Subway's system interruptions impacts on adjacent streetcar and bus transit service performance & Shuttle service optimization

iCity - ORF 2ND annual student presentations

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Miserable morning rush hour fades into memory as TTC service resumes

Thousands of commuters left scrambling after overnight fire in hydro vault kills downtown subways and streetcars.

TORONTO

Toronto's manic morning: How the TTC's troubles unfolded Tuesday

Subway service is up and running again after a power failure Tuesday morning scuttled trains and streetcar routes across downtown Toronto, creating chaos, **Oliver Moore** reports

OLIVER MOORE
URBAN TRANSPORTATION REPORTER | The Globe and Mail | Last updated: Monday, Mar. 28, 2016 11:05AM EDT

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https://www.thestar.com/news/gta/2016/03/01/power-failure-closes-yonge-subway-diverts-downtown-streetcars.html
http://www.theglobeandmail.com/news/toronto/torontos-manic-morning-how-the-ttcs-troubles-areunfolding/article28962684/

TTC subway passengers dealt with 'absolutely brutal' commute

Passengers faced 30-minute delay between Finch and Bloor stations

A twitter user captured this shot of a crowded subway platform this morning. Passengers faced delays
30 minutes (Tariq Fancy/Twitter.)

Tariq Fancy
@sosofancy

Follow

Thanks @TTChelps for bringing #Toronto together this AM. (Posted an hour later b/c #TTC WIFI never works..) #the6ix

10:16 AM - 9 Feb 2016 · Toronto, Ontario, Canada

5 11

Thee Mike D
@thatdrotho

Follow

Stuck at Yonge for over 30 mins. Easily the worst subway system in NA, possibly the world? #ttc #fairhike #toronto

10:00 AM - 9 Feb 2016

3 7

http://www.cbc.ca/news/canada/toronto/ttc-delays-1.3440052

https://www.thestar.com/news/gta/2016/03/01/power-failure-closes-yonge-subway-diverts-downtown-streetcars.html

Research Gap

- Exploring the quality of transit service is traditionally done on a mode-by-mode basis
  - It is rare to find studies that investigated the impacts of breakdown of one transit mode on other functioning modes in multimodal integrated transit systems

Research Gap

- Furthermore, although one of the main strategies that has been widely employed to deal with rail service interruptions is “bus bridging”, whereby buses from scheduled services are retracted and deployed to offer shuttle services
  - It is rare to find studies that optimize shuttle service employment in order to minimize subway service’s interruptions impact on bus users

Research Objective (or Projects)

1. Aims at understanding the impact of incident and interruption delays of Toronto’s subway system on the performance of adjacent surface transit system, namely buses and streetcars

2. Develop a shuttle service optimization model to help transit agencies in determining the optimal routes from which to pull buses from as well as to find the optimal number of buses

First project:

Understanding the impacts of subway's system interruptions on adjacent streetcar and bus transit service performance

Diab, E., & Shalaby, A. (2017) *Understanding the impacts of subway's system interruptions on streetcar and bus transit service performance.* paper presented at the 3rd International Workshop and Symposium TransitData in Santiago, Chile, May 22-24, 2017.

Methodology - Data

- Two sets of data:
  - Detailed dataset of subway incidents in 2013 compiled by the Toronto Transit Commission (TTC)
  - TTC's Automatic Vehicle Location (AVL) system data for bus and streetcar routes that are within a short walking distance (200 m) from the subway stations investigated in this study

