Capacity Analysis of the Union Station Rail Corridor using Integrated Rail and Pedestrian Simulation

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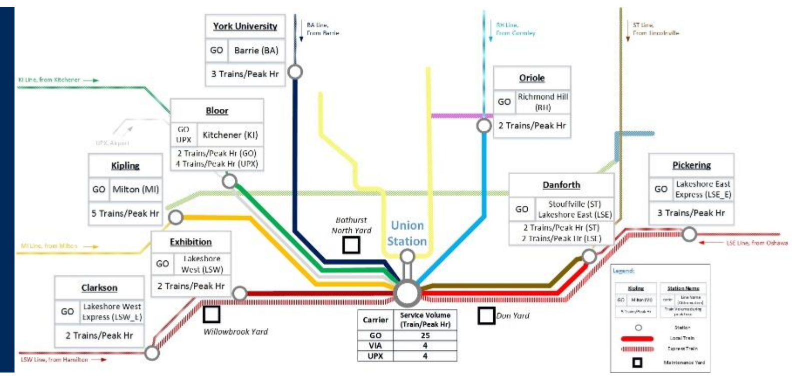


UNIVERSITY OF TORONTO

FACULTY OF APPLIED SCIENCE & ENGINEERING

Transportation Research Institute

Presentation Outline

- Introduction
- Railway Capacity Approaches
- Toronto Union Station Rail Corridor
- Data
- Analytical Capacity Methods
- Railway Simulation
- Integrated Rail and Pedestrian Simulation – Nexus
- Scenario Tests and Results
- Conclusion

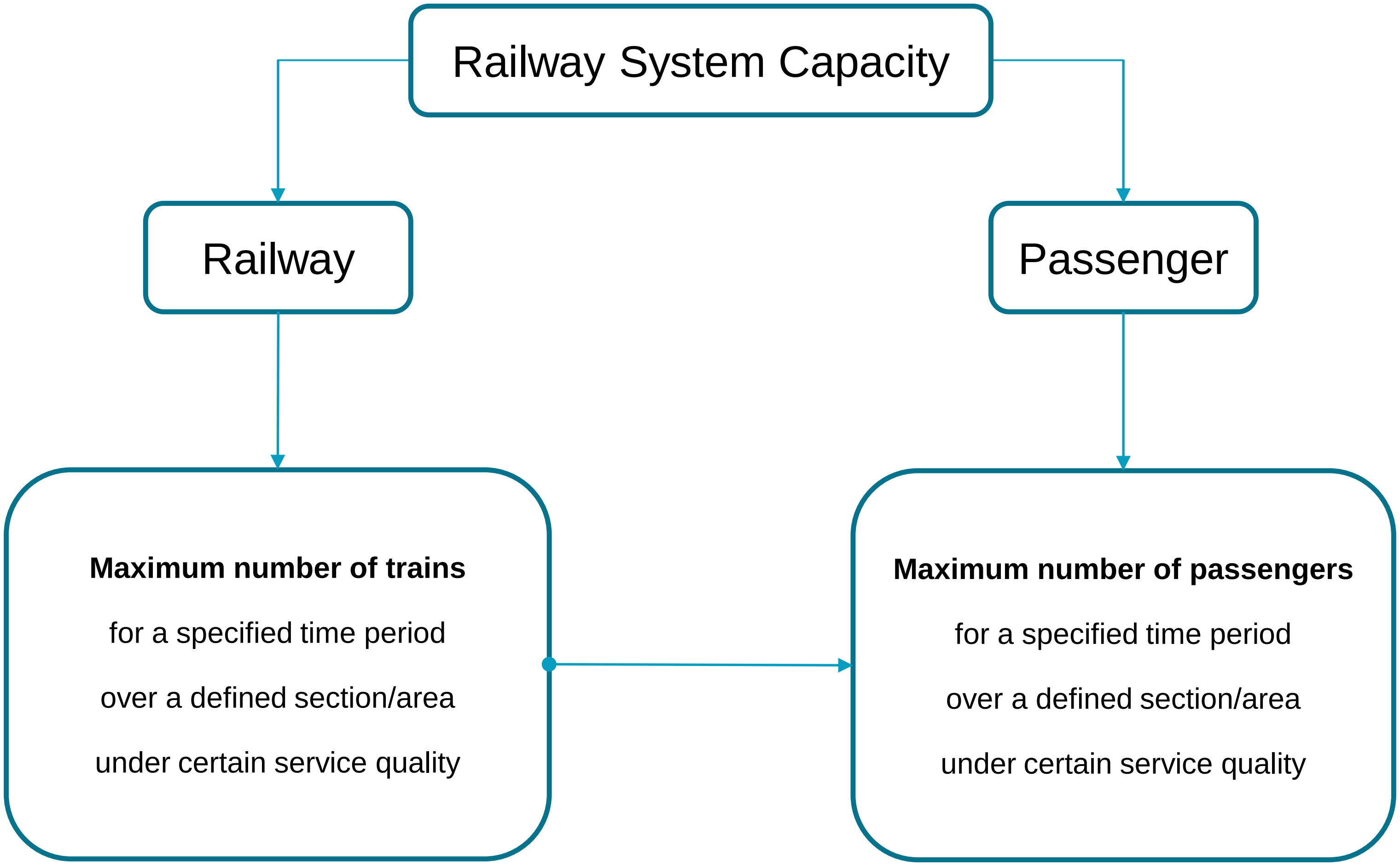
Introduction

Motivation

- Growing train traffic at existing railway network
- Platform crowding and limited platform space

- Increased train arrivals could affect platform density while extended dwell time could delay train departures
- Whether the infrastructure could support the anticipated service expansion (i.e. RER)
- Comprehensive capacity analysis of a complex station area is necessary to identify the bottleneck

Railway Capacity Approaches


Railway System Capacity
Railway
Passenger
Maximum number of trains
for a specified time period
over a defined section/area
under certain service quality
Maximum number of passengers
for a specified time period
over a defined section/area
under certain service quality

Railway Capacity

Article Name	Author	Year	Type
An analytical approach for the analysis of railway nodes extending the Schwanhäußer's method to railway stations and junctions	De Kort et al.	1999	Analytical
UIC Code 406 1st edition	International Union of Railways	2004	
Techniques for absolute capacity determination in railways	Burdett and Kozan	2006	
Development of Base Train Equivalents to Standardize Trains for Capacity Analysis	Lai et al.	2012	
Transit Capacity and Quality of Service Manual	Kittelson & Associates, Inc. et al.	2013	
A synthetic approach to the evaluation of the carrying capacity of complex railway node	Malavasi et al.	2014	
A Model, Algorithms and Strategy for Train Pathing	Carey & Lockwood	1995	Optimization
Optimal scheduling of trains on a single line track	Higgins et al.	1996	
A Job-Shop Scheduling Model for the Single-Track Railway Scheduling Problem	Oliveira and Smith	2000	
UIC Code 406 2nd edition	International Union of Railways	2013	
An assessment of railway capacity	Abril et al.	2008	Simulation
US & USRC Track Capacity Study	AECOM	2011	
Evaluation of ETCS on railway capacity in congested area : a case study within the network of Stockholm: A case study within the network of Stockholm	Nelladal et al.	2011	
Simulation Study Based on OpenTrack on Carrying Capacity in District of Beijing-Shanghai High-Speed Railway	Chen and Han	2014	
Railway capacity analysis: methods for simulation and evaluation of timetables, delays and infrastructure	Lindfeldt	2015	

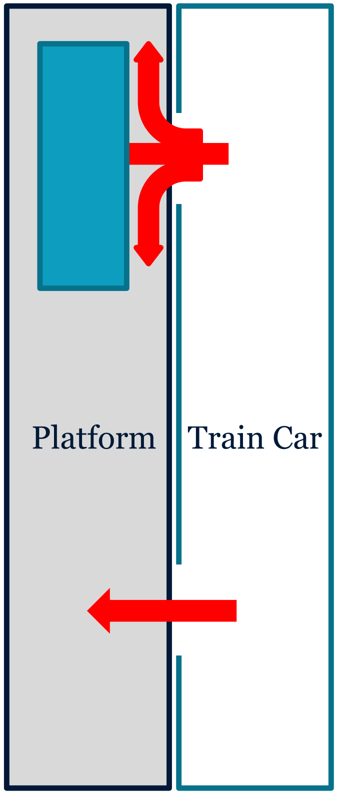
- Problem:
  - Results could vary largely due to different assumptions
  - Few studies compared methods in different categories
  - Virtually all dwell time is fixed (TCQSM, 2013)

Pedestrian Movements

- Traditional dwell time modeling
  - Boarding/Alighting/Through passengers, Regression models (San & Masirin, 2016)
- Pedestrian Modelling
  - Analytical modelling
  - Simulation

Article Name	Author	Year	Simulation
Pedestrian planning and design	Fruin	1971	
Social force model for pedestrian dynamics	Helbing & Molnár	1995	
The Flow of Human Crowds	Hughes	2003	
Autonomous Pedestrians	Shao and Terzopoulos	2007	
Pedestrian Simulation Research of Subway Station in Special Events	Zhao et al.	2009	Legion
Using Simulation to Analyze Crowd Congestion and Mitigation at Canadian Subway Interchanges	King et al.	2014	MassMotion
Use of Agent-Based Crowd Simulation to Investigate the Performance of Large-Scale Intermodal Facilities	Hoy et al.	2016	MassMotion

- Problem
  - Traditional dwell time models can not show the platform density, or reflect the flow complication due to infrastructure layout
  - Transit vehicle arrival/departure time is fixed

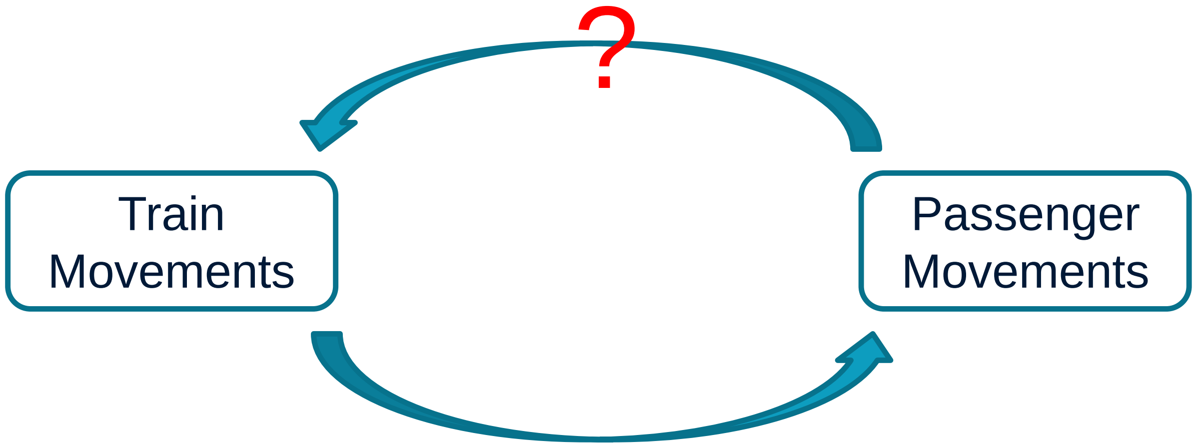


Integrated Simulation

- Key assumptions for individual simulators:
  - ~~Fixed dwell time~~
  - ~~Fixed train arrival/departure time~~
- Current models:
  - Rail simulation with mathematical dwell time model (Jiang et al., 2015) (D'Acierno et al., 2017)
  - Rail simulation with pedestrian simulation model (Srikukenthiran & Shalaby, 2017)

Problem Statement

- Few studies compared methods in different categories
- Interactive effects of pedestrian and train movements are not well captured by individual simulator



Study approach

Analytical Capacity Analysis

(TCQSM, Potthoff method, DB method, Compression method)

↓

Railway Simulation

OpenTrack

↓

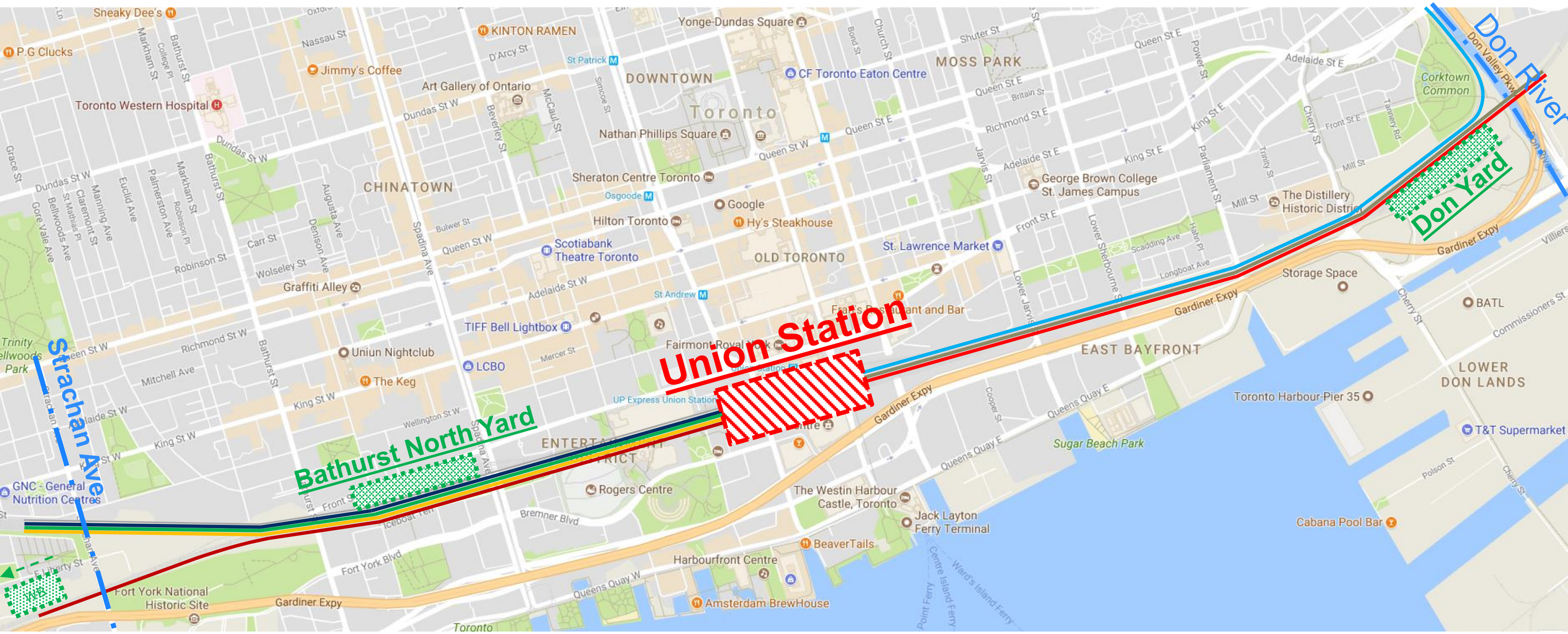
Railway and Pedestrian Simulation

Nexus Platform – OpenTrack and MassMotion

Case Study

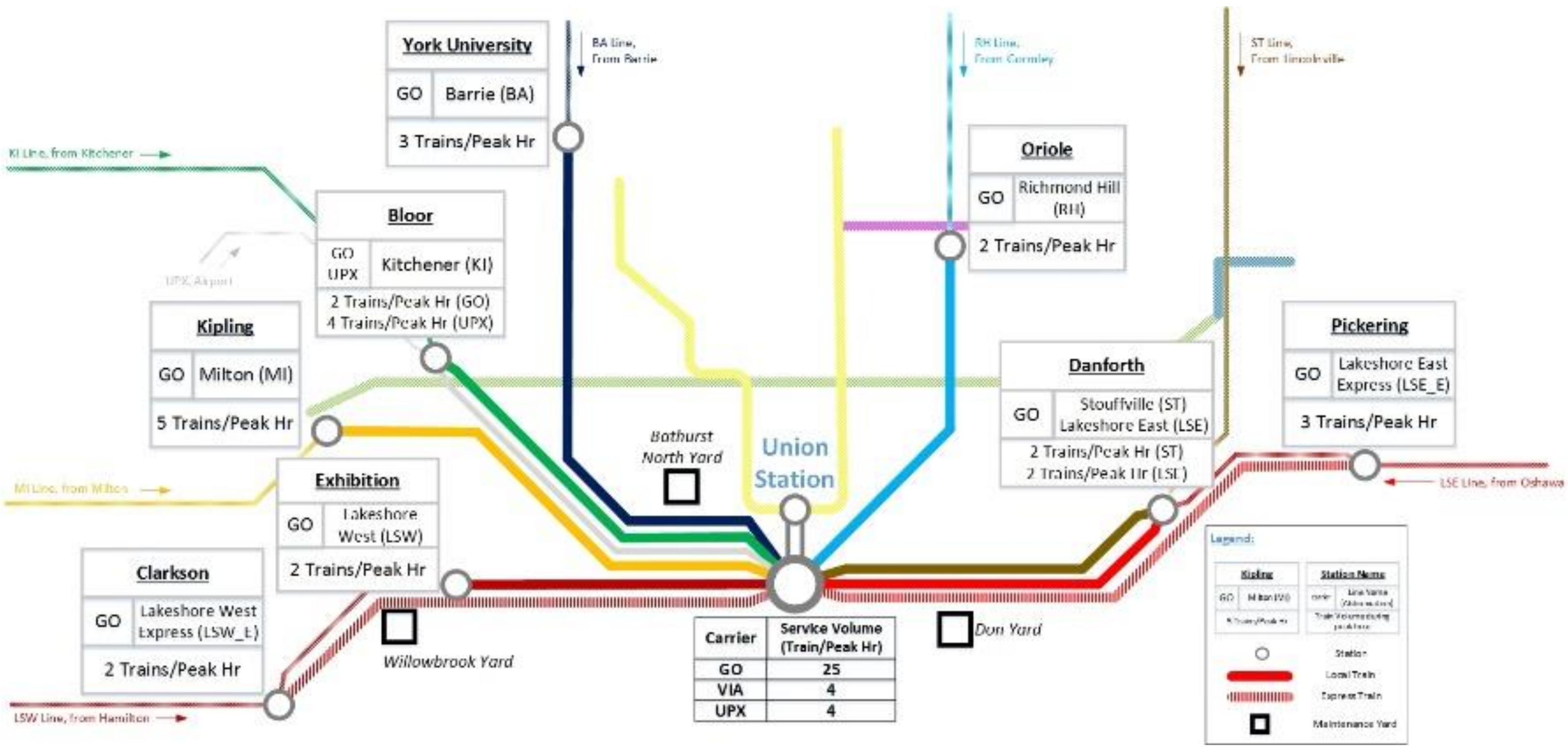
- Toronto Union Station Rail Corridor (USRC)

Union Station Rail Corridor (USRC)



- Built and opened in 1927
- 760,000 square feet of total floor space
- 14 track depots, 23 platforms, 350m long and 5m wide on average
- Toronto's transportation hub for GO Transit, VIA Rail and UP Express; as well as TTC
- Canada's busiest transportation facility: 200,000 passengers pass through Union Station on most business day
- 155,000 GO Train passengers and 10,000 bus passengers on a typical business day
- 208 daily GO Train trips
- 43 million annual passengers for GO train and bus
- 20 million annual passengers for TTC
- 2.4 million annual passengers for VIA

