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

TRANSIT DATA 2017: RESEARCH AND APPLICATIONS ON THE USE OF PASSIVE DATA FROM PUBLIC TRANSPORT – MAY 22-24, 2017. SANTIAGO, CHILE

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Introduction

- Research gap and study objective
- Study context
- Methodology
- Analysis
- Conclusion
- Future Work

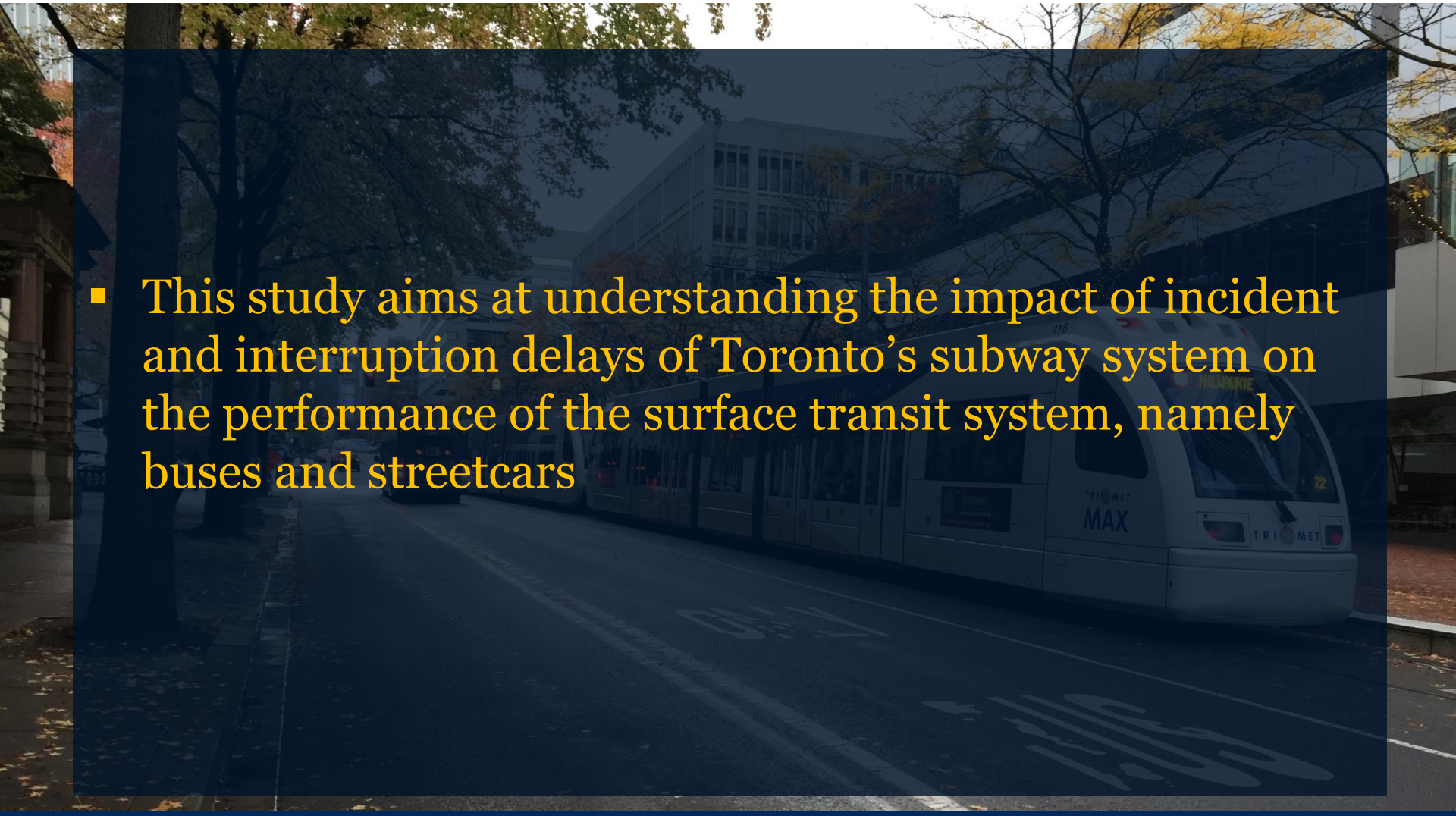
Research Gap

- Exploring the quality of transit service is traditionally done on a mode-by-mode basis
  - Focusing on understanding the impact of different transit improvement strategies (TSP, reserved bus lanes., etc.) or the impacts of events or general factors (weather conditions, distance, number of stops, etc.)