Methodology - Data

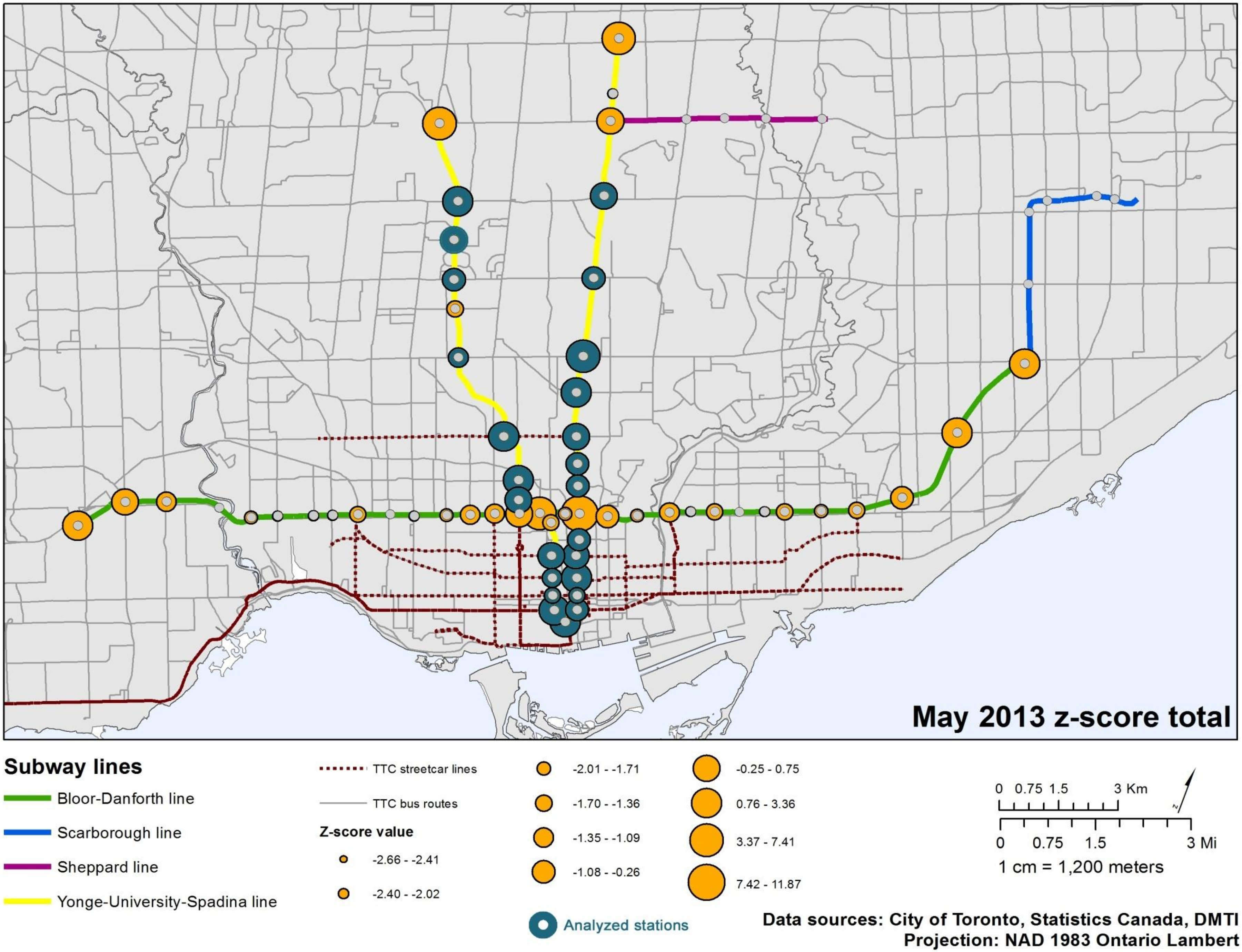
- Subway system interruption data:
  - A total of 12,000 subway incidents at the station level of analysis in 2013
  - For each record, the TTC's dataset includes:
    - date, time
    - subway station, direction of travel
    - amount of delay (in minutes)
    - train number and type
    - a brief description of the incident and a code representing the incident type

Methodology - Study Time Frame

- The time frame of interest include all weekdays of **May 2013**
- That month saw the greatest number of incidents with the largest amount of delay, and lowest standard deviations at the system level in 2013

Methodology - Subway Stop Selection

- Focus on **24 subway stations** along Line 1 (YUS line)
- These stations were selected according to a composite indicator that was generated to identify the most vulnerable stations in the subway system.


May 2013 z-score total
Subway lines
Bloor-Danforth line
Scarborough line
Sheppard line
Yonge-University-Spadina line
TTC streetcar lines
TTC bus routes
Z-score value
-2.66 - -2.41
-2.40 - -2.02
-2.01 - -1.71
-1.70 - -1.36
-1.35 - -1.09
-1.08 - -0.26
-0.25 - 0.75
0.76 - 3.36
3.37 - 7.41
7.42 - 11.87
Analyzed stations
0 0.75 1.5 3 Km
0 0.75 1.5 3 Mi
1 cm = 1,200 meters
Data sources: City of Toronto, Statistics Canada, DMTI
Projection: NAD 1983 Ontario Lambert

Methodology – Analyzed Incidents

- Allowing us to analyze the impacts of **388 incidents** with total **delay of 1702 minutes**, ranging from 2 minutes incidents to 73 minutes incidents