Scope

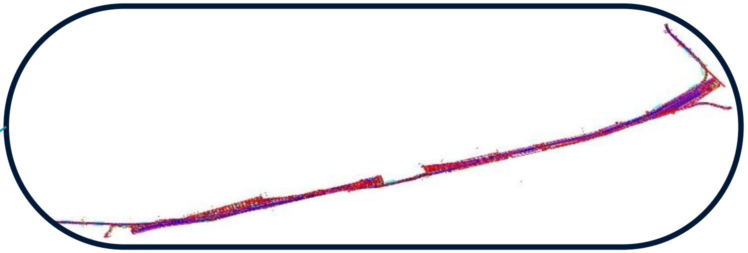


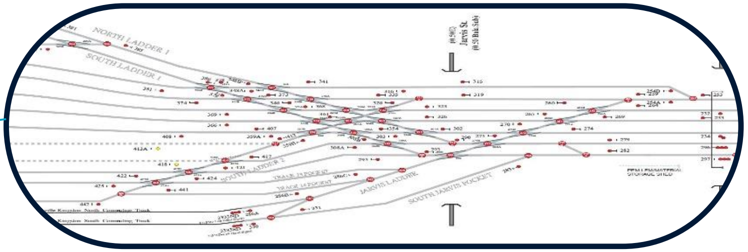
- Study time period: 8am to 9am
- One station away on any rail service
- Assume unlimited capacity at yards and through movements at the station
- Focus on maximum number of GO train trips during peak hour

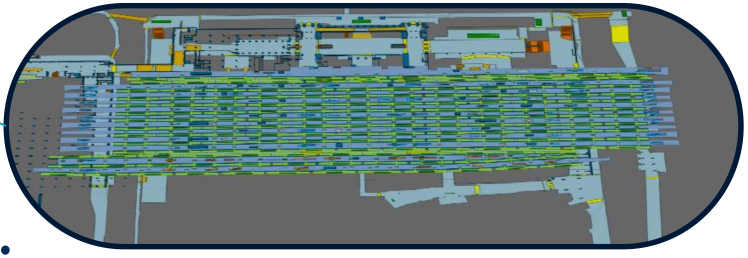
Data

Required Data

- Infrastructure data
  - Track layout
  - Signal location
  - Station layout
- Operational data
  - Speed limit
  - Train profile and configuration
  - Schedule
  - Delay data
  - Ridership
  - Passenger flow

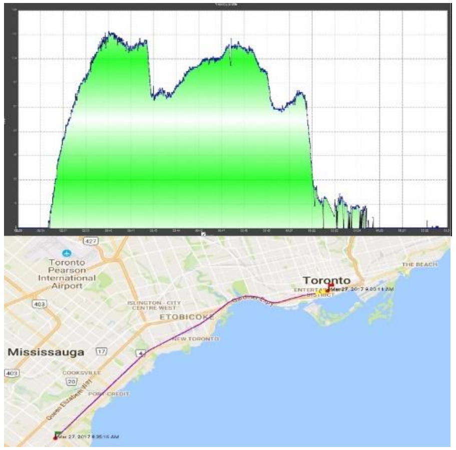


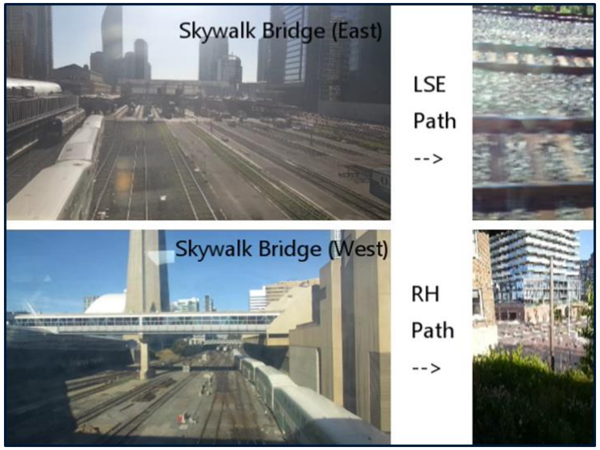


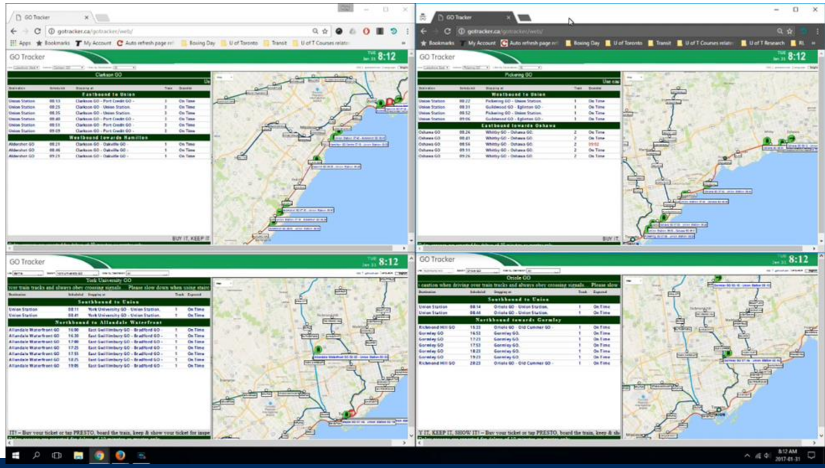


Manual Data Collection

- Train Speed (GPS)
- Commonly-used Train Path Identification (Video Recording)
- Entry Delay at prior stations and Arrival Delay at Union Station (gotracker.ca)

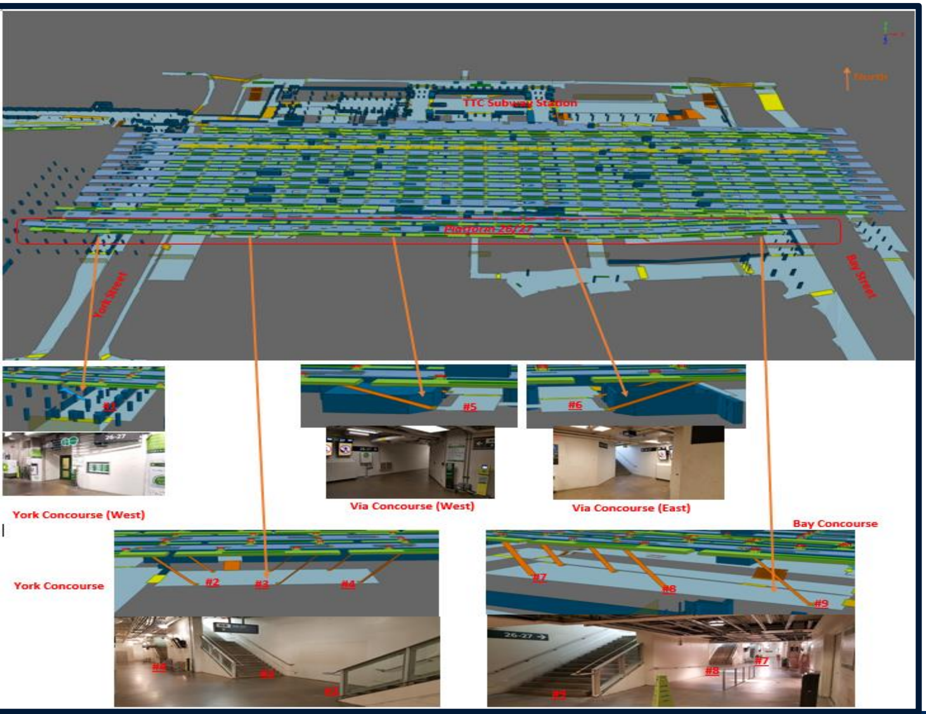


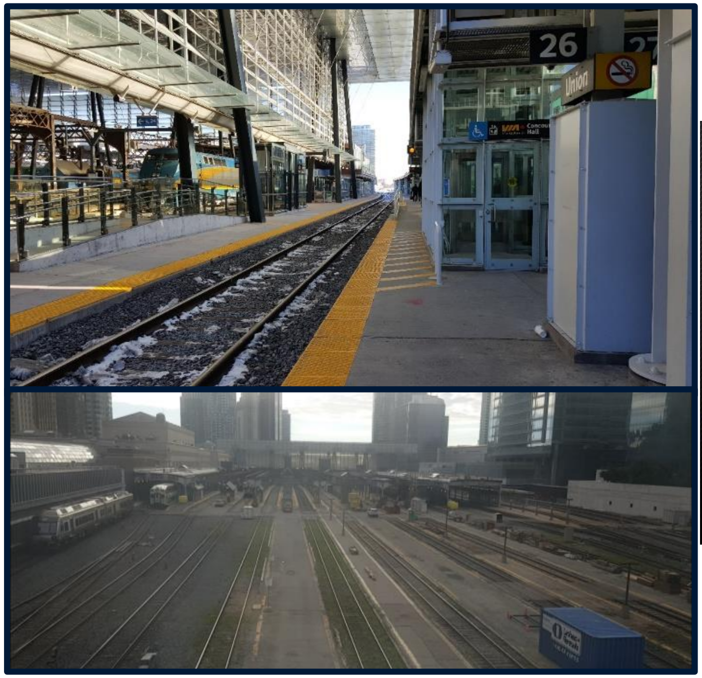




Manual Data Collection

- Platform Staircase Passenger Volume Count
- Passenger Flow Count at Train Door
- Dwell Time





Analytical Capacity Methods

Analytical Methods

- Transit Capacity and Quality of Service Manual (TCQSM)
- Potthoff method
- Deutsche Bahn (DB) method
- UIC Compression Method

TCQSM

- Min. headway at Mainline
  - minimum train separation + operating margin

$$t_{cs} = \sqrt{\frac{2(L_t + d_{eb})}{a + a_g G_0}} + \frac{L_t}{v_a} + \left(\frac{1}{f_{br}} + b\right)\left(\frac{v_a}{2(d + a_g G_i)}\right) + \frac{(a + a_g G_0) l_v^2 t_{os}^2}{2 v_a}\left(1 - \frac{v_a}{v_{max}}\right) + t_{os} + t_{jl} + t_{br}$$

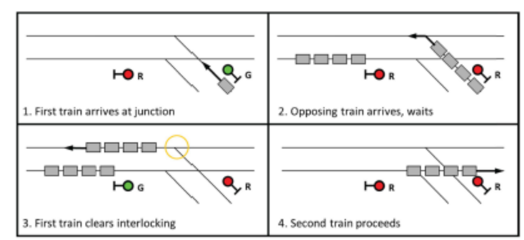
$$h_{ni} = t_{cs} + t_{om}$$

- Min. headway at Station Area
  - minimum train separation + critical station dwell time + operating margin

$$h_{ni} = t_{cs} + t_{d,crit} + t_{om}$$

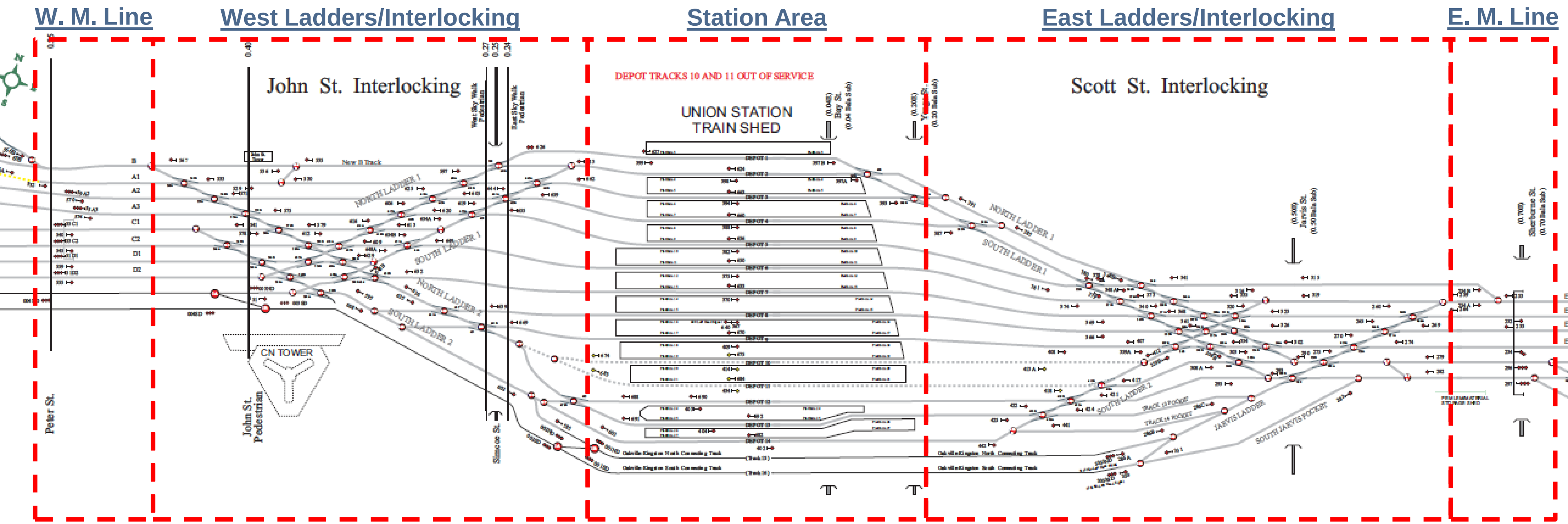
- Min. headway at Mainline with switches
  - if a train is encountered with a switch blocking when traveling at main line

$$h_j = t_{cs} + \sqrt{\frac{2(L_t + n \cdot f_{sa} d_{ts})}{a}} + \frac{v_{max}}{a + d} + t_{sw} + t_{om}$$



Note: R = red, G = green.

TCQSM



- TCQSM – Detailed calculation for line capacity, simple junction capacity calculation
- Need for methods calculating node capacity

Potthoff method and Deutsche Bahn (DB) method

- Assume trains could arrive at any instant of an assigned time period with the same probability
- Timetable not required
- Input:
  - Identify all possible train paths in a system
  - Summarize number of movements concerning each path (n_i)

Path	1-I	1-II	1-IV	4-III	4-IV	III-2	IV-2	I-3	II-3	IV-3
# of movements	56	55	7	112	8	112	8	56	55	7

  - Matrix of occupancy time for conflicting movements (t_{ij})

Path	1-I	1-II	1-IV	4-III	4-IV	III-2	IV-2	I-3	II-3	IV-3
1-I	3.8	1.55	0.97	0	0	0	0	0	0	0
1-II	0.9	1.95	0.61	0	0	0	0	0	0	0
1-IV	1.45	1.45	4.03	0	4.21	1.47	0	0	0	0
4-III	0	0	0	1.67	0.61	0	0	0	0	0.61
4-IV	0	0	3.7	1.54	3.44	0	0	0	0	0
III-2	0	0	1.22	1.06	0	1.56	1.56	0	0	0
IV-2	0	0	2.16	0	1.9	2.93	2.93	0	0	0
I-3	2.74	0	0	0	0	0	0	3.17	3.17	3.17
II-3	0	1.2	0	0	0	0	0	1.54	1.54	1.54
IV-3	0	0	2.56	2.74	2.74	0	0	3.17	3.17	3.17

  - Priority Matrix (DB method, Optional)

Capacity indicator

- Potthoff method

$$\frac{B+R}{T} \leq 1 \; (over\ capacity\ if\ bigger\ than\ 1)$$

B: Total time of occupation

R: Average delay

T: Study period

- Deutsche Bahn (DB) method

$$L_z = \frac{k \cdot P_b \cdot x^2}{T - x \cdot B} \; (usually = 0.6);$$
$$x \geq 1 \; (over\ capacity\ if\ smaller\ than\ 1)$$

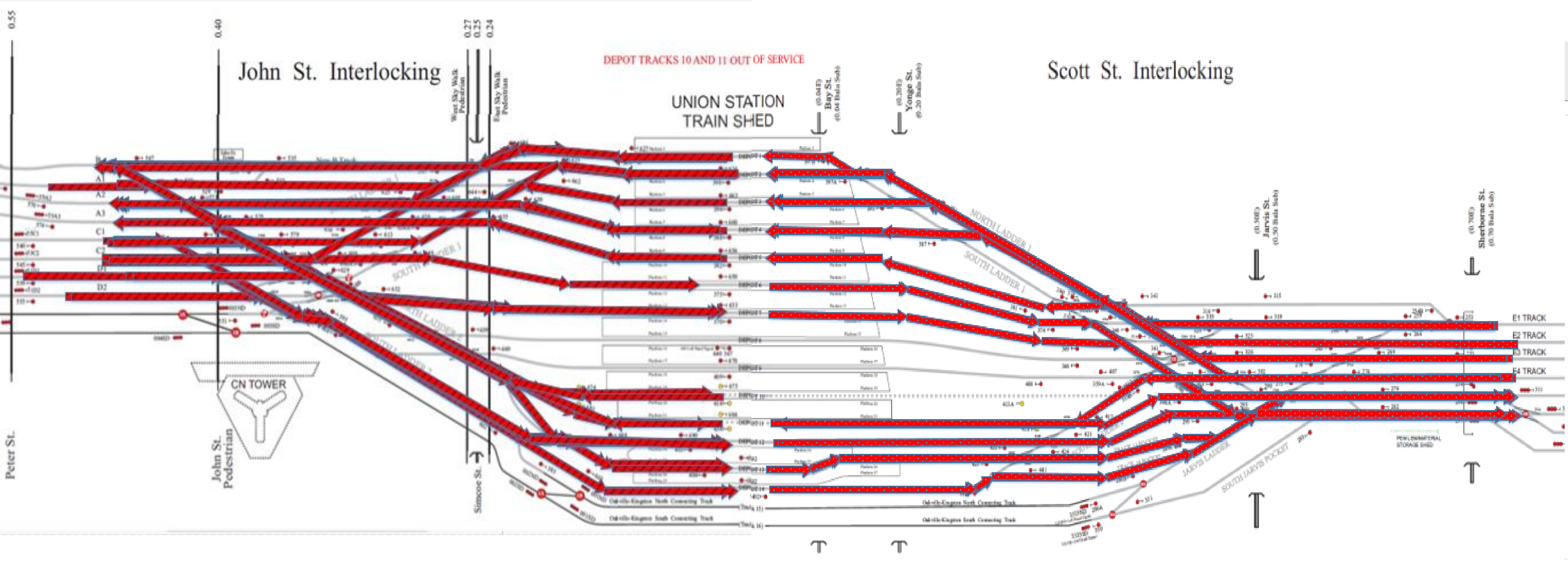
L_z : average number of trains in the waiting queue (to evaluate operation quality)

k: Probability with which the movements relating to the complex node are mutually exclusive

P_b: Occupancy time considering priority

x: Scale factor

Union Station Case



- Two complex interlocking areas located at west and east of the station
- Possible combination of routes could add up to 4000
- 30 and 24 identified commonly used train paths for west interlocking and east interlocking areas respectively
- Train paths shared by GO trains, VIA rail trains, and UP Express trains
- Some paths might be affected by the station dwell time

Matrices of occupancy time for conflicting movements

West Interlocking (30 x 30)