Research Gap

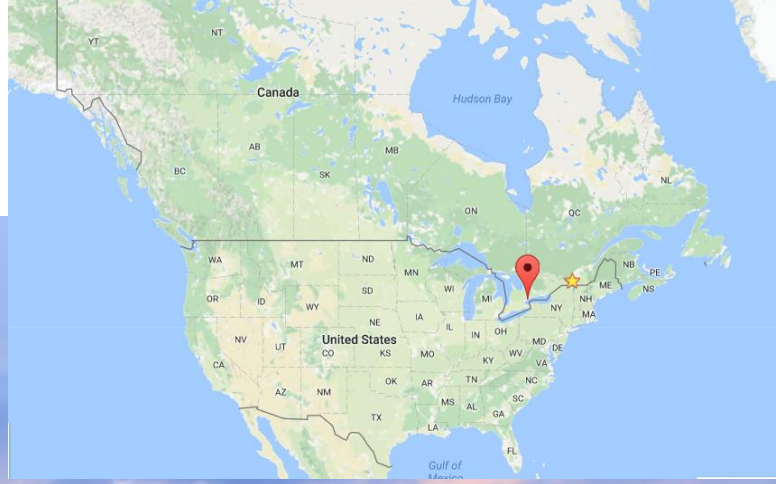
- It is rare to find studies that investigated the impacts of poor performance or breakdown of one transit mode on other functioning modes in multimodal integrated transit systems
  - This is because, normally, researchers remove periods of major service interruption from their analysis

Research Objective



- This study aims at understanding the impact of incident and interruption delays of Toronto's subway system on the performance of the surface transit system, namely buses and streetcars