Methodology

- More than **80 million** observations were collected from the TTC's AVL system for **41 bus routes** and **10 streetcar routes** for the weekdays between May 1st and 31st, 2013
  - AVL data include information on bus and streetcar locations (x and y coordinates) recorded every 20 seconds as well as other information related to time of record and route number

Methodology – data preparation

- Trip-time-point segment is the study's unit of analysis
  - defined as the part of a trip over a route section between every two consecutive time points along a route
- Thus, all the variables were summarized according to that
  - E.g., average speed per trip-segment

Methodology – data preparation

- After this process, about **1,200,000** and **800,000** trip-segment records were included in the analysis for the bus and streetcar datasets, respectively

Methodology

- Descriptive statistics
- Two statistical models using the bus and streetcar service average speed (kilometre/hour) per trip-segment as the dependent variable
  - Bus speed model
  - Streetcar speed model

Methodology

	Variable
Control Variables	Direction
	Segment sequence
	Number of scheduled stops
	Adjacent segment (within 200 meters)
	Segment with a layover
	Segment distance (KM)
	Streetcar—Bus
	Streetcar STC—ALRV
	Streetcar —Flexity
	Bus route number *i (41 dummy variables)*
	Streetcar route number *i* (10 dummy variables)
	Distance to Union Station (KM)
	Morning peak
	Afternoon peak
	Early evening
	Late evening
	Subway station ridership (in thousands)
	Subway station ridership^2
Policy variables	Trips starting within 5 minutes of an incident
	Trips starting within 5-10 minutes of an incident
	Trips starting within 10-20 minutes of an incident
	Trips starting within 20-30 minutes of an incident
	Trips starting within 30-60 minutes of an incident
	Trips starting within 60+ minutes of an incident
	Segments after an impacted segment
	Trips in same direction of an incident
	Trips starting after a cleared incident

Analysis - Models

Streetcar speed model

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	10.113	.032		312.398	.000	10.050	10.177
	DIR_of_TT	-.412	.010	-.037	-39.379	.000	-.433	-.392
	TP	.047	.002	.028	19.749	.000	.042	.052
	Sm_TPStp_count	-.028	.001	-.048	-43.338	.000	-.029	-.026
	Stops_witihin100	-2.909	.018	-.215	-163.695	.000	-2.944	-2.875
	Layover	-1.830	.013	-.160	-143.606	.000	-1.855	-1.805
	Seg_dis	.002	.000	.269	229.598	.000	.002	.002
	BusType	-.323	.035	-.017	-9.248	.000	-.392	-.255
	STC-AIRV	-.211	.041	-.012	-5.125	.000	-.291	-.130
	Flexity	.406	2.034	.000	.200	.842	-3.581	4.393
	DIST_Union	.000	.000	.130	51.645	.000	.000	.000
	AmP	1.503	.015	.105	99.001	.000	1.473	1.533
	Afternoon_P	-.721	.014	-.056	-51.703	.000	-.748	-.694
	night_P	1.168	.017	.072	69.479	.000	1.135	1.201
	Early_morning	3.984	.017	.239	231.406	.000	3.950	4.018
	T_riderhsipF1000	-.033	.003	-.036	-13.244	.000	-.038	-.028
	T_riderhsipF1000_2	.000	.000	.034	13.448	.000	.000	.000
	N30_STR_0_5	-.442	.272	-.002	-1.627	.104	-.975	.091
	N30_STR_5_10	-1.403	.342	-.006	-4.103	.000	-2.074	-.733
	N30_STR_10_20	-1.168	.315	-.007	-3.709	.000	-1.785	-.551
	N30_STR_20_30	-1.064	.322	-.006	-3.302	.001	-1.696	-.433
	N30_STR_within_60	-1.145	.354	-.004	-3.236	.001	-1.838	-.451
	N30_STR_above_60	-1.798	.851	-.002	-2.114	.035	-3.466	-.131
	Fix_TPs_after_Incident	-.016	.030	-.001	-1.711	.092	-.076	.013
	N30_After_INC_Cleared_ Dummy	1.001	.283	.010	3.538	.000	.447	1.556
	R501	-.789	.045	-.042	-17.596	.000	-.876	-.701
	R502	-.697	.047	-.015	-14.825	.000	-.789	-.605
	R503	-.162	.071	-.002	-2.278	.023	-.302	-.023
	R504	-.078	.018	-.005	-4.321	.000	-.114	-.043
	R506	.220	.021	.012	10.275	.000	.178	.263
	R509	1.540	.048	.072	32.377	.000	1.447	1.633
	R510	-2.484	.025	-.154	-99.625	.000	-2.533	-2.435
	R511	-1.194	.027	-.056	-44.636	.000	-1.247	-1.142
	R512	-.579	.040	-.033	-14.375	.000	-.658	-.500