	Path # - Excluded	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Path # - Actual	(min)	D2-SL2-UD14	D2-SL2-UD13	D1-SL2-UD13	D1-SL2-UD14	C2-NL2-UD12	C2-NL2-UD7	A1-NL2-UD7	C1-NL2-UD12	C1-NL2-UD7	C1-SL2-UD12	C2-SL2-UD12	C1-SL1-UD4	C1-NL2-UD6	A1-NL1-UPXS	C2-NL1-UPXS	UPXS-NL1-B	D1-NL2-UD11	D1-NL2-UD10	UD11-NL2-A3	UD10-NL2-A3	UD2-SL1-NL1-B	UD2-SL1-A2	UD1-NL1-A2	UD1-NL1-B	UD3-SL1-A2	UD3-SL1-A2-NL2-B	UD4-SL1-NL1-A2	UD4-A2-NL2-B	UD5-A3-NL2-B	UD5-A3-NL2-A2
1	D2-SL2-UD14	6.5	2	2	6.5						2	2																			
2	D2-SL2-UD13	2	6.5	6.5	2	3			3		2	2																			
3	D1-SL2-UD13	2	6.5	6.5	2	3			3		2	2						1.5	1.5												
4	D1-SL2-UD14	6.5	2	2	6.5						2	2						1.5	1.5												
5	C2-NL2-UD12		2	2		6.5	2	2	6.5	1.5	7	7		1.5		1.5		2	2	2.5	2.5										
6	C2-NL2-UD7					2	6.5	6.5	2	6.5	1.5	1.5		1.5		1.5		2	2	1.5	1.5										
7	A1-NL2-UD7					2	7	6.5	2	7			1.5	1.5	1.5	2		2	2	2	2		0	0		0	0	0	0	0	0
8	C1-NL2-UD12		2	2		6.5	2	2	6.5	1.5	7	7	1.5	1.5		1.5		2	2	2.5	2.5										
9	C1-NL2-UD7					2	6.5	6.5	2	6.5	1.5		1.5	1.5		1.5		2	2	1.5	1.5										
10	C1-SL2-UD12	2	2	2	2	6.5	1.5		6.5	1.5	6.5	6.5	1.5	1.5		1.5		1.5	1.5												
11	C2-SL2-UD12	1.5	2	2	1.5	6.5	1.5		6.5		6.5	6.5				1.5		1.5	1.5												
12	C1-SL1-UD4							1.5	1.5	1.5	1.5		7.5	1.5		2				1	1		2.5			2	2	8.5	8.5	1.5	1.5
13	C1-NL2-UD6					1.5	1.5	1.5	1.5	1.5	1.5		1.5	6.5		1.5				1.5	1.5										
14	A1-NL1-UPXS							1							6	6	6					2		6	6		2		0	0	
15	C2-NL1-UPXS					1	1	1	1	1	1	1	1	1	6	6	7			0.5	0.5	1.5	1.5	7	7	1.5	1.5	0.5	0.5	0.5	0.5
16	UPXS-NL1-B														0	1	1.5					1		0.5	1		0		0	0	
17	D1-NL2-UD11			1.5	1.5	2	2	2	2	2	1.5	1.5						23	2	23	2.5										
18	D1-NL2-UD10			1.5	1.5	2	2	2	2	2	1.5	1.5						2	23	2.5	23										
19	UD11-NL2-A3					2.5	2.5	2.5	2.5	2			2	2		2.5		2.5	2.5	1.5	1.5									0.5	0.5
20	UD10-NL2-A3					2.5	2.5	2.5	2.5	2			2	2		2.5		2.5	2.5	1.5	1.5									0.5	0.5
21	UD2-SL1-NL1-B														1	2	2.5					2.5	1.5	1.5	2.5		1.5		0.5	1	
22	UD2-SL1-A2							0					1.5			2.5						1.5	2	2		2	2	2	2	1	1
23	UD1-NL1-A2							2.5							1	2.5	2					2	1.5	2	2	2	2	1.5	1.5	0.5	0.5
24	UD1-NL1-B														0	1	1.5					1.5		1	1.5		0.5		0.5	0.5	0
25	UD3-SL1-A2							0					1.5			2.5							2	2		2	2	2	2	1	1
26	UD3-SL1-A2-NL2-B							0					1.5		2.5	2.5	2					1.5	2	2	2	2	2	2	2	1	1
27	UD4-SL1-NL1-A2							0					1.5			2.5							2	2		2	2	2	2	1	1
28	UD4-A2-NL2-B							0					1.5		0	2.5	0					1.5	2	3	2	2	2	2	2	1	1
29	UD5-A3-NL2-B							0					1.5		0	2.5	2			2.5	2.5	1.5	1	1	1.5	1	1	1	1	2	2
30	UD5-A3-NL2-A2							0					1.5			2.5				2	2		1	1		0	0	0.5	0.5	2	2

East Interlocking (24 x 24)

	Path # - Excluded	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Path # - Actual	(min)	E1-NL1-UD3	E1-NL1-UD4	E1-NL1-UD2	E1-NL1-UD1	E2-NL1-UD3	E4-NL1-UD3	E3-NL1-UD3	E3-NL1-UD5	E3-NL1-UD2	E3-NL1-UD4	E4-NL1-UD2	UD13-JL-E5	UD14-JL-E5	UD12-JL-E5	UD12-JL-E6	UD7-SL1-E5	UD7-SL1-E6	UD6-SL1-E5	UD6-SL1-E6	UD13-JL-E6	UD14-JL-E6	E4-SL2-UD11	UD11-SL2-E5	E4-NL1-UD4
1	E1-NL1-UD3	7	2	2	2	7	7	7	2	2	2	2													2
2	E1-NL1-UD4	2	7.5	2	2	2	2	2	2	2	7.5	2													7.5
3	E1-NL1-UD2	2	2	6.5	2	2	2	2	2	6.5	2	6.5													2
4	E1-NL1-UD1	2	2	2	6.5	2	2	2	2	2	2	2													2
5	E2-NL1-UD3	7	2	2	2	7	7	7	2	2	2	2													2
6	E4-NL1-UD3	7	2	2	2	7	7	7	2	2	2	2											2		2
7	E3-NL1-UD3	7	2	2	2	7	7	7	2	2	2	2													2
8	E3-NL1-UD5	2.5	2.5	2.5	2.5	2.5	3	2.5	7	2.5	2.5	3													3
9	E3-NL1-UD2	2	2	6.5	2	2	2	2	2	6.5	2	6.5													2
10	E3-NL1-UD4	2	7.5	2	2	2	2	2	2	2	7.5	2													7.5
11	E4-NL1-UD2	2	2	6.5	2	2	2	2	2	6.5	2	6.5											2		2
12	UD13-JL-E5												2	2	2	1.5	2	1.5	2	1.5	2.5	2	0	2	
13	UD14-JL-E5												2	2.5	2	1.5	2	1.5	2	1.5	1.5	2.5	0	2	
14	UD12-JL-E5												2	2	2.5	2.5	2	1.5	2	1.5	1.5	1.5	0	2	
15	UD12-JL-E6												1.5	2	2.5	2.5		2		2	2	2			
16	UD7-SL1-E5												2	2	2		2	2	2	2			1.5	2	
17	UD7-SL1-E6												1.5	2	2	2	2	2	2	2	2	2	1.5	1.5	
18	UD6-SL1-E5												2	2	2		2	1.5	2	2			1.5	2	
19	UD6-SL1-E6												1.5	2	2	2	1.5	2	2	2	2	2	1.5	1.5	
20	UD13-JL-E6												2.5	2	2	2		2		2	2.5	2			
21	UD14-JL-E6												1.5	2.5	2	2		2		2	2	2.5			
22	E4-SL2-UD11						1.5					1.5	0	0	0		1.5	1.5	1.5	1.5			21.5	24	1.5
23	UD11-SL2-E5												1.5	1.5	1.5		1.5	1	1.5	1			0	2	
24	E4-NL1-UD4	2	7.5	2	2	2	2	2	2	2	7.5	2											2		7.5

Potthoff method and Deutsche Bahn method

- Result for at capacity:
  - Capacity parameters:
    - Potthoff Method:

Potthoff	**n_med**	**T**	**t_med**	**B(min)**	**U20h**	**Sum of Rij**	**R (Sum of Rij/n_med)**	**(B+R)/T**
W.I.	3.34	60	2.78	36.69	0.61	68.81	20.61	0.96
E.I.	1.86	60	2.33	40.25	0.67	37.03	19.96	1.00

    - Deutsche Bahn Method:

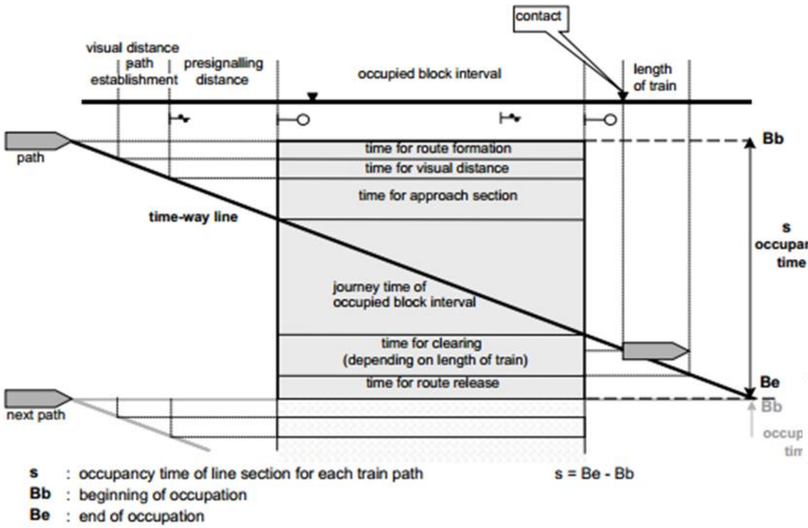
DB	**K**	**E(t)**	**B**	**h**	**Er**	**Lz**	**T**	**Pb**	**x**
W.I.	0.30	2.86	33.32	0.56	2.29	0.60	60.00	53.62	1.00
E.I.	0.54	2.32	33.94	0.57	1.78	0.60	60.00	27.17	1.02

  - # of GO trains:

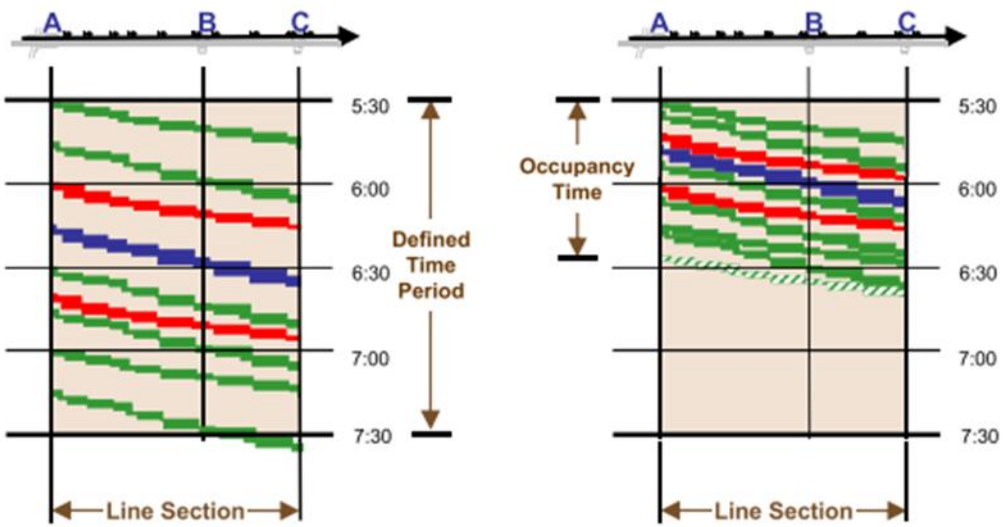
Method	Total	LSW	LSW_E	LSE	LSE_E	MI	KI	RH	BA	ST
Potthoff	31	3	5	3	4	5	3	3	3	2
DB	26	3	4	3	3	5	2	2	2	2

Compression Method

- Introduction



Blocking Time Model



Compression Method on a uni-directional track section before and after compression

Procedure

- Identify all possible train paths in an interlocking area
- A full $n \times n$ matrix is set up by listing the actual path against all excluded paths. The value in the specific cell means how long the train that is taking the excluded train path has to wait when the actual train path is being taken (Matrix of occupation time for conflicting paths)

	(min)	pA	pB	aP	aF	fB	fA	bF	bP
Actual Trip i	pA	1.7	1.4				1.7		
	pB	1.4	1.7	1.4	1.4	1.7	1.4		
	aP		1.5	1.8	1.3		1.3		1.8
	aF		2.4	2.2	2.9	2.4	2.4	2.9	2.4
	fB		2.4		2	2.4	2		2
	fA	2.4	2	2.1	2.1	2	2.4		2
	bF				2.3			2.3	1.7
	bP			1.8	1.5	1.5	1.5	1.5	1.8

- Provide a sequence of paths as in the timetable

min	3	6	6
Route	pB	pA	fB
Order	1	2	3

- Calculate the occupancy time based on the path sequence and exclusion matrix

Order	Trip	Begin of occupation	pA	pB	aP	aF	fB	fA	bF	bP
1	pB	0	$\boxed{1.4}$	1.7	1.4	1.4	$\boxed{1.7}$	1.4		
2	pA	1.4	=1.4+1.7 =3.1	=1.4+1.4 =2.8	*/1.4	*/1.4	*/1.4	=1.4+1.7 =3.1	*/0	*/0
3	fB	1.7	*/3.1	=1.7+2.4 =4.1	*/1.4	=1.7+2 =3.7	=1.7+2.4 =4.1	=1.7+2.4 =3.7	*/0	=1.7+2 =3.7

Rules

- Each route-occupation starts, considering the sequence of trains, as soon as possible after the preceding route regarding the referring exclusion time
- The total of all occupation times results as the sum of the excluding times of concatenated routes
- Possible simultaneous train movements on parallel routes are considered
- Insert the first trip at the bottom of the calculation table again (last trip). Hence there is no “open end”
- Occupancy Time Rate (OTR) calculation:

$$\boxed{Occupancy\ Time\ Rate\ [\%] = \frac{Ocupancy\ Time}{Defined\ Time\ Period} \times 100\%}$$

- Additional Time Rate (ATR):

$$Additional\ Time\ Rate\ [\%] = [\frac{100}{Occupancy\ Time\ Rate} - 1] \times 100$$

- Capacity Consumption (CC) value:

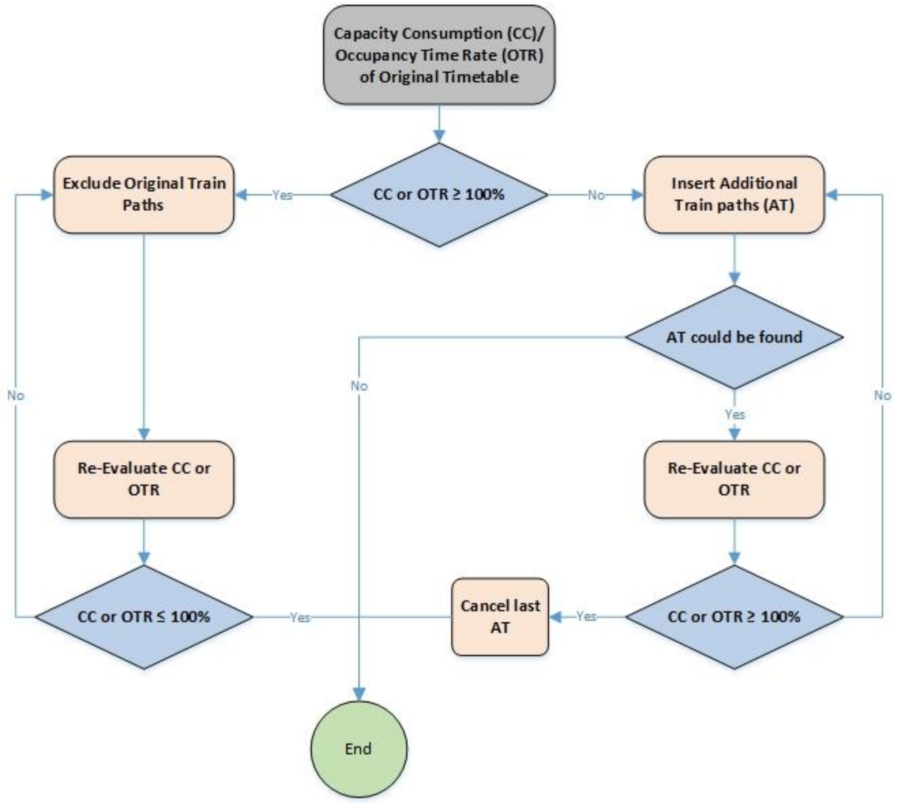
$$\boxed{Capacity\ Consumption\ [\%] = \frac{Occupancy\ Time\ \times (1 + Additional\ Time\ Rate)}{Defined\ Time\ Period} \times 100}$$

- Concatenation rate: φ:

$$\varphi(Concatenation\ Rate) = \frac{K}{Z} \times 100\%$$

Procedure to insert trains

- Main assumptions:
  - All trains have through movements
  - Uniform headway at every depot



Results for capacity analysis

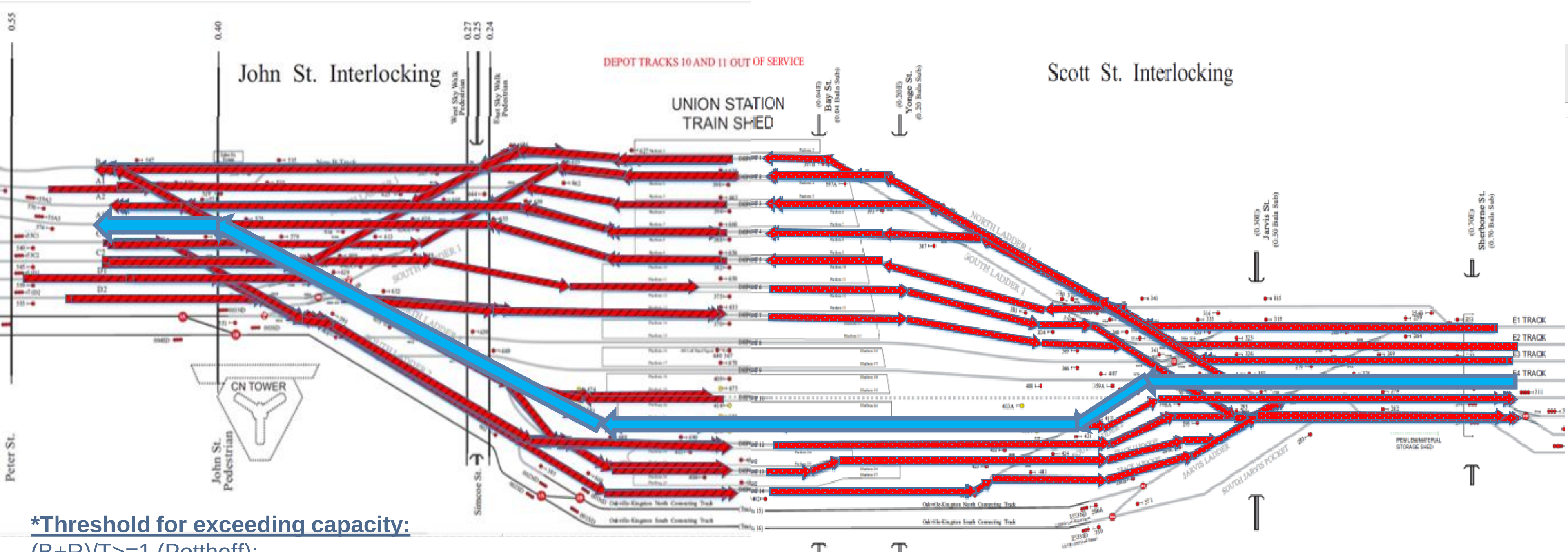
- Capacity Indicators

Critical Indicator	Evaluating Capacity based on CC		Evaluating Capacity based on OTR	
Max. Train Volume	50		55	
Indicator	West Interlocking	East Interlocking	West Interlocking	East Interlocking
Occupancy Time Rate (OTR)	73%	85%	85%	99%
Concatenation Rate	17%	47%	29%	42%
Additional Time Rate	215%	87%	215%	87%
Capacity Consumption (CC)	34%	98%	39%	113%

- # of Trains compared against other methods

Method	Total	LSW	LSW_E	LSE	LSE_E	MI	KI	RH	BA	ST
		Lakeshore West	Lakeshore West (Express)	Lakeshore East	Lakeshore East (Express)	Milton	Kitchener	Richmond Hill	Barrie	Stouffville
Current Schedule	25	2	4	2	3	5	2	2	3	2
Potthoff	31	3	5	3	4	5	3	3	3	2
DB	26	3	4	3	3	5	2	2	2	2
Compression (OTR)	55	6	7	6	6	5	6	6	7	6
Compression (CC)	50	6	7	6	6	5	4	6	4	6

