	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00
Night	23:00	1:30*	2.5	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00
Weekday Daily Subtotal			*20.5*								
Saturday											
Base	6:00	19:00	13	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Eve	19:00	2:15	7.25	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00
Saturday Daily Subtotal			*20.25*								
Sunday / Holiday											
All Day	6:00	19:00	13	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
	19:00	23:00	4	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
Sunday / Holiday Daily Subtotal			*17*								

Summary Information		2018-2021	2022-2024	2025-2027	2028-2030	2031-2035	2036-2040	2041-2045	2046-2048
Peak Hour Capacity (max standee density of 3.33 pass per sq/m)	**pphpd**	**11,668**	**13,543**	**15,478**	**17,637**	**18,960**	**19,750**	**21,067**	**21,545**
Max. Trains in Service	**Trains**	**17**	**19**	**22**	**24**	**26**	**22**	**24**	**24**
Nominal Consist Size	**metre**	**120**	**120**	**120**	**120**	**120**	**150**	**150**	**150**
Weekday One-Way Trips		**499**	**533**	**569**	**608**	**632**	**575**	**594**	**601**
Max. Vehicles in Service	**LRVs**	**68**	**76**	**88**	**96**	**104**	**110**	**120**	**120**
Annual Rev. Train km	**Rev. Tr. km**	**2,144,494**	**2,189,330**	**2,301,108**	**2,489,387**	**2,565,812**	**2,383,241**	**2,444,098**	**2,466,228**
Annual Rev. Car km	**Rev. Car km**	**8,577,977**	**8,757,320**	**9,204,433**	**9,957,548**	**10,263,249**	**11,916,205**	**12,220,490**	**12,331,140**