Toronto, Canada

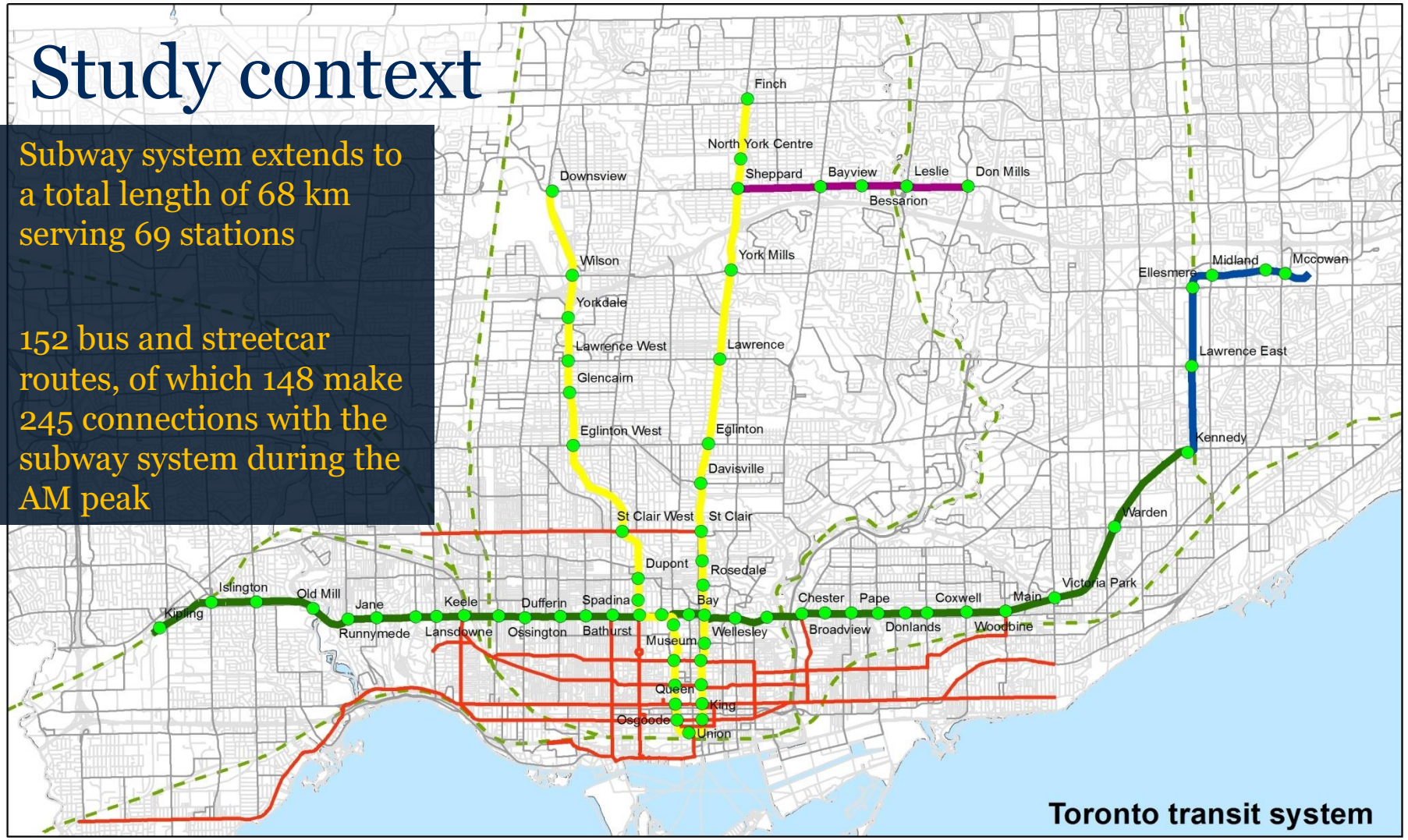


- Most populous city in Canada: 2.8 million inhabitants in 2015
- Fourth most populous city in North America
- One of North America's fastest-growing cities: to reach of 3.7 million in 2041

http://wallpapersdsc.net/cities/toronto-30412.html

Study context

- Subway system extends to a total length of 68 km serving 69 stations
- 152 bus and streetcar routes, of which 148 make 245 connections with the subway system during the AM peak



Subway stops

Street network

TTC bus routes

Go_trains

Streetcar routes

Subway lines

Bloor-Danforth line (Green line)

Scarborough line (Blue line)

Sheppard line (Magenta line)

Yonge-University-Spadina line (Yellow line)

0 0.75 1.5 3 Km

0 0.75 1.5 3 Mi

1 cm = 1 kilometers

Data sources: City of Toronto, Statistics Canada, DMTI
Projection: NAD 1983 Ontario Lambert

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

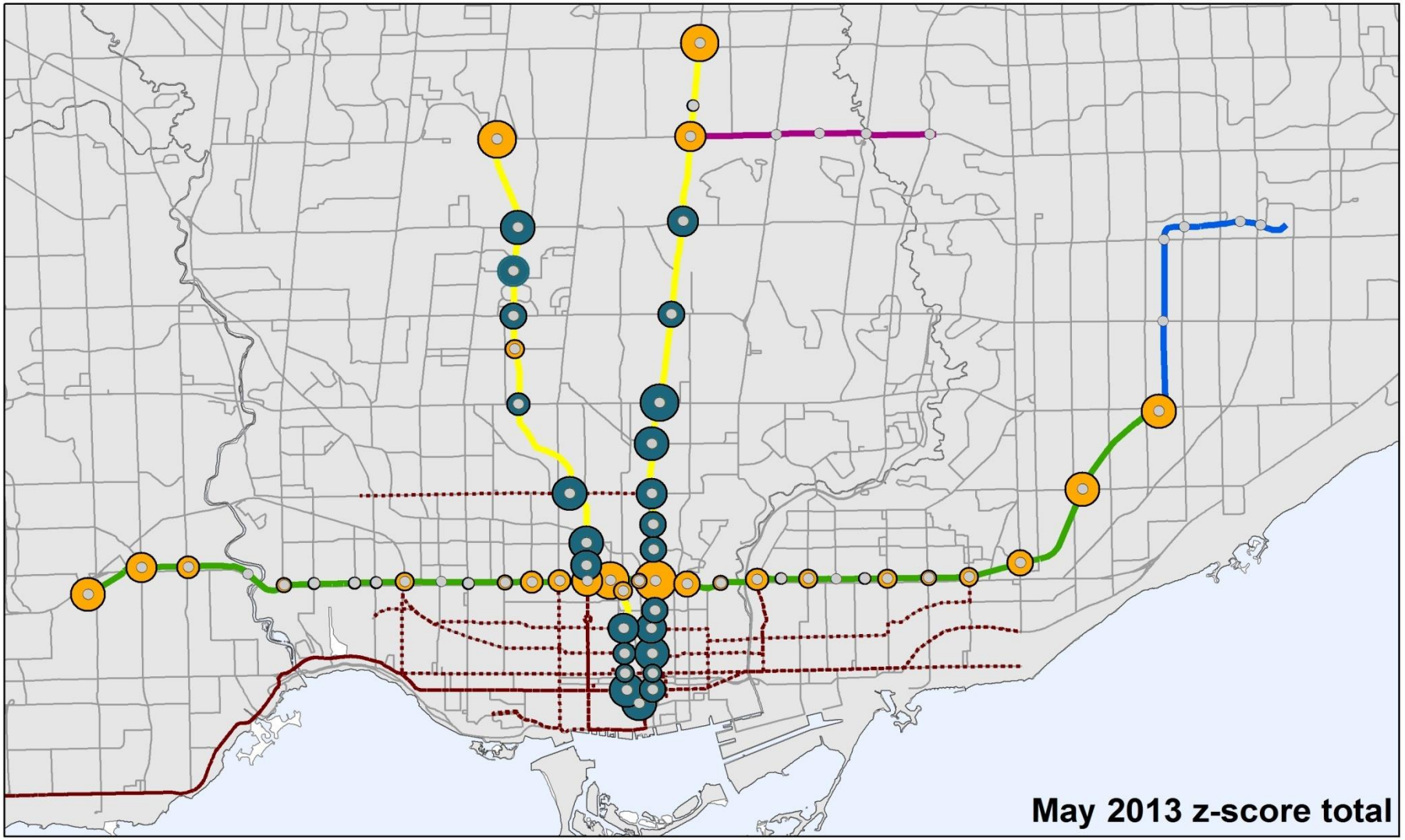
- Subway system interruption data:
  - A total of 12,600 subway incidents at the station level of analysis in 2013
  - For each record, the TTC's dataset includes:
    - date, time
    - subway station, direction of travel
    - amount of delay (in minutes)
    - train number and type
    - a brief description 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