Effect of adding 1 trip



***Threshold for exceeding capacity:**
(B+R)/T>=1 (Potthoff);
x <=1 (DB)

Method	Capacity Indicator	West Interlocking	East Interlocking
Potthoff	(B+R)/T	0.85	0.81
DB	x	1.00	1.02
Compression	OTR	73%	85%
	CC	34%	98%

Add 1 VIA trip

West Interlocking	East Interlocking
0.90	0.96
0.97	0.88
73%	85%
34%	98%

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Discussion

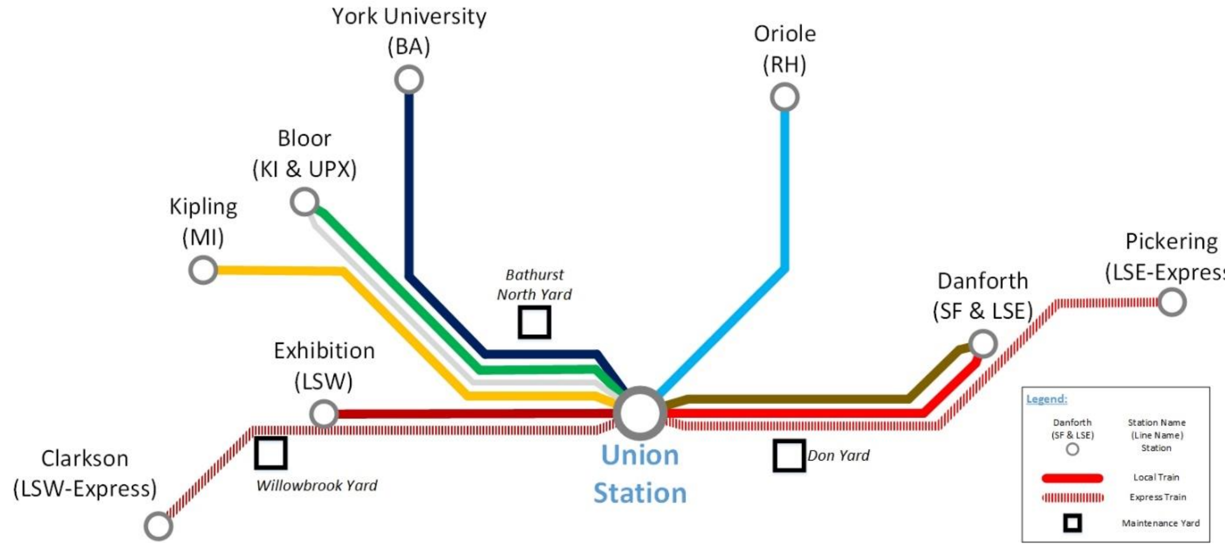
- Potthoff and DB:
  - timetable not required;
  - highly averaged results
- Compression Method:
  - timetable required;
  - determined by the maximum occupancy of all train paths within the same section;
  - possible to maximize the capacity with careful scheduling on a timetable
- Both require a matrix of occupancy time for conflicting paths:
  - only a pair of paths needs to be evaluated for conflicts
  - size of the matrix grows exponentially with the increase of possible train paths
- System stochasticity not considered

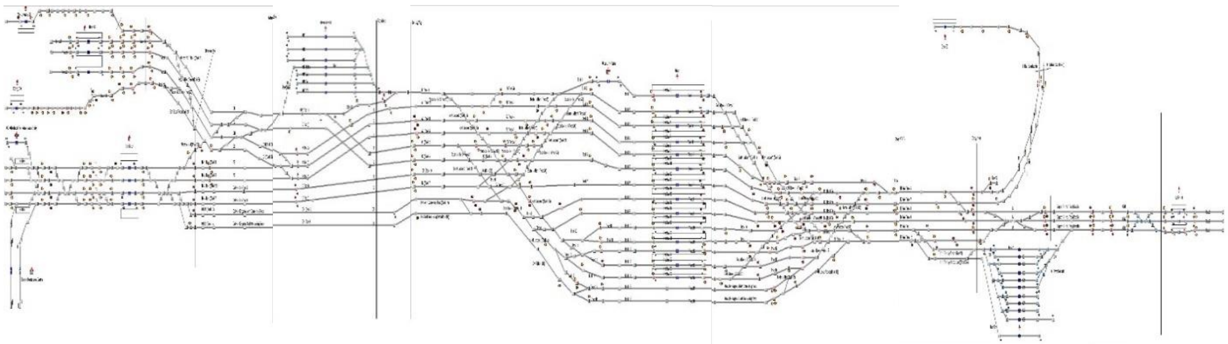
Railway Simulation

Railway Simulation

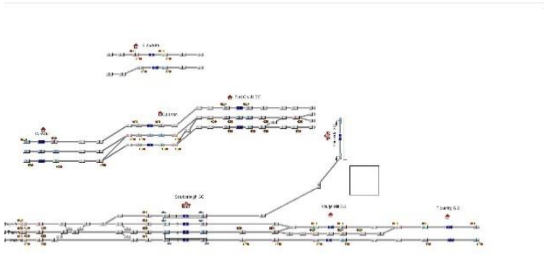
- Simulation tools are recommended to analyze complex railway infrastructure
- General procedure for simulation:
  - Data collection
  - Model construction
  - Model calibration
  - Model validation
- OpenTrack was selected as the railway simulator

Model Construction





Main network (including maintenance yards)



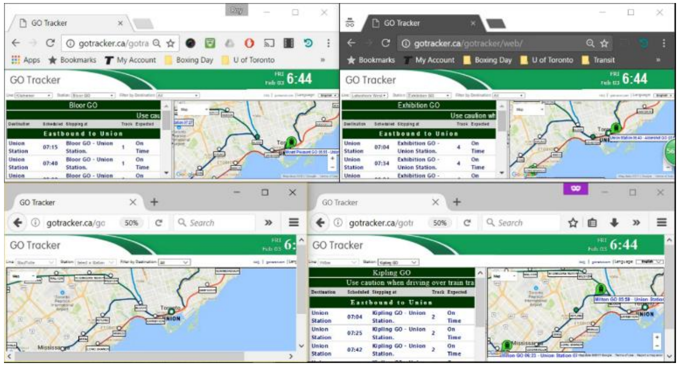
Expansion network including express stations

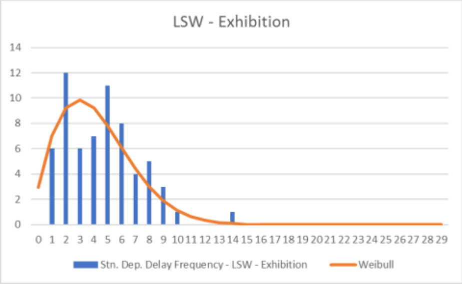
Model Input

- Infrastructure layout
- Speed limits
- Train configurations (locomotive, rolling stock)
- Schedules
- Entry delay distributions

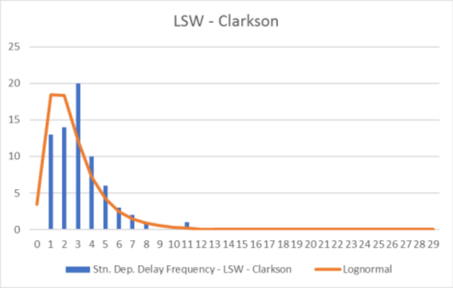
Entry Delay Distribution

- Gotracker.ca

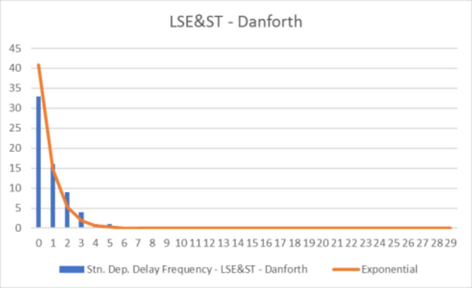




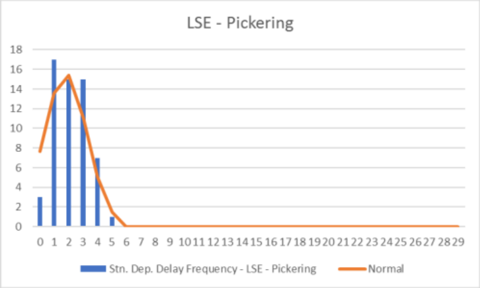
Weibull



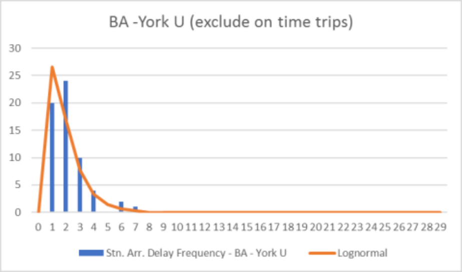
Lognormal



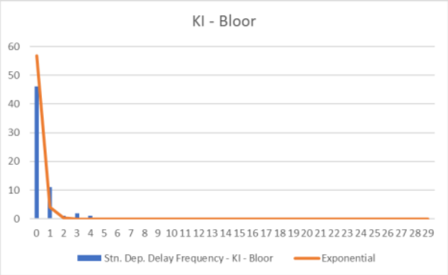
Exponential



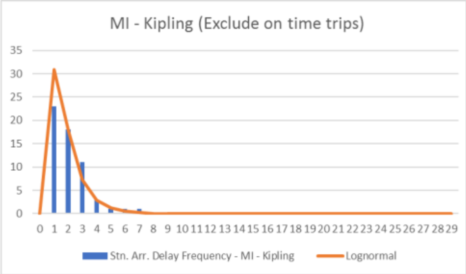
Normal



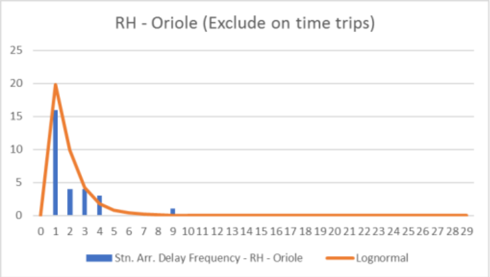
Lognormal



Exponential

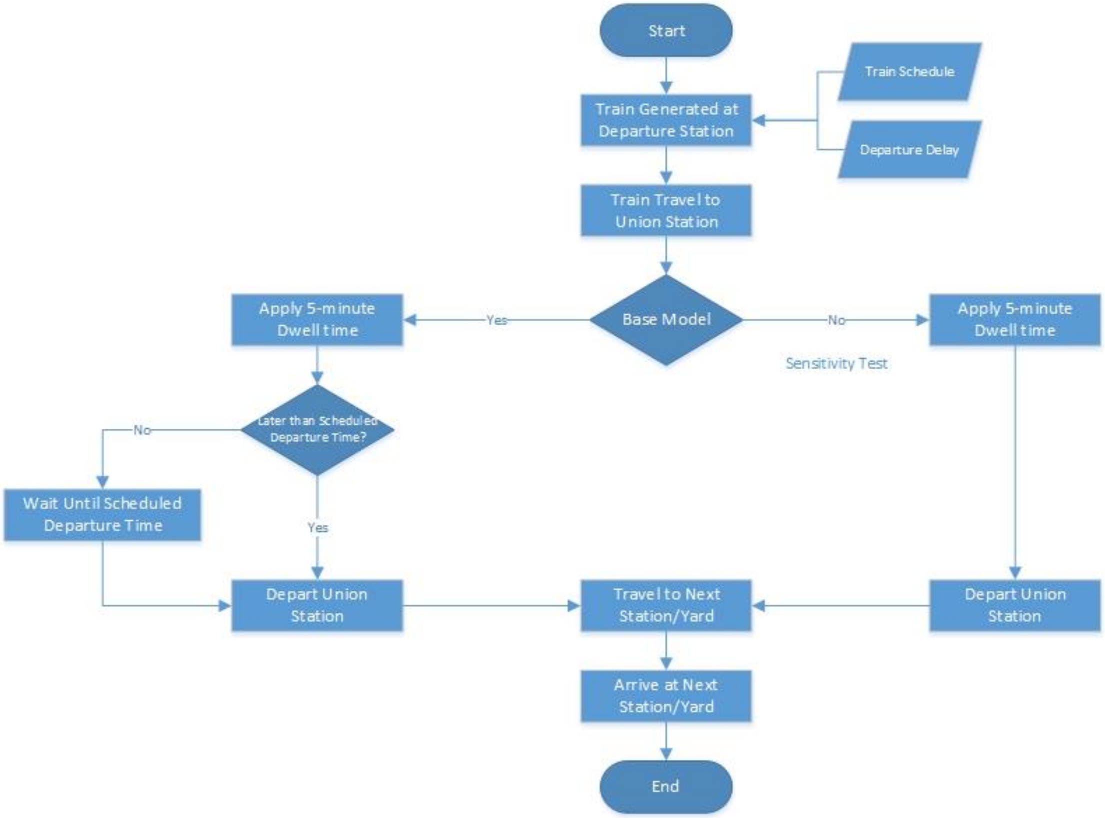


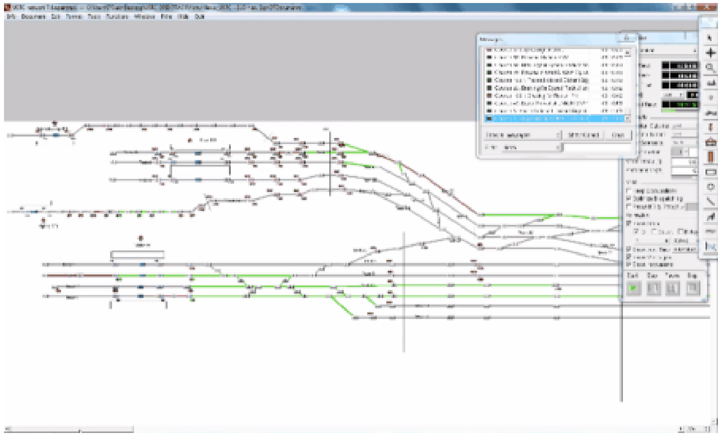
Lognormal



Lognormal

Simulation Flow Chart





Performance Evaluation

- Result evaluation:
  - Simulated On-time Performance (SOTP)

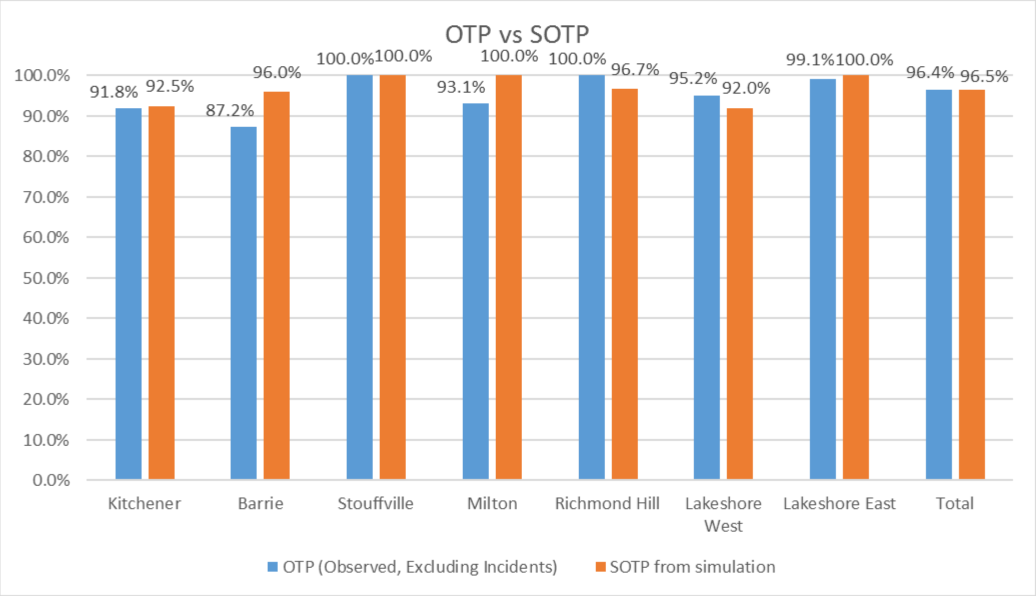
$$SOTP = \frac{\#\ of\ trips\ arrive\ within\ a\ specified\ range\ of\ schedule\ time}{total\ \#\ of\ trips\ scheduled} \times 100\%$$

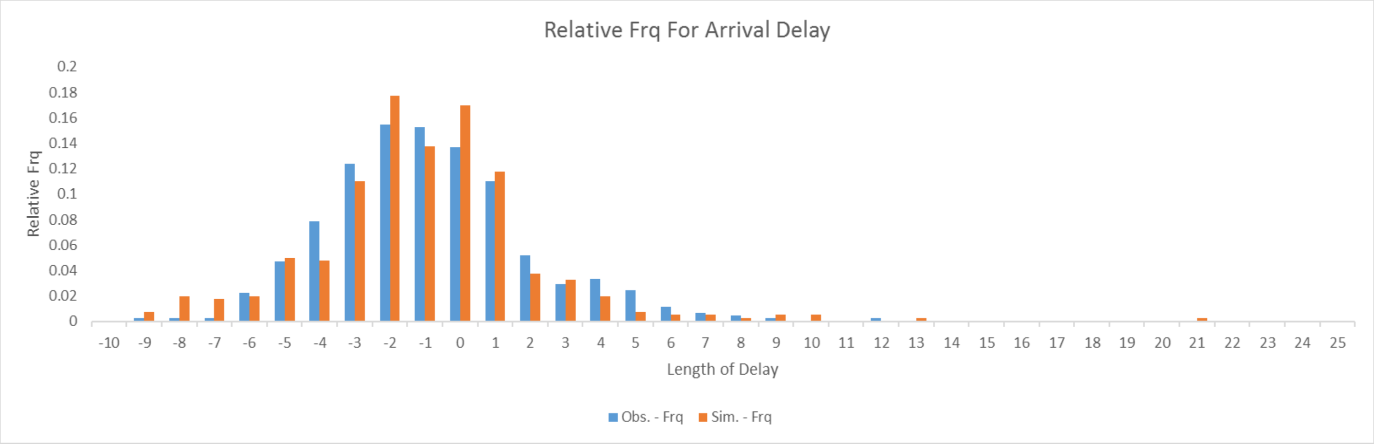
  - Simulated Average Delay

- GO Transit's target On-time performance (OTP): 95%

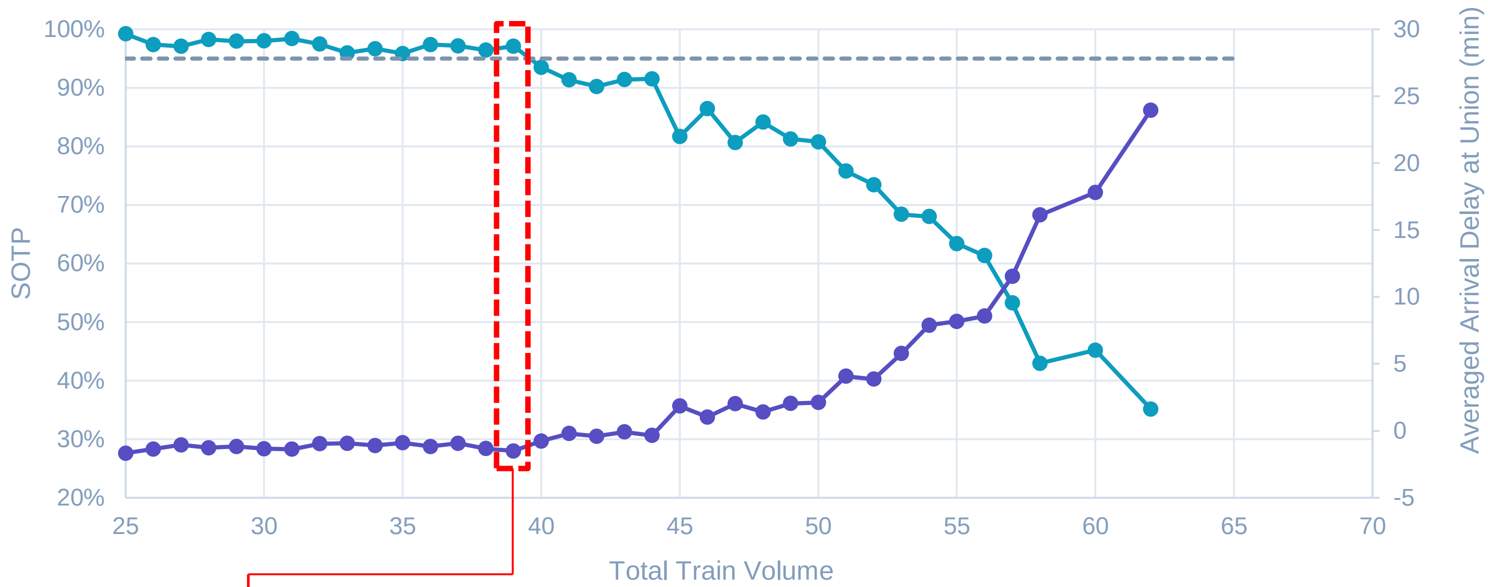
- OTP from data collection: 96.4%

Base model calibration and validation





Sensitivity Result



Method	Total # of Trains	LSW	LSW_E	LSE	LSE_E	KI	MI	BA	RH	ST
OpenTrack	39	4	5	4	4	4	5	4	4	5