a. Dependent Variable: Av_SP_KMH

Bus speed model

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	14.215	.053		266.535	.000	14.110	14.319
	DIR_of_TT	.290	.014	.015	21.202	.000	.263	.317
	TP	.034	.003	.016	11.508	.000	.028	.040
	Sm_TPStp_count	-.208	.004	-.055	-49.560	.000	-.216	-.200
	Stops_witihin100	-3.941	.017	-.194	-232.417	.000	-3.974	-3.908
	Layover	-7.691	.023	-.312	-336.518	.000	-7.736	-7.646
	Seg_dis	.003	.000	.243	204.144	.000	.003	.003
	DIST_Union	.000	.000	.059	44.209	.000	.000	.000
	AmP	.485	.020	.021	24.832	.000	.447	.523
	Afternoon_P	-2.087	.019	-.095	-112.732	.000	-2.123	-2.051
	night_P	1.968	.022	.071	87.818	.000	1.924	2.012
	Early_morning	6.385	.023	.221	273.918	.000	6.339	6.431
	T_ridership_F1000	-.033	.003	-.031	-12.397	.000	-.039	-.028
	T_ridership_F1000_2	.000	.000	.033	13.858	.000	.000	.001
	N30_STR_0_5	.062	.195	.000	.321	.748	-.319	.444
	N30_STR_5_10	.140	.189	.001	.740	.459	-.230	.509
	N30_STR_10_20	.018	.142	.000	.127	.899	-.261	.297
	N30_STR_20_30	-.293	.144	-.002	-2.033	.042	-.576	-.011
	N30_STR_within_60	-.597	.231	-.002	-2.583	.010	-1.050	-.144
	N30_STR_above_60	-3.548	2.589	-.001	-1.370	.171	-8.623	1.527
	Fix_TPs_after_Incident	-.432	.038	-.008	-11.214	.000	-.507	-.356
	N30_Same_direction	.357	.201	.001	1.772	.076	-.038	.752
	R6	-2.395	.048	-.056	-49.606	.000	-2.489	-2.300
	R5	3.586	.062	.047	58.222	.000	3.465	3.706
	R7	.172	.032	.005	5.311	.000	.109	.236
	R11	2.618	.035	.066	74.753	.000	2.550	2.687
	R14	3.213	.064	.041	50.444	.000	3.088	3.338
	R26	1.371	.078	.014	17.598	.000	1.218	1.524
	R29	.564	.036	.017	15.566	.000	.493	.636
	R33	1.097	.102	.008	10.805	.000	.898	1.296
	R34	3.069	.045	.065	68.168	.000	2.980	3.157
	R51	4.503	.070	.049	64.443	.000	4.366	4.640
	R52	1.914	.035	.051	54.787	.000	1.845	1.982
	R54	3.141	.044	.068	72.090	.000	3.056	3.227
	R58	.656	.048	.011	13.641	.000	.561	.750
	R59	4.653	.068	.052	68.479	.000	4.519	4.786
	R61	.067	.065	.001	1.030	.303	-.060	.194
	R78	6.064	.082	.058	74.219	.000	5.904	6.224
	R82	4.772	.095	.040	50.361	.000	4.586	4.957
	R88	2.555	.059	.036	43.166	.000	2.439	2.671
	R90	.834	2.440	.000	.342	.733	-3.949	5.617
	R94	-3.683	.066	-.052	-55.622	.000	-3.813	-3.553
	R95	9.709	.054	.158	178.295	.000	9.602	9.816
	R96	1.234	.041	.027	29.756	.000	1.153	1.315
	R97	2.090	.042	.041	49.452	.000	2.007	2.172
	R100	3.078	.045	.058	67.657	.000	2.989	3.167
	R103	1.058	.092	.009	11.500	.000	.877	1.238
	R104	3.045	.069	.036	43.966	.000	2.909	3.180
	R109	.848	.060	.012	14.216	.000	.731	.965
	R115	10.127	.100	.077	101.262	.000	9.931	10.323
	R120	4.353	.088	.038	49.731	.000	4.182	4.525
	R122	9.943	.080	.098	124.250	.000	9.786	10.100
	R124	1.519	.066	.019	22.962	.000	1.389	1.648
	R126	-.335	.095	-.003	-3.512	.000	-.522	-.148
	R127	1.245	.078	.013	16.015	.000	1.092	1.397
	R141	-1.129	.178	-.005	-6.352	.000	-1.478	-.781
	R142	2.712	.107	.019	25.414	.000	2.503	2.921
	R144	-.734	.136	-.004	-5.411	.000	-1.000	-.468
	R145	-1.202	.154	-.006	-7.812	.000	-1.504	-.901
	R160	1.468	.070	.017	21.037	.000	1.331	1.605
	R162	5.528	.121	.034	45.619	.000	5.291	5.766
	R165	1.607	.043	.035	36.991	.000	1.522	1.692