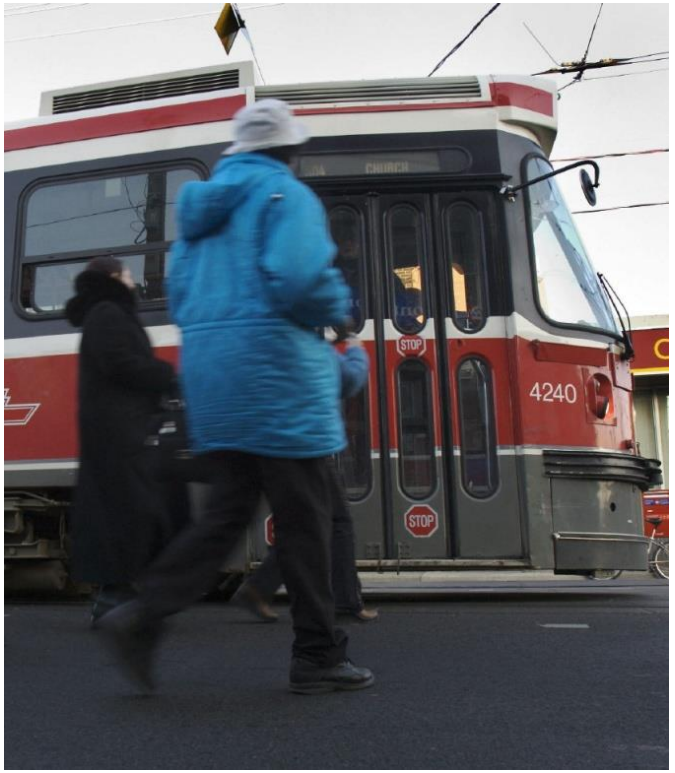
Methodology – data preparation

- 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 is computed as the average speed of all GPS points of a given trip within a given segment

Methodology – data preparation

- In the analysis, we kept segment that start within 3 kilometres of the Line 1
- Python script was used to clean the data and identify trips in ArcGIS
- After this process, about **1,170,000** and **780,000** 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

Other variables have been tested but they were eliminated from the study due to their insignificance and/or correlation to other used variables such as:

- *Subway stations spacing*
- *Number of nearby bus/streetcar lines (to account for route competition)*
- *Express routes*
- *Headway and Headway^2*

	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 -Streetcar descriptive statistics