LSW: Lakeshore West Line
LSW_E: Lakeshore West Express
LSE: Lakeshore East Line
LSE_E: Lakeshore East Express

KI: Kitchener Line
MI: Milton Line
BA: Barrie Line
RH: Richmond Hill Line
ST: Stouffville Line

Discussion

Method	Total	LSW Lakeshore West	LSW_E Lakeshore West (Express)	LSE Lakeshore East	LSE_E Lakeshore East (Express)	MI Milton	KI Kitchener	RH Richmond Hill	BA Barrie	ST Stouffville
Current Schedule	25	2	4	2	3	5	2	2	3	2
Potthoff	31	3	5	3	4	5	3	3	3	2
DB	26	3	4	3	3	5	2	2	2	2
Compression (OTR)	55	6	7	6	6	5	6	6	7	6
Compression (CC)	50	6	7	6	6	5	4	6	4	6
OpenTrack	39	4	5	4	4	5	4	4	4	5

- OpenTrack offers a more realistic result by taking the stochasticity into consideration as it attempts to simulate the real-world operation
- The result of between OpenTrack and Compression Method with OTR confirms that practical capacity is around 60% to 75% of the theoretical capacity from the previous research (Kraft, 1982)

Method	Total Trains	LSW	LSW_E	LSE	LSE_E	KI	MI	BA	RH	ST
Compression (OTR)	55	6	7	6	6	5	6	6	7	6
OpenTrack	39	4	5	4	4	4	5	4	4	5
Ratio (%)	71%	67%	71%	67%	67%	80%	83%	67%	57%	83%

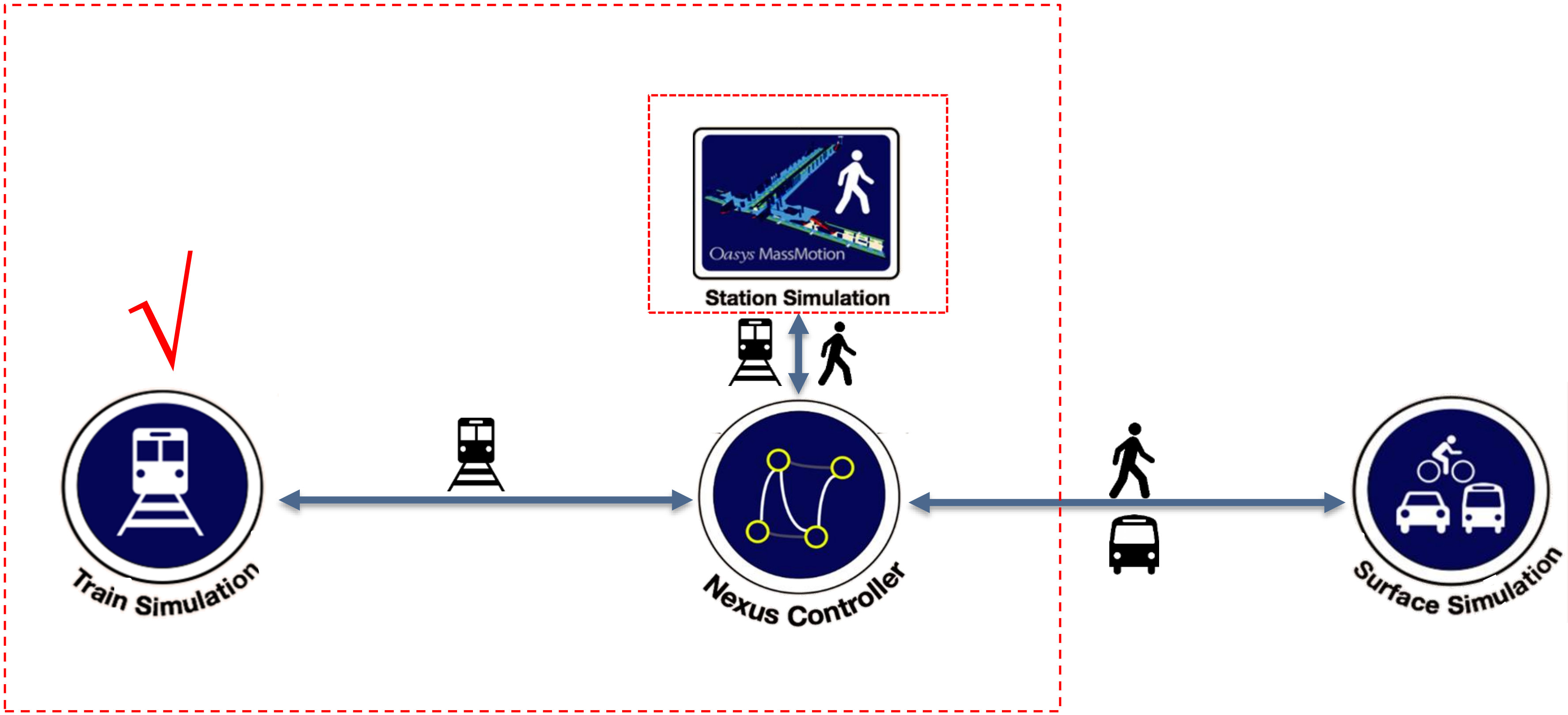
Problems

- Dwell time was fixed at 5 minutes
- Only focus on train movements on the railway
- Pedestrian flow on the platform level could be complicated due to the platform layout and barriers
- The interactive effect between train and pedestrian movements was not captured

Integrated Rail and Pedestrian Simulation

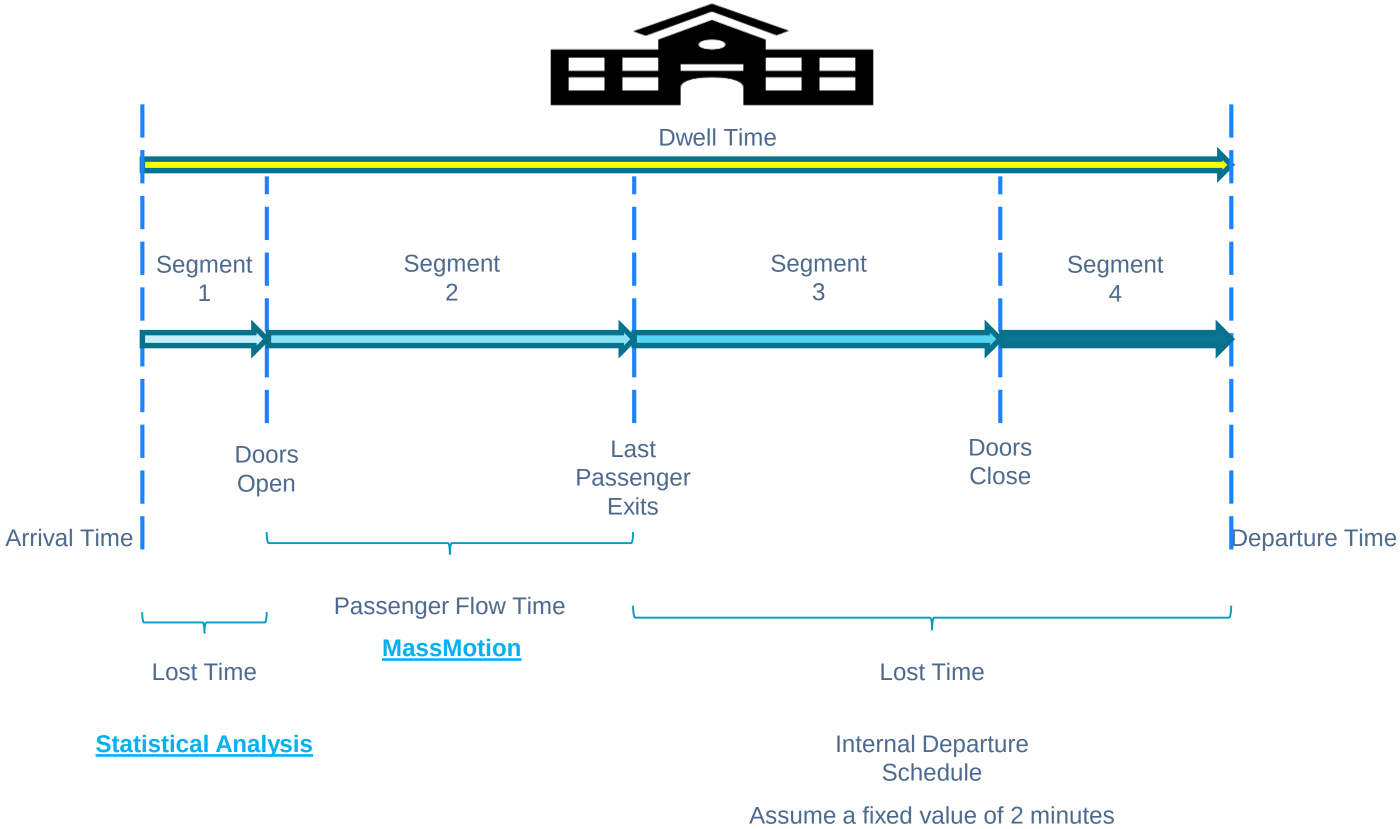
- Nexus

Nexus

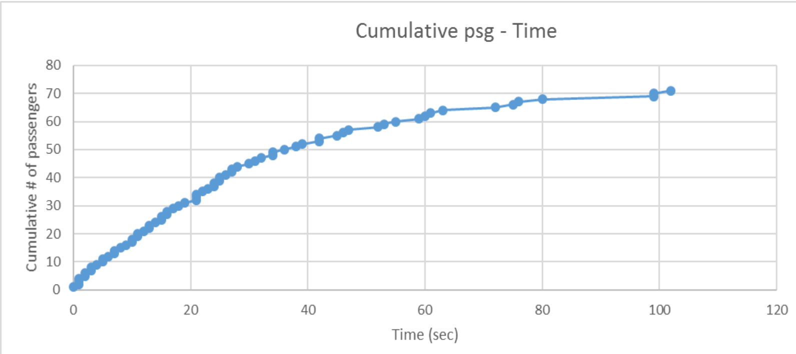


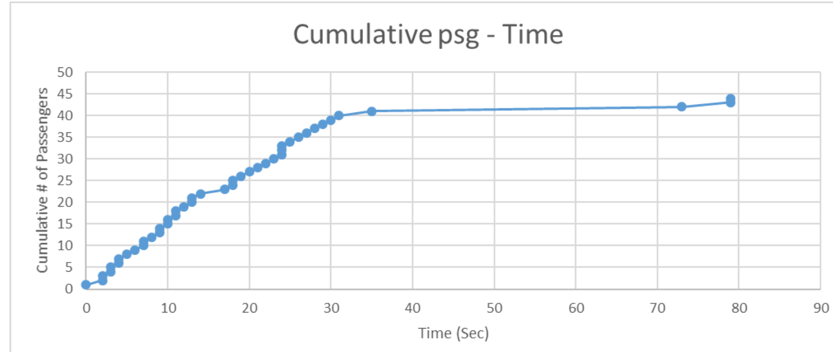
Oasys MassMotion
Station Simulation
Train Simulation
Nexus Controller
Surface Simulation

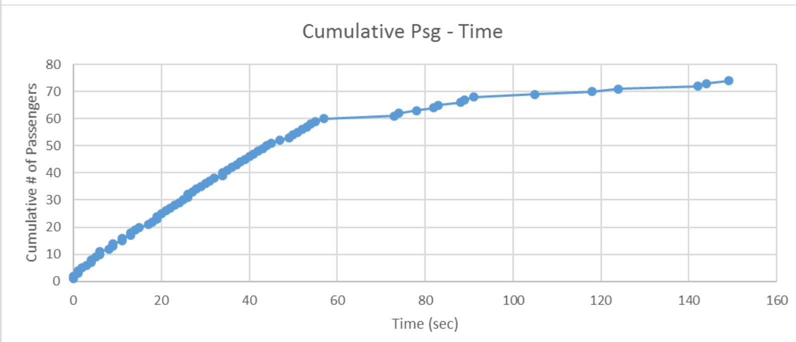
Dwell Time Components

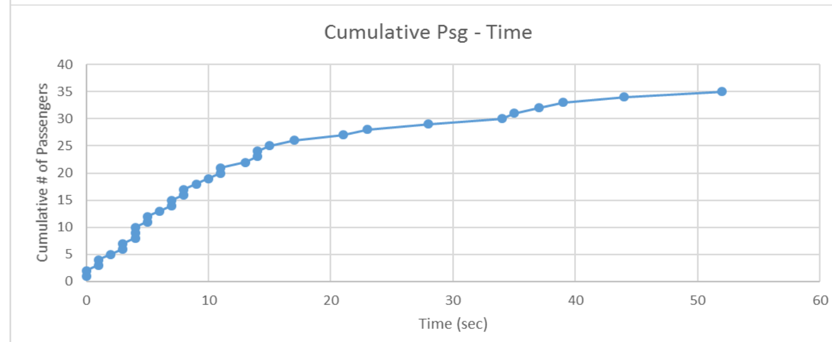


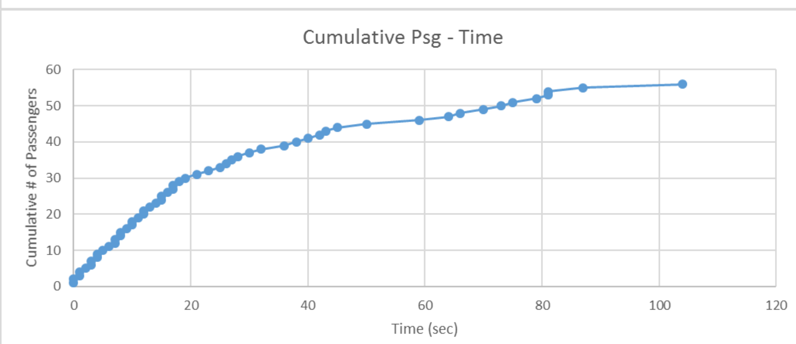
Alighting Behavior – Observation at Union

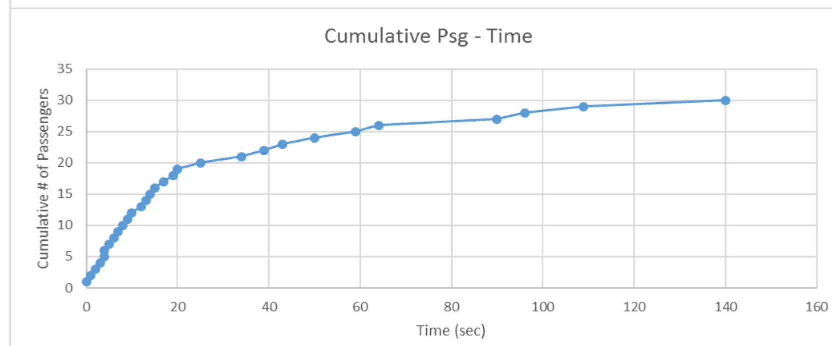










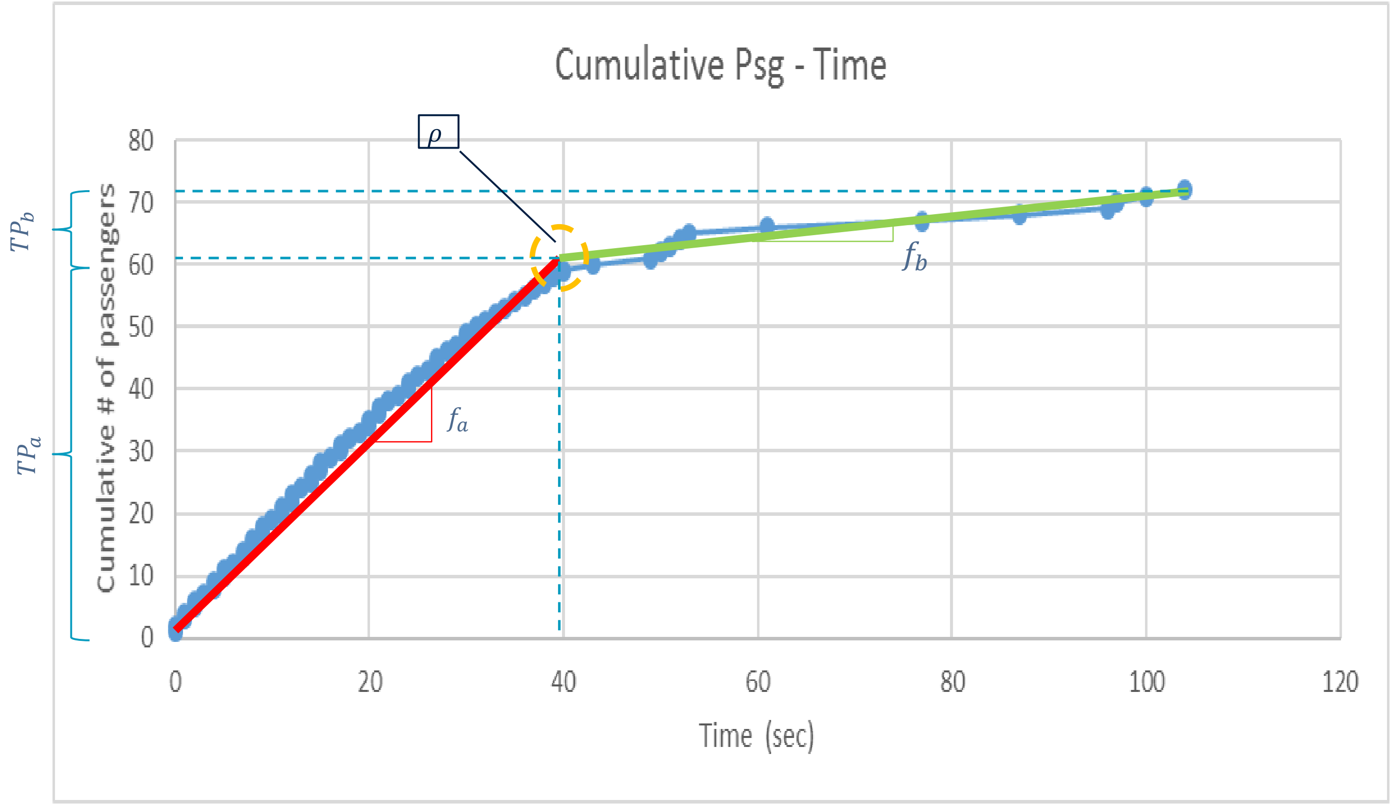


Problem Statement

- The unique behavior would influence the density and crowding on the platform differently
- The time that last passenger exit the train would affect the departure time of the train, especially for trains that become out of service after they arrive at Union, as trains cannot leave if passengers are still on board
- Traditional Passenger flow time modeling cannot represent both effects properly (Total passenger flow time and density)