a. Dependent Variable: Av_SP_KMH

Analysis - Streetcar speed model

N	780,705
Adjusted R Square	0.32
F statistics	(33, 780680) 12193
F sig.	0

Bold indicates statistical significance

*** Significant at 99%
** Significant at 95%
* Significant at 90%

	Coeff.	Z		95% Conf. Interval	
				Lower Bound	Upper Bound
(Constant)	**10.1**	**312.4**	***	**10.1**	**10.2**
Direction	**-0.41**	**-39.38**	***	**-0.43**	**-0.39**
Time-point sequence	**0.05**	**19.75**	***	**0.04**	**0.05**
Number of scheduled stops	**-0.03**	**-43.34**	***	**-0.03**	**-0.03**
Adjacent segment (within 200 meters)	**-2.91**	**-163.7**	***	**-2.94**	**-2.87**
Segment with a layover	**-1.83**	**-143.6**	***	**-1.86**	**-1.81**
Segment distance (KM)	**2.34**	**229.6**	***	**2.32**	**2.36**
Streetcar CLRV (Base case)					
Streetcar bus	**-0.32**	**-9.25 *****		**-0.39**	**-0.25**
Streetcar ALRV	**-0.21**	**-5.12 *****		**-0.29**	**-0.13**
Streetcar Flexity	0.41	0.20		-3.58	4.39
Distance to Union Station (KM)	**0.48**	**51.65 *****		**0.46**	**0.50**
Morning peak	**1.50**	**99.00*****		**1.47**	**1.53**
Midday (Base case)					
Afternoon peak	**-0.72**	**-51.70*****		**-0.75**	**-0.69**
Early evening	**1.17**	**69.48*****		**1.13**	**1.20**
Late evening	**3.98**	**231.41*****		**3.95**	**4.02**
Subway station ridership (in thousands)	**-0.03**	**-13.24*****		**-0.04**	**-0.03**
Subway station ridership^2	**0.00**	**13.45*****		**0.00**	**0.00**
Trips starting during normal operations (base case)					
Trips starting within 5 minutes of an incident	-0.44	-1.63		-0.98	0.09
Trips starting within 5-10 minutes of an incident	**-1.40**	**-4.10*****		**-2.07**	**-0.73**
Trips starting within 10-20 minutes of an incident	**-1.17**	**-3.71*****		**-1.79**	**-0.55**
Trips starting within 20-30 minutes of an incident	**-1.06**	**-3.30*****		**-1.70**	**-0.43**
Trips starting within 30-60 minutes of an incident	**-1.14**	**-3.24*****		**-1.84**	**-0.45**
Trips starting within 60+ minutes of an incident	**-1.80**	**-2.11****		**-3.47**	**-0.13**
Time-point after an incident	**-0.02**	**-1.71***		**-0.08**	**0.01**
Time-point after a cleared incident	**1.00**	**3.54*****		**0.45**	**1.56**

Sensitivity analysis- Streetcar

- Streetcar line with median speed: Route 501-Westbound- CLRV
  - Average speed during different type periods