	Trips during subway normal operations		Trips after a subway incident	
	Mean	Std. Dev.	Mean	Std. Dev.
Segment average speed (KM/H)	12.71	5.53	9.65	3.92
Direction	0.497	0.500	0.540	0.498
Time-point sequence	5.765	3.310	6.613	1.540
Number of scheduled stops	4.744	9.604	4.505	2.867
Adjacent segment (within 200 meters)	0.208	0.406	1.000	0.000
Segment with a layover	0.191	0.483	0.131	0.388
Segment distance (KM)	0.992	0.634	0.879	0.413
Streetcar bus	0.099	0.299	0.055	0.229
Streetcar ALRV	0.106	0.308	0.085	0.279
Streetcar Flexity	0.000	0.003	0.000	0.000
Average headway	3.847	1.626	3.891	2.019
Distance to Union Station (KM)	2.196	1.490	1.950	1.847
Morning peak	0.182	0.386	0.226	0.419
Afternoon peak	0.237	0.425	0.248	0.432
Early evening	0.133	0.340	0.148	0.355
Late evening	0.126	0.331	0.056	0.231
Trips starting within 5 minutes of an incident	0.000	0.000	0.144	0.352
Trips starting within 5-10 minutes of an incident	0.000	0.000	0.150	0.357
Trips starting within 10-20 minutes of an incident	0.000	0.000	0.303	0.460
Trips starting within 20-30 minutes of an incident	0.000	0.000	0.269	0.443
Trips starting within 30-60 minutes of an incident	0.000	0.000	0.123	0.329
Trips starting within 60+ minutes of an incident	0.000	0.000	0.011	0.105
Time-point after an incident	0.030	0.171	0.000	0.000
Incident in same direction of travel	0.001	0.034	0.132	0.339
Trips starting after a cleared incident	0.000	0.000	0.866	0.341
Number of records	777,901		2,804	

Analysis - bus descriptive statistics

	Trips during subway normal operations		Trips after a subway incident	
	Mean	Std. Deviation	Mean	Std. Deviation
Segment average speed (KM/H)	18.22	9.35	14.23	9.56
Direction	0.500	0.500	0.511	0.500
Time-point sequence	6.297	4.320	6.600	5.257
Number of scheduled stops	3.599	2.481	3.069	2.513
Adjacent segment (within 200 meters)	0.298	0.457	1.000	0.000
Segment with a layover	0.173	0.378	0.287	0.453
Segment distance (KM)	1.202	0.801	1.265	0.921
Average headway	7.078	5.870	7.186	6.119
Average headway^2	84.55	157.59	89.08	163.55
Distance to Union Station (KM)	7.886	3.324	8.215	2.821
Morning peak	0.201	0.401	0.286	0.452
Afternoon peak	0.240	0.427	0.370	0.483
Early evening	0.130	0.337	0.076	0.265
Late evening	0.119	0.324	0.063	0.244
Trips starting within 5 minutes of an incident	0.000	0.000	0.148	0.355
Trips starting within 5-10 minutes of an incident	0.000	0.000	0.159	0.366
Trips starting within 10-20 minutes of an incident	0.000	0.000	0.298	0.457
Trips starting within 20-30 minutes of an incident	0.000	0.000	0.292	0.454
Trips starting within 30-60 minutes of an incident	0.000	0.000	0.103	0.303
Trips starting within 60+ minutes of an incident	0.000	0.000	0.001	0.028
Time-point after an incident	0.033	0.179	0.000	0.000
Incident in same direction of travel	0.004	0.063	0.163	0.369
Trips starting after a cleared incident	0.000	0.000	0.887	0.316
Number of records	1,162,241		10,300	

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_ridership1000	-.033	.003	-.036	-13.244	.000	-.038	-.028
	T_ridership1000_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**