Method

- Main Idea: represent the observed alighting curve with two linear lines with different flow rates
- Each record of train door passenger count is studied, break point is selected based on visual inspection; linear regression is performed on the resulting segment a and segment b respectively; R^2 values for the slopes of both lines are examined

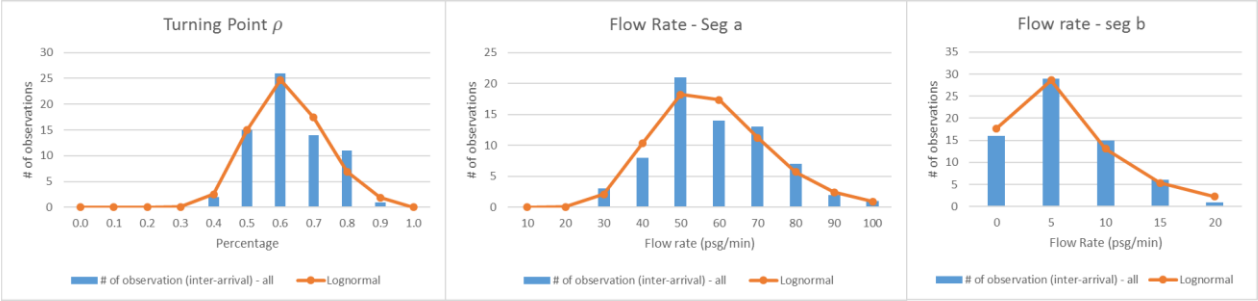


<u>Variables Extracted</u>:

- Total passengers: TP
- Turning point (%): ρ
- Passengers in segment a: TP_a
- Flow rate in segment a: f_a
- Passengers in segment b: TP_b
- Flow rate in segment b: f_b

Data Analysis

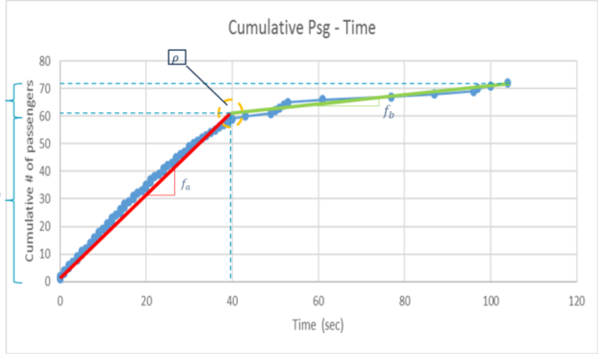
- Statistical analysis for ρ, f_a, f_b

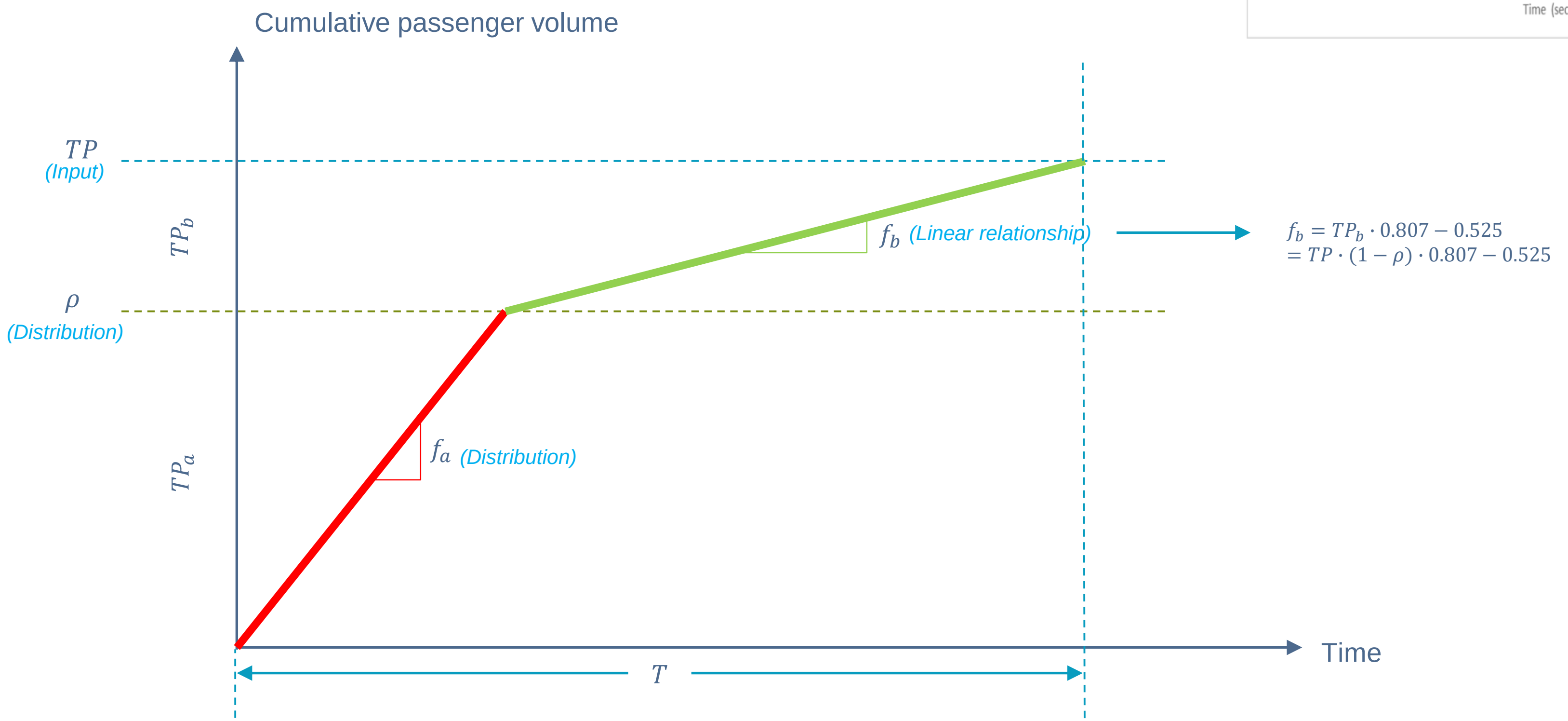


- Correlation analysis

	Total_Psg	*Total_Psg_seg_a*	*Turning_Point*	*Seg_a_Flow_Rate*	*Psg_seg_b*	*Seg_b_Flow_Rate*
Total_Psg	1					
Total_Psg_seg_a	0.911666804	1				
Turning_Point	-0.037696351	0.354965918	1			
Seg_a_Flow_Rate	0.239571138	0.200437577	-0.068153854	1		
Psg_seg_b	0.715672756	0.367111995	-0.678531836	0.197095319	1	
Seg_b_Flow_Rate	0.578958678	0.347539801	-0.391475978	0.349225841	$\boxed{0.726731882}$	1

Model Proposed

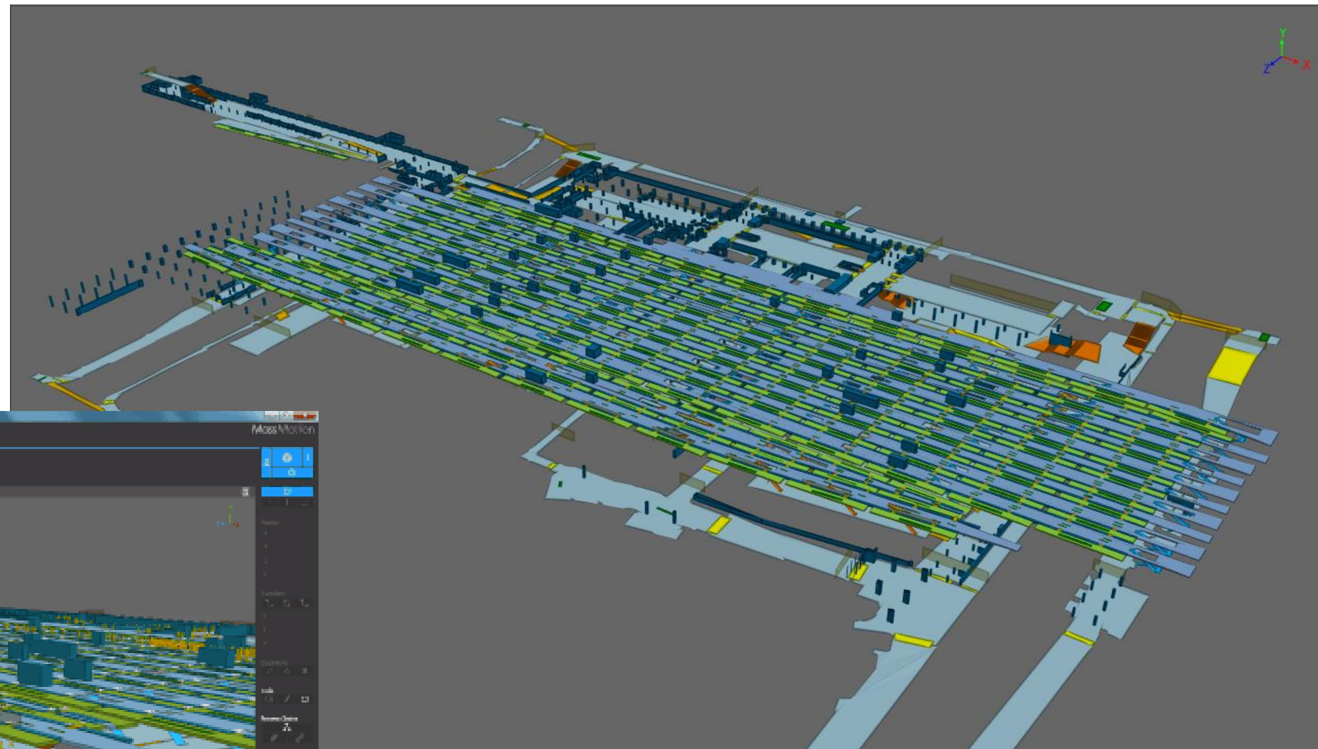


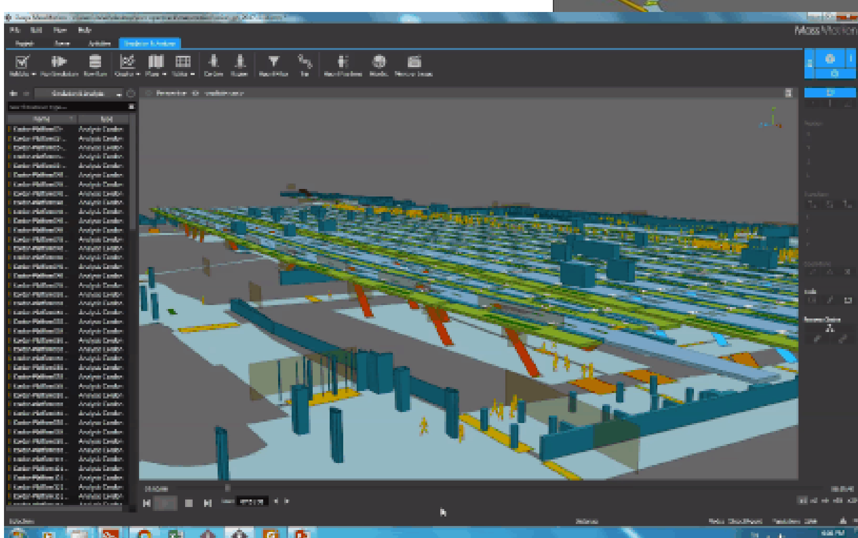


Alternative	Observed	Model
Avg. total time (sec)	104.1	107.1
Max. Total time (sec)	211.0	221.1

Pedestrian Simulation

- MassMotion





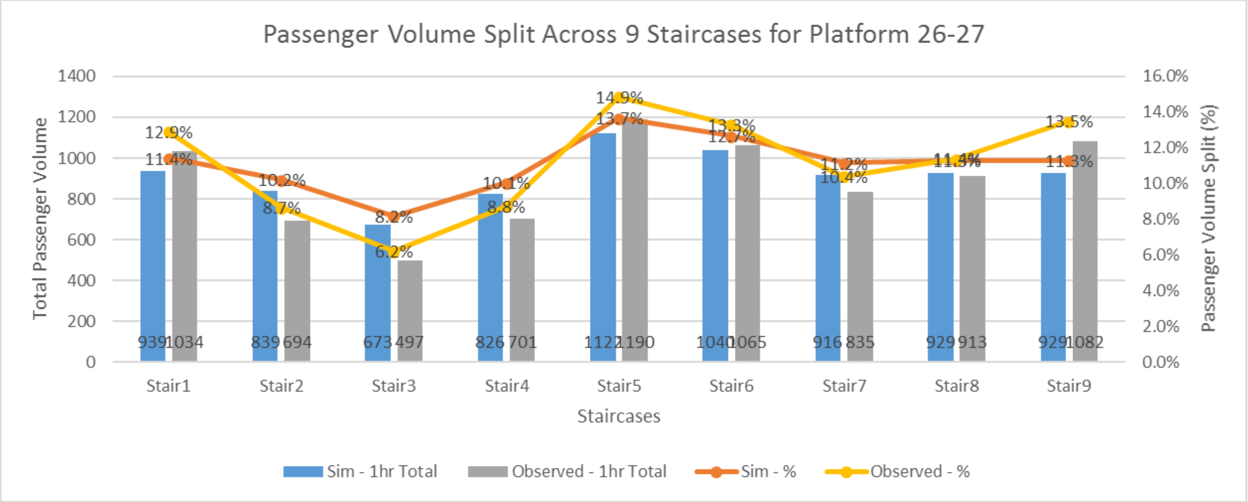
Model Calibration

- Calibration:
  - adjust queue cost at certain areas
  - adjust wait cost
  - alter agent characteristics (i.e. body radius and direction bias)
- GEH statistical method
  - compare observed and simulated traffic/pedestrian volumes at links (staircases)