	Morning peak		Midday period		Afternoon peak		Early evening		Late evening		%
	Speed (Km/h)	%	Speed (Km/h)	%	Speed (Km/h)	%	Speed (Km/h)	%	Speed (Km/h)	%	
Trips starting during normal operations	**11.02**		**9.52**		**8.80**		**10.69**		**13.50**		
Trips starting within 5 minutes of an incident	11.02	0.0%	9.52	0.0%	8.80	0.0%	10.69	0.0%	13.50	0.0%	0.0%
Trips starting within 5-10 minutes of an incident	**9.62**	**-12.7%**	**8.12**	**-14.7%**	**7.39**	**-16.0%**	**9.28**	**-13.1%**	**12.10**	**-10.4%**	**-13.4%**
Trips starting within 10-20 minutes of an incident	**9.85**	**-10.6%**	**8.35**	**-12.3%**	**7.63**	**-13.3%**	**9.52**	**-10.9%**	**12.33**	**-8.6%**	**-11.1%**
Trips starting within 20-30 minutes of an incident	**9.96**	**-9.7%**	**8.45**	**-11.2%**	**7.73**	**-12.1%**	**9.62**	**-10.0%**	**12.44**	**-7.9%**	**-10.2%**
Trips starting within 30-60 minutes of an incident	**9.88**	**-10.4%**	**8.37**	**-12.0%**	**7.65**	**-13.0%**	**9.54**	**-10.7%**	**12.36**	**-8.5%**	**-10.9%**
Trips starting within 60+ minutes of an incident	**9.22**	**-16.3%**	**7.72**	**-18.9%**	**7.00**	**-20.4%**	**8.89**	**-16.8%**	**11.70**	**-13.3%**	**-17.2%**
Averages	**9.9**	**-9.9%**	**8.4**	**-11.5%**	**7.7**	**-12.5%**	**9.6**	**-10.3%**	**12.4**	**-8.1%**	

% of change in speed = (trip speed during an incident category - trip speed during normal operations)/ trip speed during normal operations

Analysis - Bus speed model

N	1,172,542
Adjusted R Square	0.39
F statistics	(61, 1172521) 25431
F sig.	0

Bold indicates statistical significance

*** Significant at 99%
** Significant at 95%
* Significant at 90%

	Coeff.	Z	95% Conf. Interval	
			Lower Bound	Upper Bound
(Constant)	**14.21**	**266.5*** **	**14.11**	**14.32**
Direction	**0.29**	**21.20*** **	**0.26**	**0.32**
Time-point sequence	**0.03**	**11.51*** **	**0.03**	**0.04**
Number of scheduled stops	**-0.21**	**-49.56*** **	**-0.22**	**-0.20**
Adjacent segment (within 200 meters)	**-3.94**	**-232.4*** **	**-3.97**	**-3.91**
Segment with a layover	**-7.69**	**-336.5*** **	**-7.74**	**-7.65**
Segment distance (KM)	**2.83**	**204.1*** **	**2.81**	**2.86**
Distance to Union Station (KM)	**0.17**	**44.21*** **	**0.16**	**0.17**
Morning peak	**0.48**	**24.83*** **	**0.45**	**0.52**
Midday (Base case)				
Afternoon peak	**-2.09**	**-112.7*** **	**-2.12**	**-2.05**
Early evening	**1.97**	**87.82*** **	**1.92**	**2.01**
Late evening	**6.38**	**273.9*** **	**6.34**	**6.43**
Subway station ridership (in thousands)	**-0.03**	**-12.40*** **	**-0.04**	**-0.03**
Subway station ridership^2	**0.00**	**13.86*** **	**0.00**	**0.00**
Trips starting during normal operations (base case)				
Trips starting within 5 minutes of an incident	0.06	0.32	-0.32	0.44
Trips starting within 5-10 minutes of an incident	0.14	0.74	-0.23	0.51
Trips starting within 10-20 minutes of an incident	0.02	0.13	-0.26	0.30
Trips starting within 20-30 minutes of an incident	**-0.29**	**-2.03** **	**-0.58**	**-0.01**
Trips starting within 30-60 minutes of an incident	**-0.60**	**-2.58*** **	**-1.05**	**-0.14**
Trips starting within 60+ minutes of an incident	-3.55	-1.37	-8.62	1.53
Time-point after an incident	**-0.43**	**-11.21*** **	**-0.51**	**-0.36**
Incident in same direction of travel	**0.36**	**1.77* **	**-0.04**	**0.75**

Sensitivity analysis- Streetcar

- For bus line with median speed: Route 96 - Eastbound
  - Average speed during different type periods