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

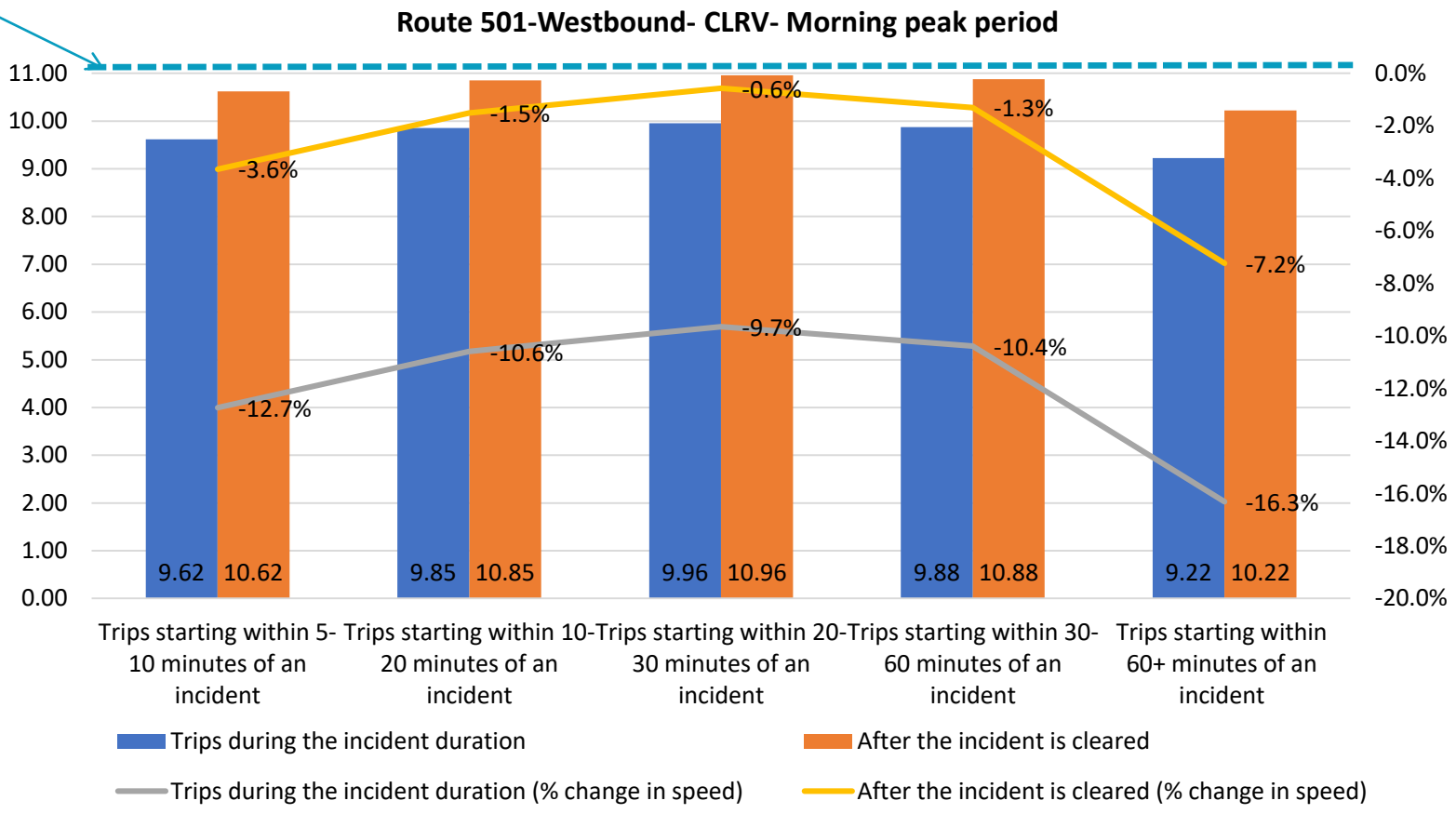
- Streetcar line with median speed: Route 501-Westbound- CLRV
  - Average speed during different type periods

	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

Sensitivity analysis- Streetcar

Trips starting during normal operations = 11.02 km/h



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 service interruptions have a statistically significant negative impact on bus and streetcar service operations.
- Nevertheless, the intensity of delay varies according to the mode, and the trip starting time category relative to the incident's starting time

Conclusions

- Subway incidents have more immediate and long lasting negative impacts on streetcar service than for buses

- This may be reflecting the TTC's used protocols of deploying buses (or shuttle service) to deal with subway transit service disruptions, when unexpected interruptions occur.
  - The used protocols deploys a very few shuttle service along the south section of the subway system (U-shaped section) where parallel streetcar service is available

Future steps

- Testing and developing of models to understand the impacts of subway incidents on bus service reliability

- Understanding the impacts of different incidents types while controlling for the actual change

Thank you!

Transit data 2017: Research and applications on the use of passive data from public transport - 22-23-24 May, 2017. Santiago, Chile

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