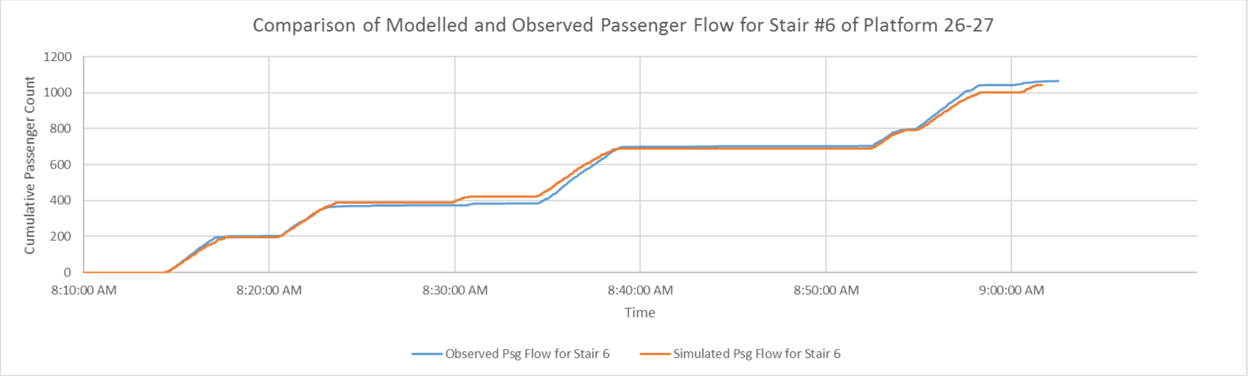
$$G_H = \sqrt{\frac{2(m-c)^2}{m+c}}$$

  - Visual inspection

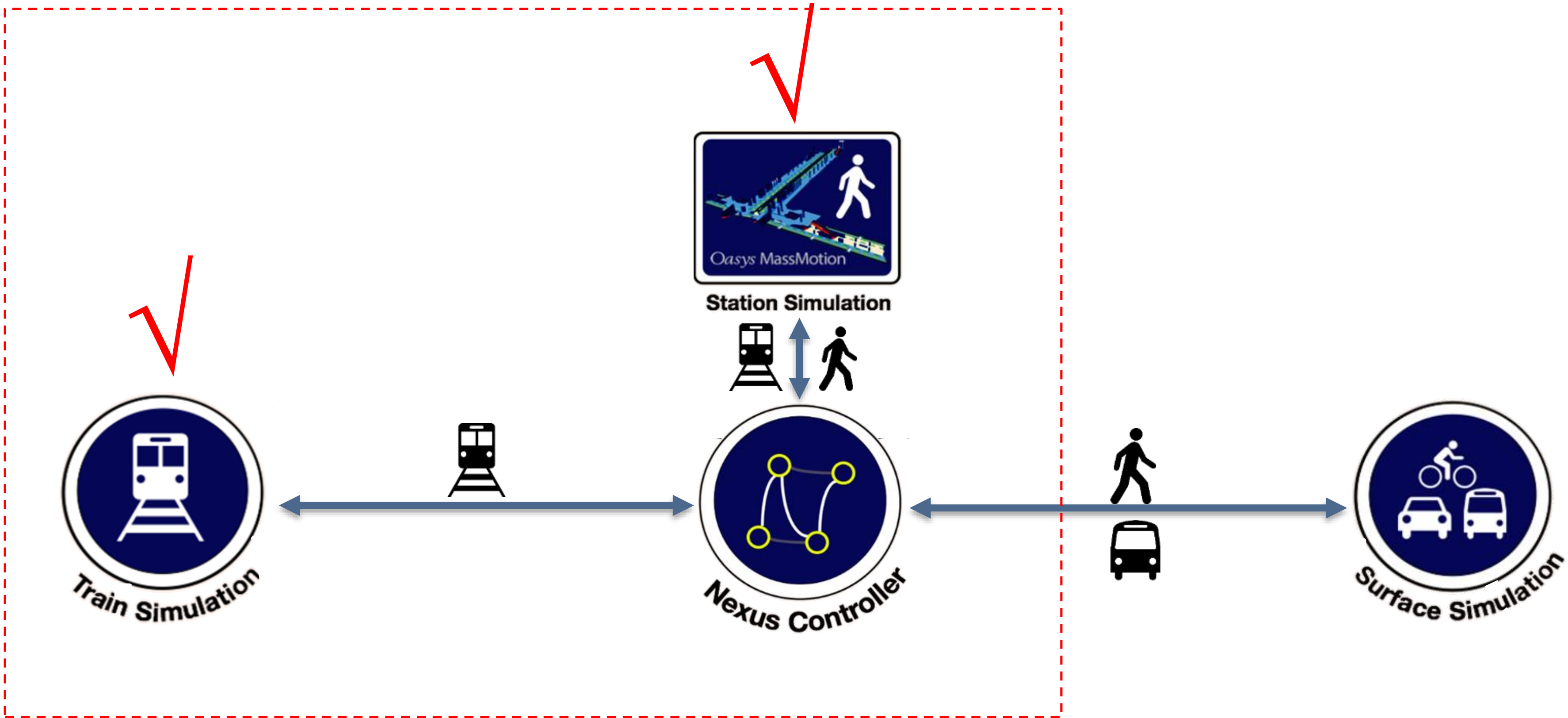
Model Calibration and Validation



- Validation



Nexus



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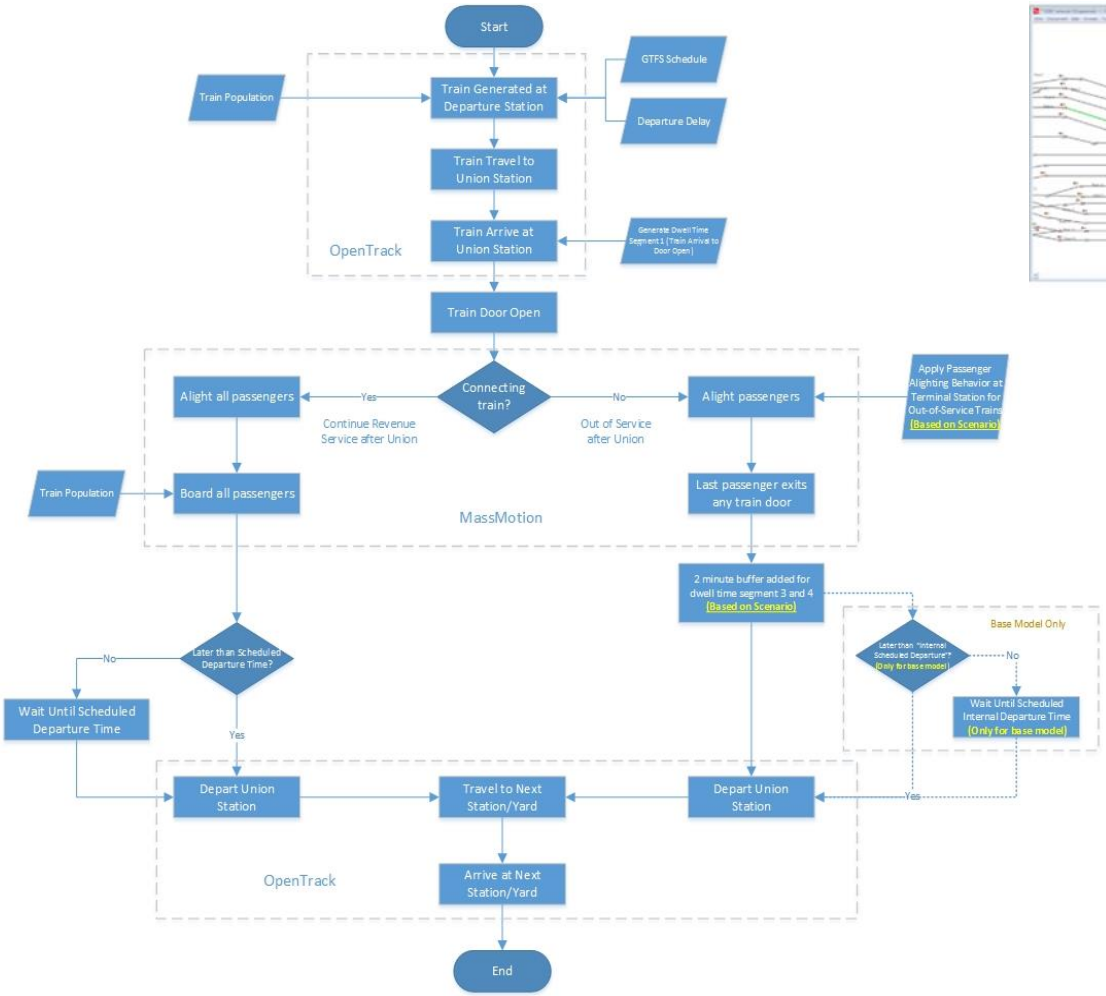
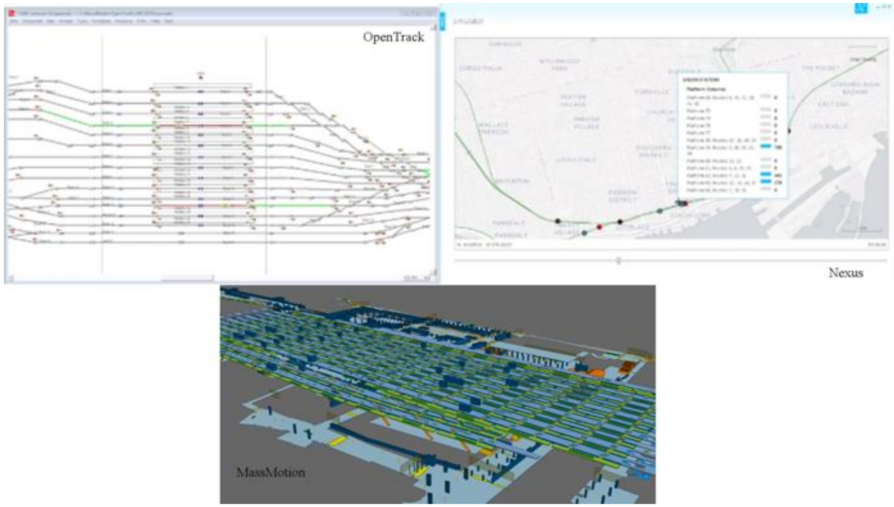
√
Oasys MassMotion
Station Simulation
Train Simulation
Nexus Controller
Surface Simulation

Model Input

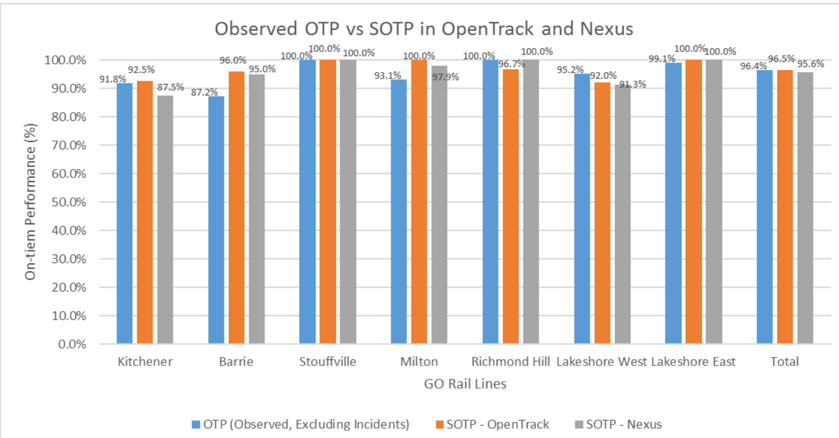
- Individual simulation models (MassMotion, OpenTrack)
- General Transit Feed Specification dataset (GTFS)
- Complete list of agents with OD itinerary

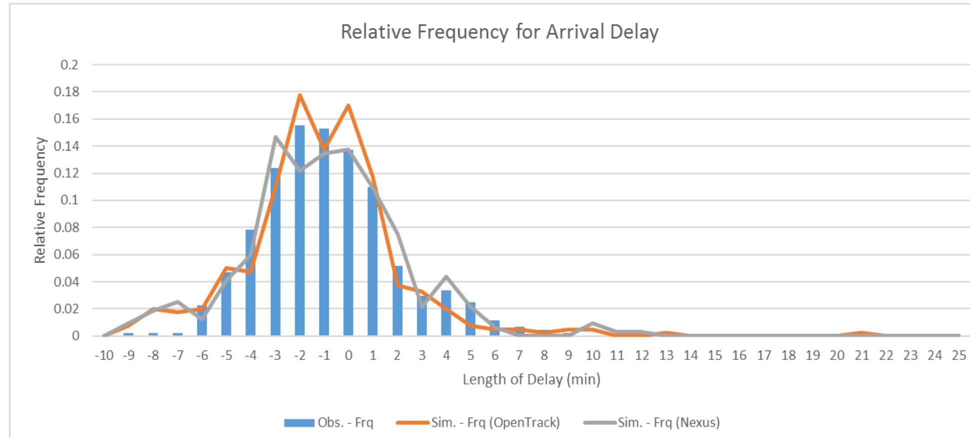
Simulation Flow Chart

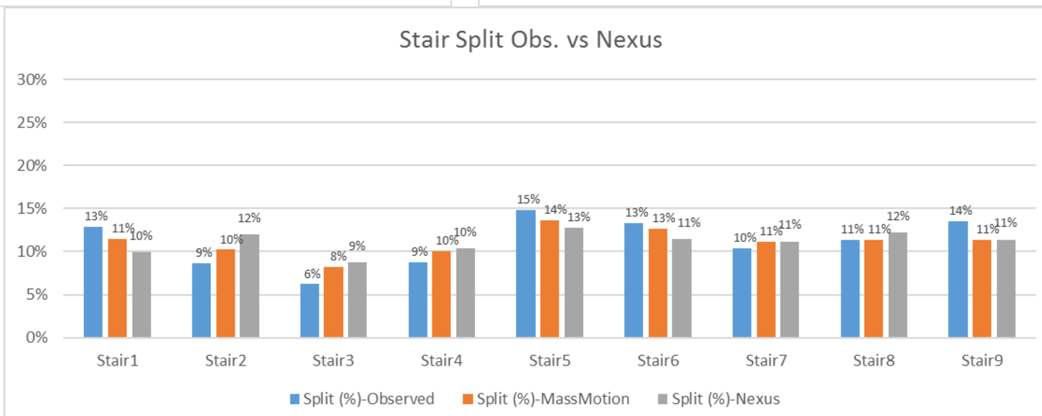




Model calibration and validation







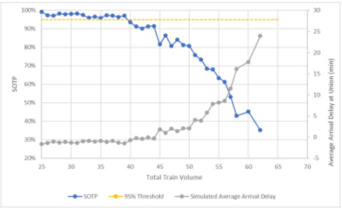
Evaluating System Performance

- Simulated On-time Performance (SOTP, %)
- Simulate average arrival delay at Union (min)
- Average dwell time (min)
- Hourly inbound and outbound passenger volume (Person)
- Average percentage of inbound and outbound passengers per second at LOS F (%)
- Average duration at LOS F for each inbound and outbound passenger (Sec)

LOS	Platforms (queueing)		Stairways	
	Density ($person/m^2$)	Space ($m^2/person$)	Density ($person/m^2$)	Space ($m^2/person$)
A	x<=0.826	x>1.21	x<=0.541	x>=1.85
B	0.826<x<=1.075	1.21>x>=0.93	0.541<x<=0.719	1.85>x>=1.39
C	1.075<x<=1.538	0.93>x>=0.65	0.719<x<=1.076	1.39>x>=0.93
D	1.538<x<=3.571	0.65>x>=0.28	1.076<x<=1.539	0.93>x>=0.65
E	3.571<x<=5.263	0.28>x>=0.19	1.539<x<=2.702	0.65>x>=0.37
F	5.263<x	0.19>x	2.702<x	0.37>x

Scenario Tests

Scenario Tests



OpenTrack Sensitivity Test:
39 trains, 5 min dwell time

OpenTrack Model

Train Schedule

NEXUS

MassMotion Model

Population File

Person Capacity:
Peak Hour Factor (PHF)

$$P = T \cdot N_c \cdot P_c \cdot (PHF)$$

39 trains/h *12 Cars/Train* *162 seats + 256 standees/car*

Scenario Tests

Current schedule and passenger volume — Base Model

OpenTrack Sensitivity Test final schedule and current level of train load — Scenario 1

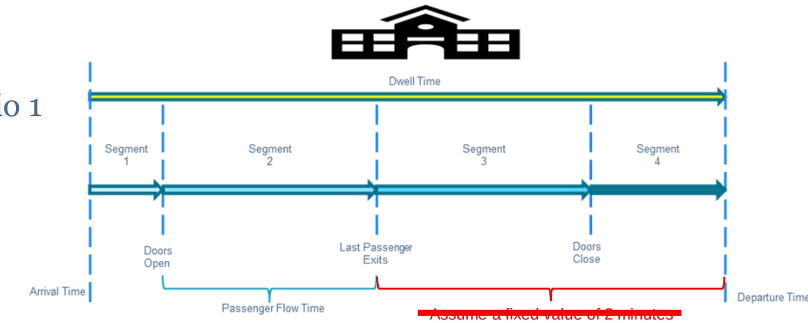
Train load increased by adjusting the PHF to 0.49

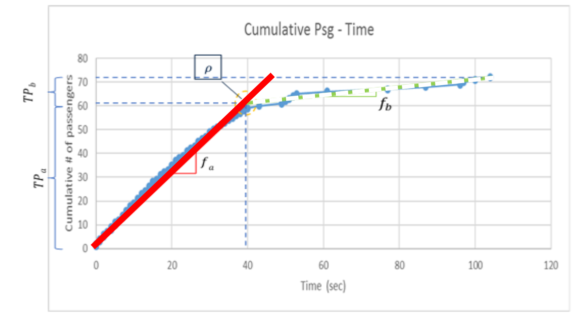
PHF increased by 0.1 or 0.05 stepwise

Scenario 2-5

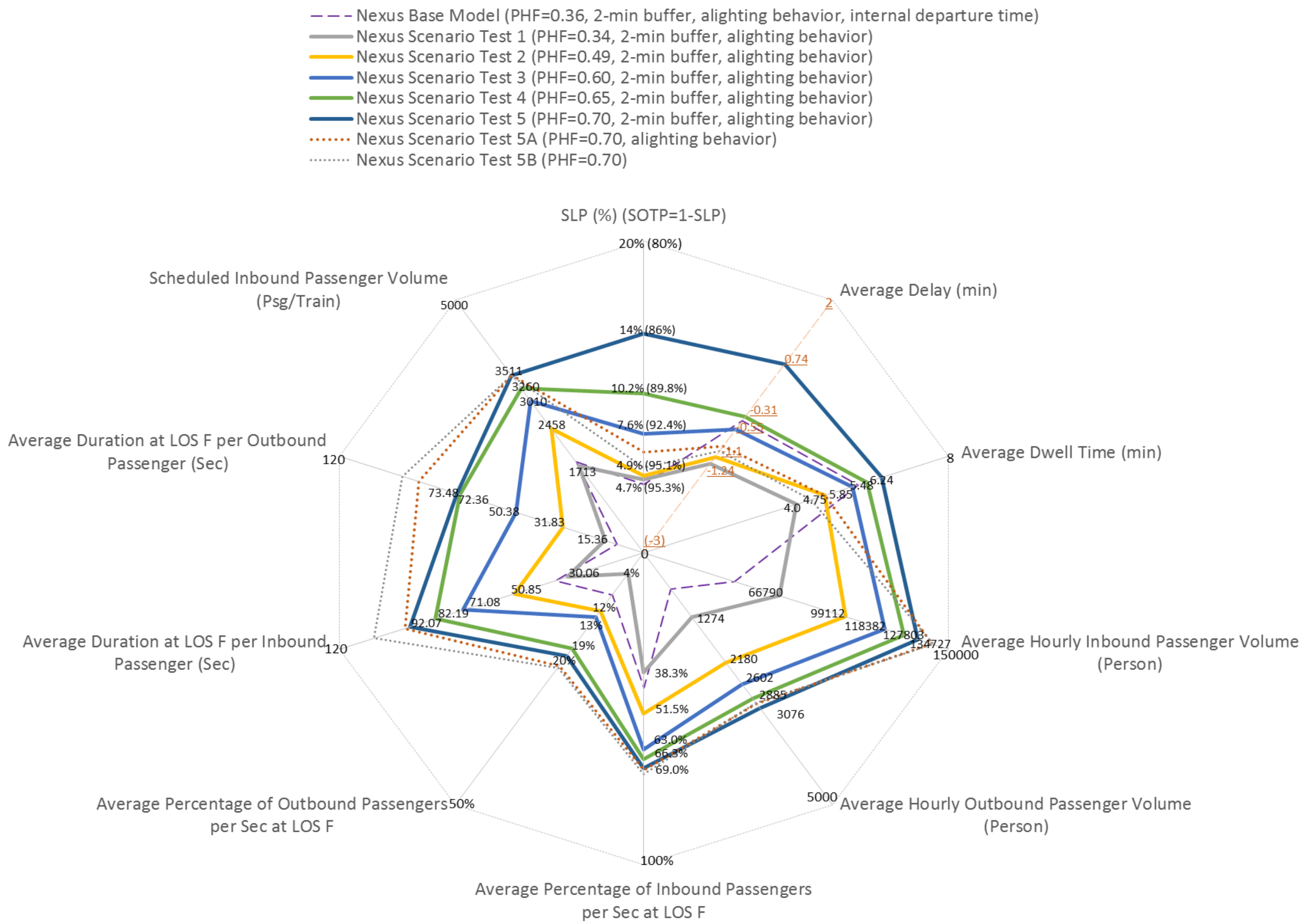
Remove 2-minute buffer time (segment 3 and 4) — Scenario 5A