	Morning peak		Midday period		Afternoon peak		Early evening		Late evening		%
	Speed (Km/h)	%	Speed (Km/h)	%	Speed (Km/h)	%	Speed (Km/h)	%	Speed (Km/h)	%	
Trips starting during normal operations	**17.02**		**16.53**		**14.45**		**18.50**		**22.92**		
Trips starting within 5 minutes of an incident	17.02	0.0%	16.53	0.0%	14.45	0.0%	18.50	0.0%	22.92	0.0%	0.0%
Trips starting within 5-10 minutes of an incident	17.02	0.0%	16.53	0.0%	14.45	0.0%	18.50	0.0%	22.92	0.0%	0.0%
Trips starting within 10-20 minutes of an incident	17.02	0.0%	16.53	0.0%	14.45	0.0%	18.50	0.0%	22.92	0.0%	0.0%
Trips starting within 20-30 minutes of an incident	**16.72**	**-1.7%**	**16.24**	**-1.8%**	**14.15**	**-2.0%**	**18.21**	**-1.6%**	**22.62**	**-1.3%**	**-1.7%**
Trips starting within 30-60 minutes of an incident	**16.42**	**-3.5%**	**15.94**	**-3.6%**	**13.85**	**-4.1%**	**17.90**	**-3.2%**	**22.32**	**-2.6%**	**-3.4%**
Trips starting within 60+ minutes of an incident	17.02	0.0%	16.53	0.0%	14.45	0.0%	18.50	0.0%	22.92	0.0%	0.0%
Averages	16.9	-0.9%	16.4	-0.9%	14.3	-1.0%	18.4	-0.8%	22.8	-0.6%	

% of change in speed = (trip speed during an incident category - trip speed during normal operations)/ trip speed during normal operations

Conclusions

- Subway incidents have more immediate and long lasting negative impacts on **streetcar service** than for buses
- Reflecting the TTC practice of **directing users to streetcar service** when a service interruption occurs along the south section of the subway system (U-shaped section)
- Also, reflecting the used protocols of **deploying less buses for shuttle service** along the south section of the subway system where parallel streetcar service is available

Second project:

Shuttle service optimizing: Determining the optimal number of buses and routes to pull from to minimize the transit users' excess waiting time

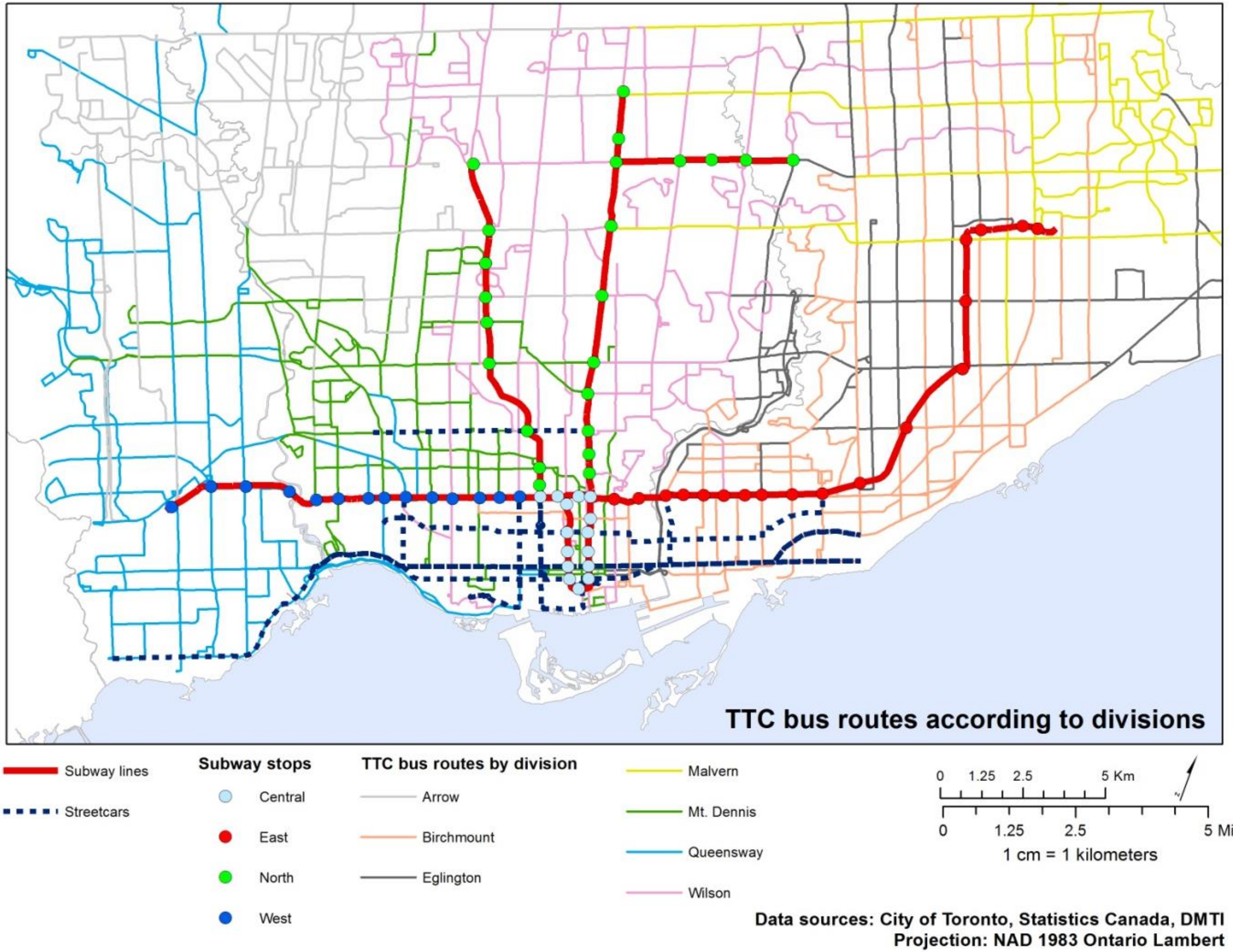
Padmanie Maulkhan
University of Toronto - Industrial Engineering undergraduate student