Remove terminal passenger alighting behavior — Scenario 5B

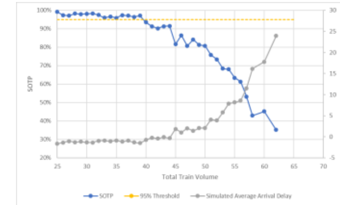


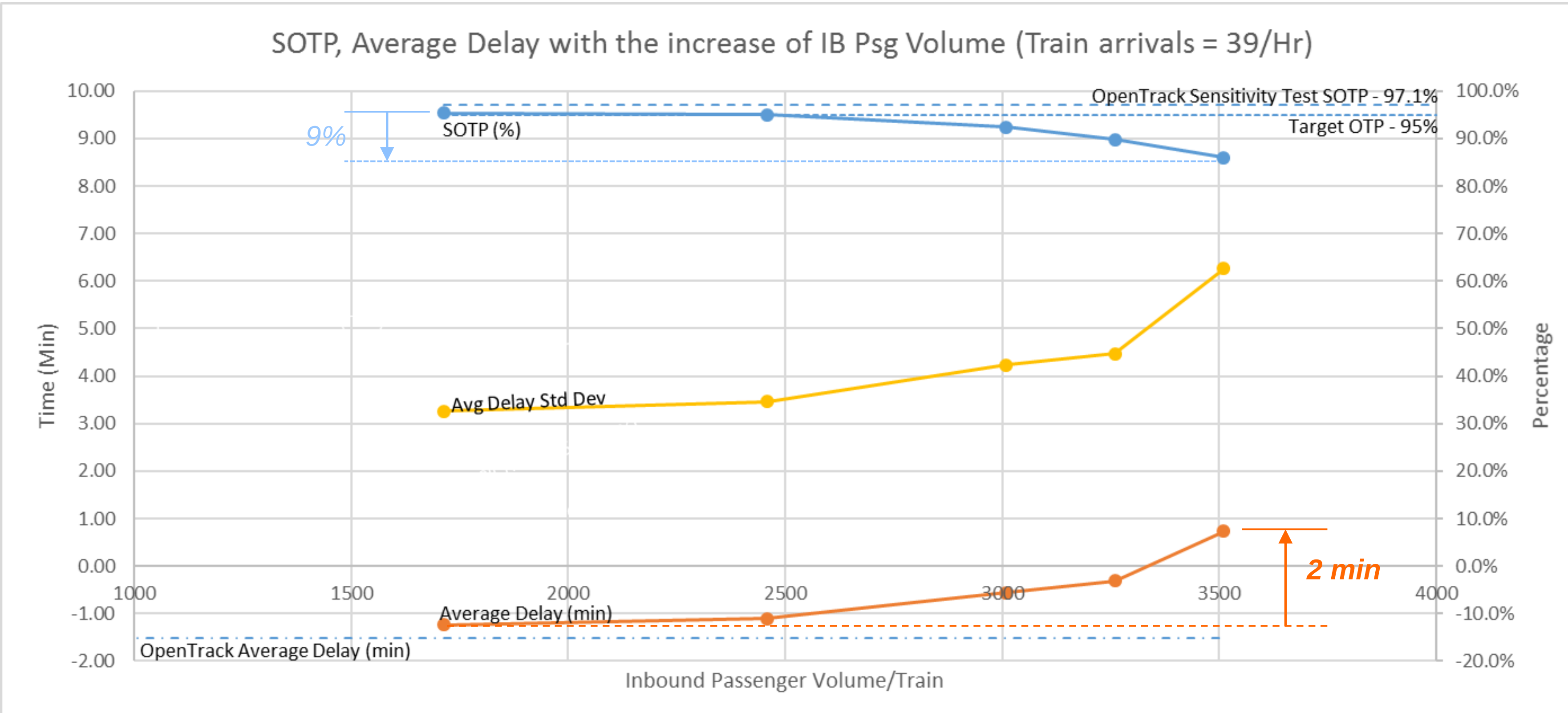


Scenario Tests Results



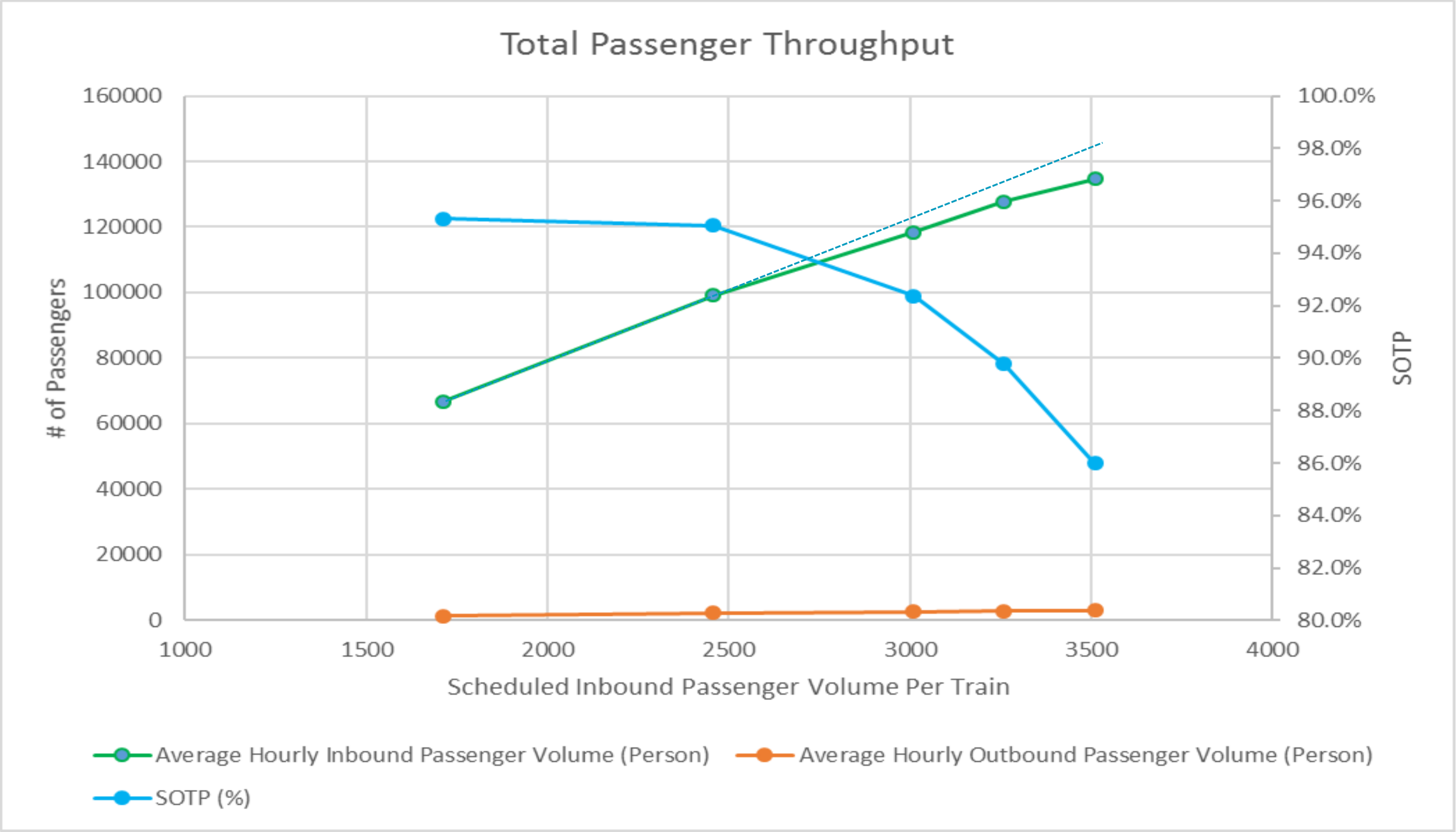
Scenario Tests Results





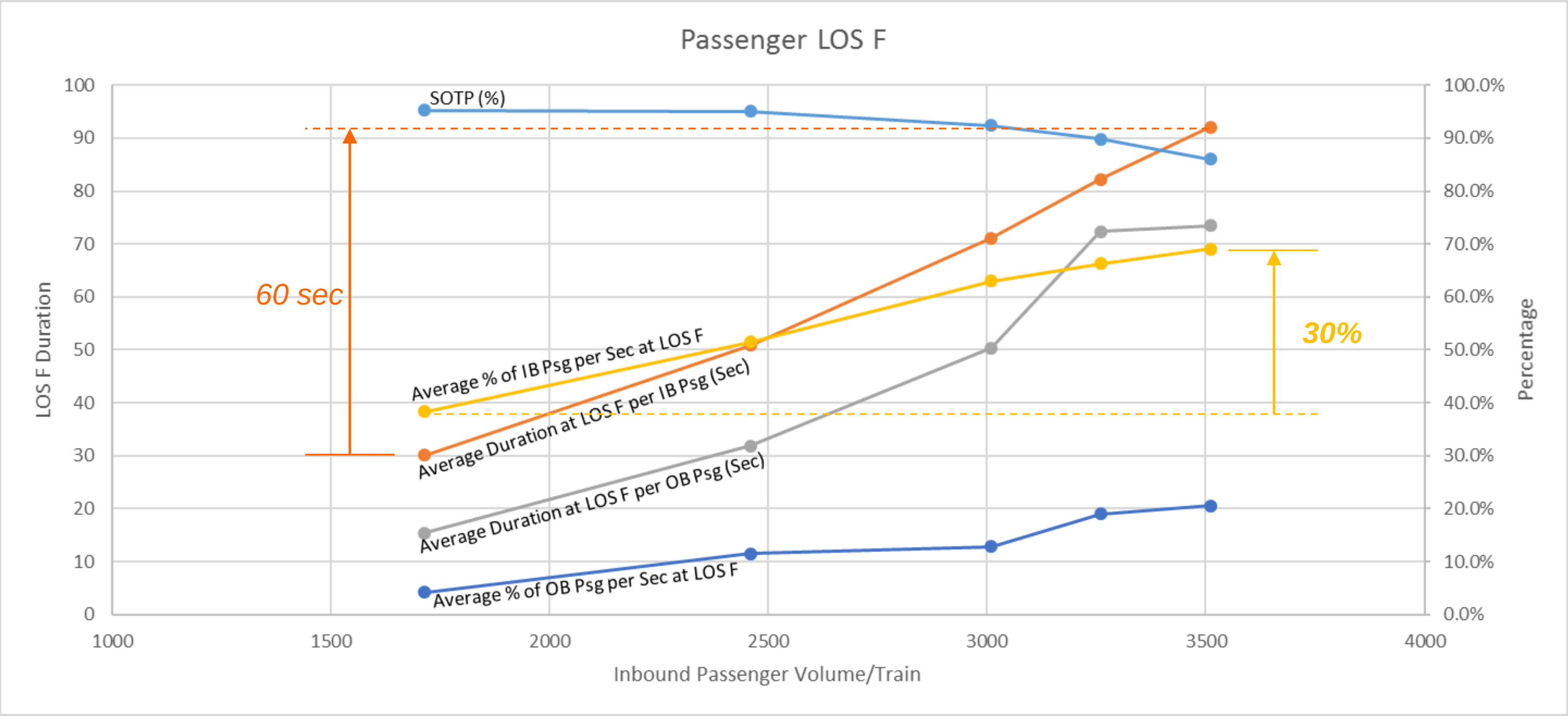
Scenario Tests Results

Scenario Tests Results



*total delay time ($number\ of\ passengers \times delay$)

Scenario Tests Results

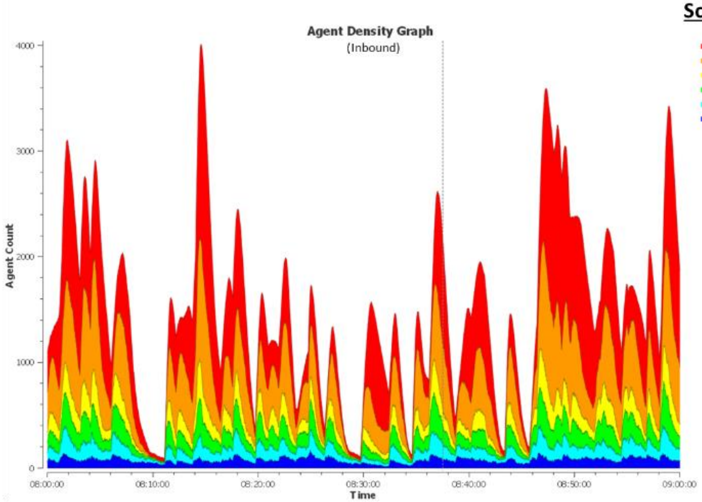


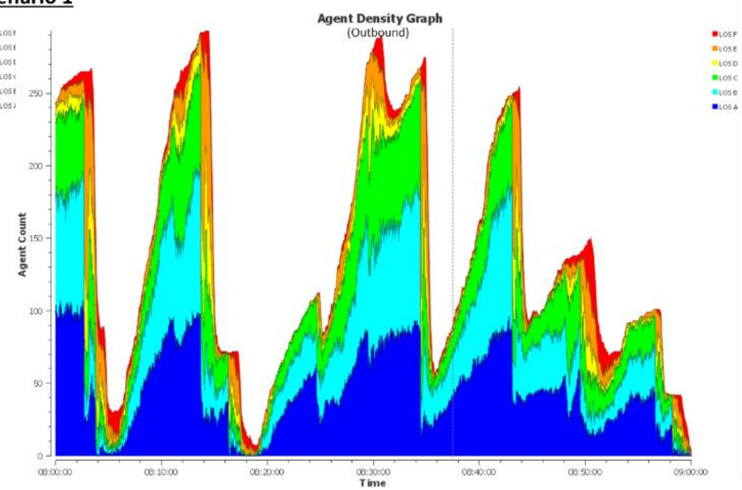
Scenario Tests Results

Inbound

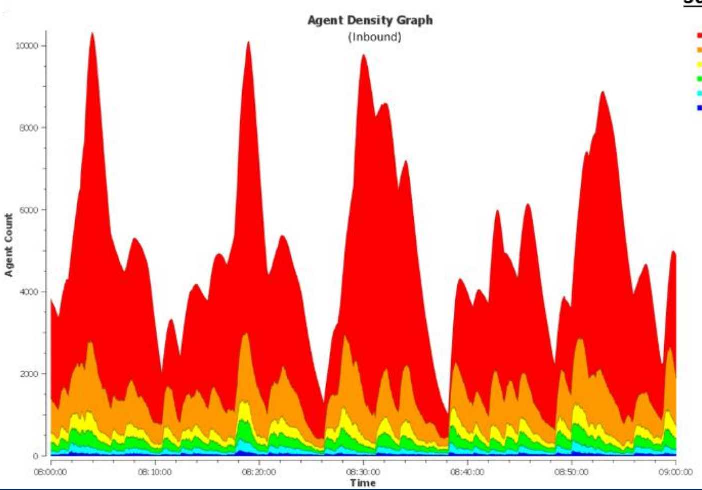
Outbound

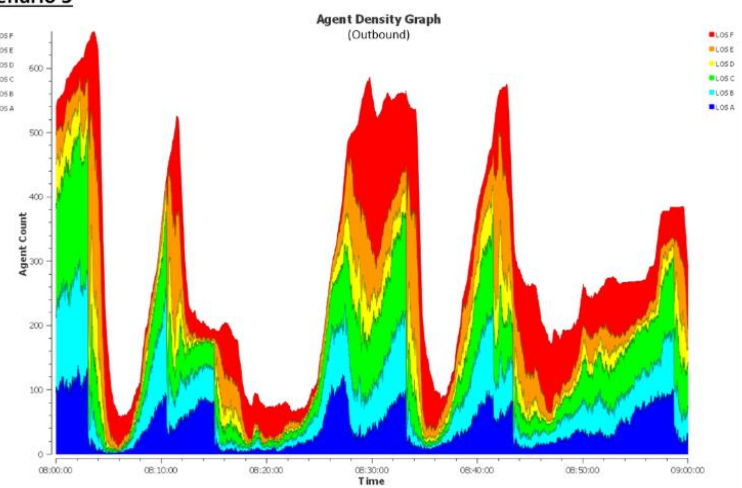
Scenario 1





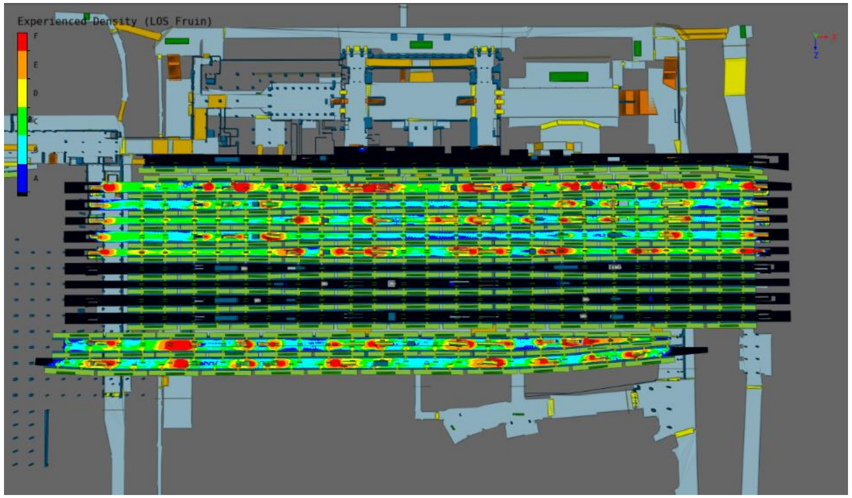
Scenario 5



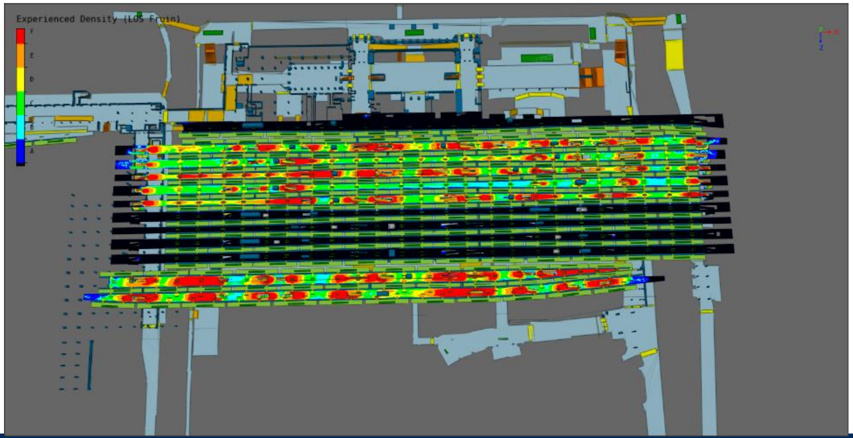


Scenario Tests Results

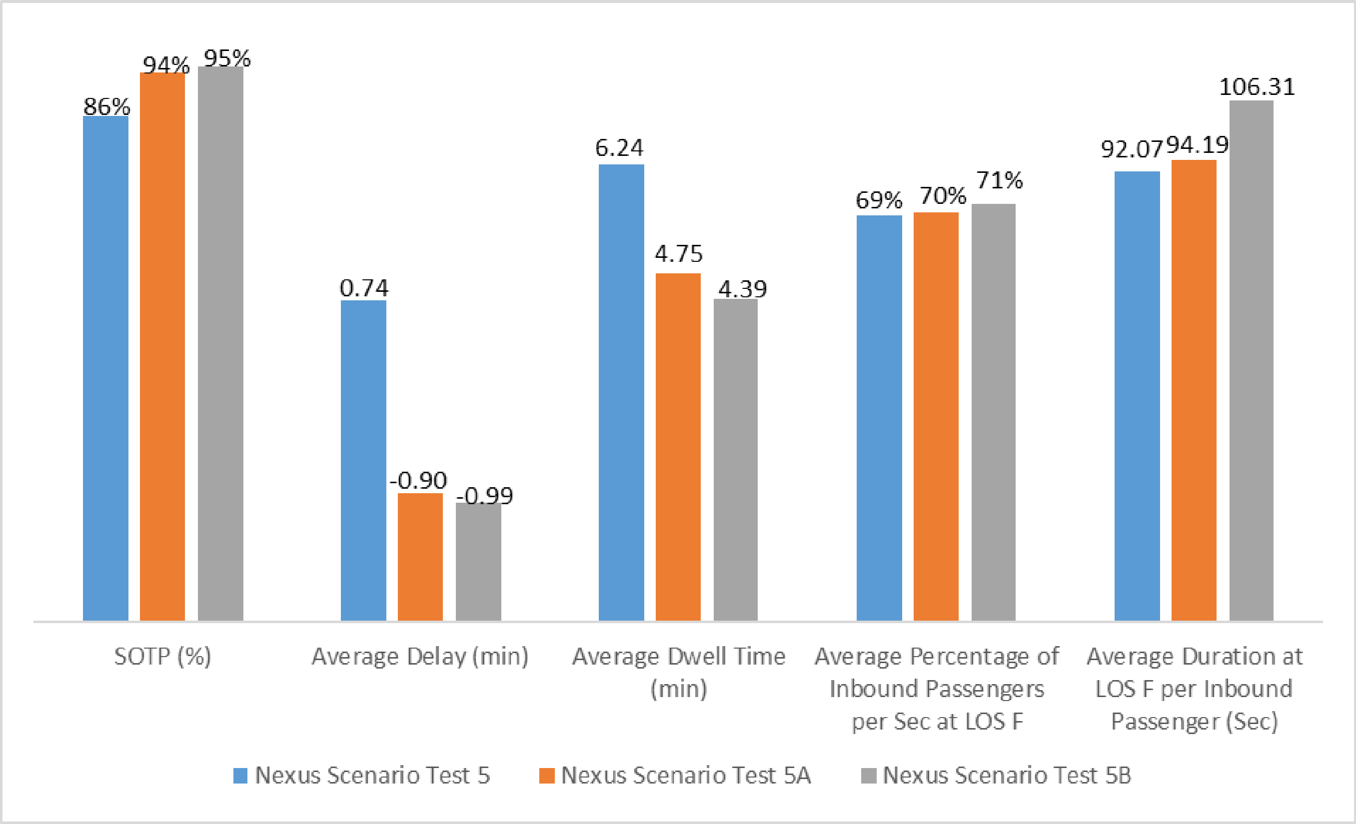
Base Model



Scenario 5



Further Scenarios



Conclusion

Conclusions

- Analytical methods are not sufficient to capture the stochasticity of a complex area
- Railway simulation fails to account for the impact of pedestrian movements
- Both pedestrian movements and train movements have interactive effect on the total capacity of a complex station area

Contribution

- Performed a comprehensive comparative analysis among various analytical and simulation methods on the capacity of a node area
- Affirmed that practical capacity is around 60% to 75% of the theoretical capacity
- Observed unique terminal passenger alighting behavior, proposed a simple initial model
- Identified the benefit of using integrated simulation model

Future Work

- Apply Nexus for new service concepts like RER
- Study optimization methods
- Consider the capacity of maintenance yards, turn-back movements at the Union Station
- Further develop the alighting behavior model for the terminal station by considering other factors
- Apply Nexus in other complex transit systems which are sensitive to delays

Acknowledgements

ARUP

UNIVERSITY OF TORONTO

METROLINX

Thank you