TTC's protocols

- TTC retracts buses from scheduled routes with high service frequencies according to certain criteria

DAILY BUSES ALLOCATION Y.U.S / B.D								
			30 MINS +	30 MINS +	30 MINS +	1 - 30 MINS	1 - 30 MINS	1 - 30 MINS
	TIME FRAME	Total buses	1 - 4 STATIONS	5 - 9 STATIONS	10 + STATIONS	1 - 4 STATIONS	5 - 9 STATIONS	10 + STATIONS
			3.33%	6.66%	10%			
A.M	6 - 9 AM	1325	44	88	133	22	44	66
MID	9 AM – 3 PM	881	29	59	88	15	29	44
PM	3 – 7 PM	1426	47	95	143	24	47	71
E.E.	7- 10 PM	819	27	55	82	14	27	41
LE.	10PM - 1AM	506	17	34	51	8	17	25

- Buses dispatched equally from each of the seven divisions managed by TTC


TTC bus routes according to divisions
Subway lines
Streetcars
Subway stops
Central
East
North
West
TTC bus routes by division
Arrow
Birchmount
Eglington
Malvern
Mt. Dennis
Queensway
Wilson
0 1.25 2.5 5 Km
0 1.25 2.5 5 Mi
1 cm = 1 kilometers
Data sources: City of Toronto, Statistics Canada, DMTI
Projection: NAD 1983 Ontario Lambert

Current problem

However, TTC does not have a clear methodology for selecting buses for shuttle service, resulting in:

- Excessive deadhead time
  - Sometimes longer than expected delay
    - In 2015, the average shuttle bus delay is 86 minutes (from bus pull-out time until bus return), while the average subway incident delay is 34 minutes.
- Passengers waiting longer than necessary
- Dispatched buses < requested buses

Research objective

- Enhance transit system resiliency:
  - by minimizing the impacts of shuttle service employment on bus system, helping the bus system to return to normal operations as quickly as possible

Research approach

- A shuttle service optimization model is currently under development to:
  - determine optimal routes from which to pull buses from to provide a shuttle service
  - find the optimal number of buses to pull

Research approach - Objective Function

- With a main goal of minimizing the excess waiting time for all TTC's customers that are:
  - directly affected (on the subway line), and
  - indirectly affected (on routes where buses are pulled from)

Research approach -Constraints

- Total number of pulled buses should not exceed recommended maximum number of buses by TTC
- Buses must arrive to site before expected disruption time
- Removal of a bus from *route i* will not send it over crush capacity
- Removal of a bus from *route i* will not increase headway to more than 30 mins (TTC Policy headway)

Still in progress…

- Preparation of data inputs is taking place (Candidate bus routes: frequency, demand, loading factor, distance from route terminal to incident location, etc.)
- Optimization Model formatting is in progress…

Thank you!

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