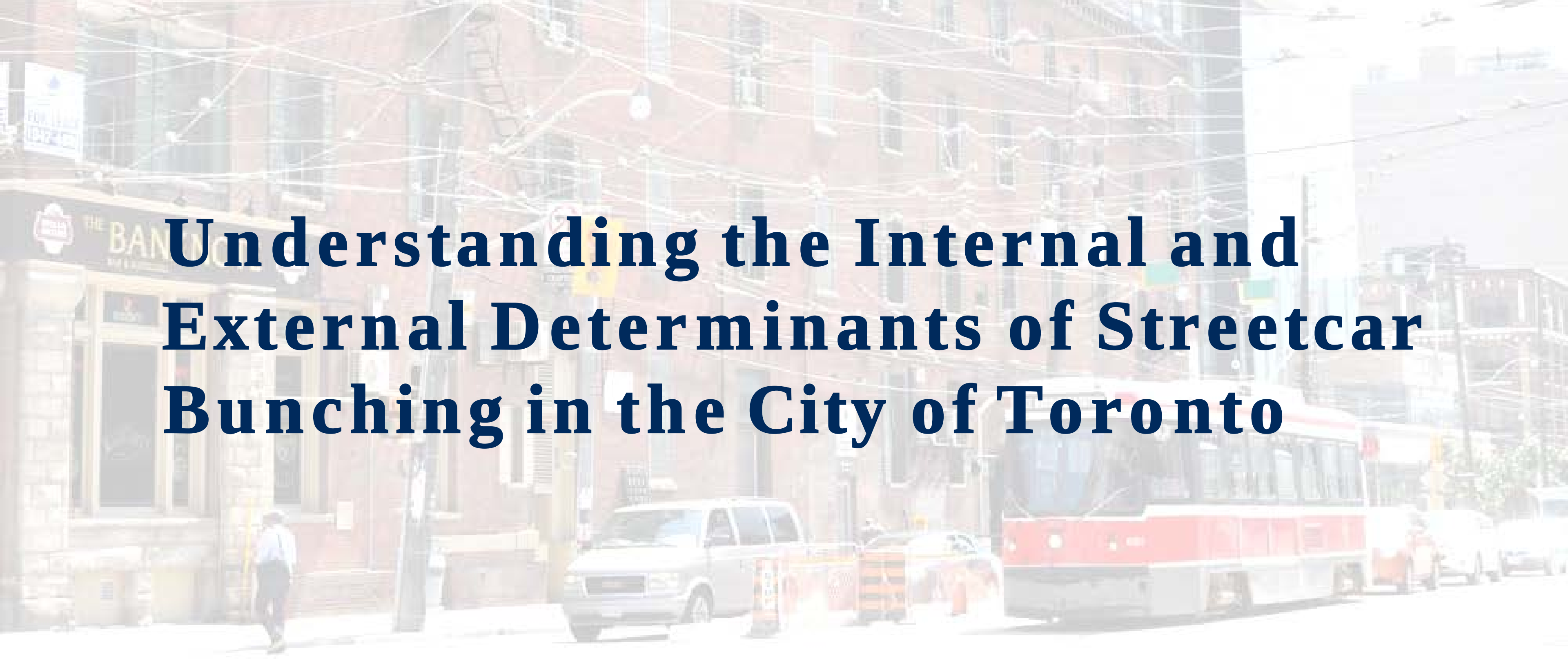

Understanding the Internal and External Determinants of Streetcar Bunching in the City of Toronto

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Transit Vehicle Bunching

- has been widely acknowledged as a main source of users' dissatisfaction
- causes longer and more inconsistent waiting times for users
- leads to inefficient use of resources by transit agencies

Why Focus on Streetcar Bunching?

- Many cities are in planning stage or construction of new streetcar/light rail systems
  - Montreal, New York City & Minneapolis
- Streetcar bunching ≠ Bus bunching
  - Streetcars cannot overtake each other. This makes bunching incidents more critical to the reliability and service quality of streetcar systems

Research Gaps

- Abundant literature on bus bunching [1-5]
  - Diab, E., Bertini, R., & El-Geneidy, A. (2016). Bus transit service reliability: Understanding the impacts of overlapping bus service on headway delays and determinants of bus bunching
  - Zhang, M., & Li, W. (2013). Factors affecting headway regularity on bus routes
- Previous models were developed mostly to investigate the odds of bunching occurrence
- However, it is rare to find models that examined the time to bunch occurrence among a pair of streetcars
- Only few studies on the impact of external factors [8]
- Even fewer studies on streetcar routes since there are limited number of cities which utilize streetcars [6-7]

Objective

- Understanding the internal and external factors of streetcar bunching in the city of Toronto
  - Specifically, focusing on the factors that influence the time to the first bunching incident for pairs of successive streetcars

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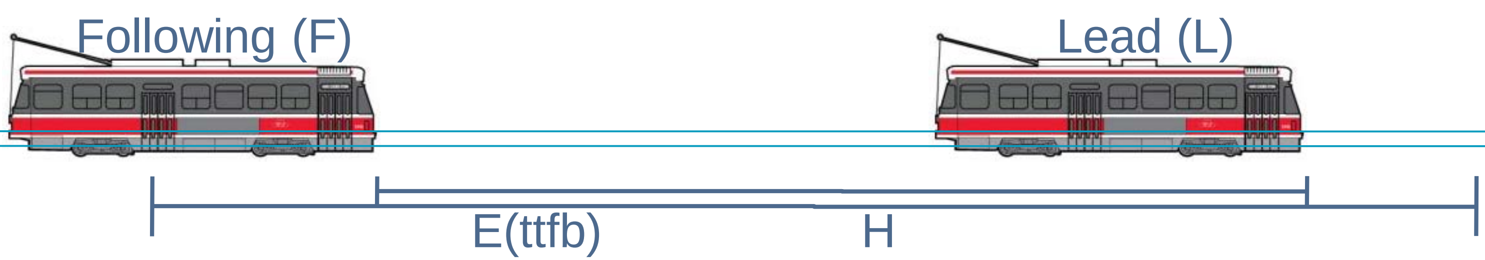


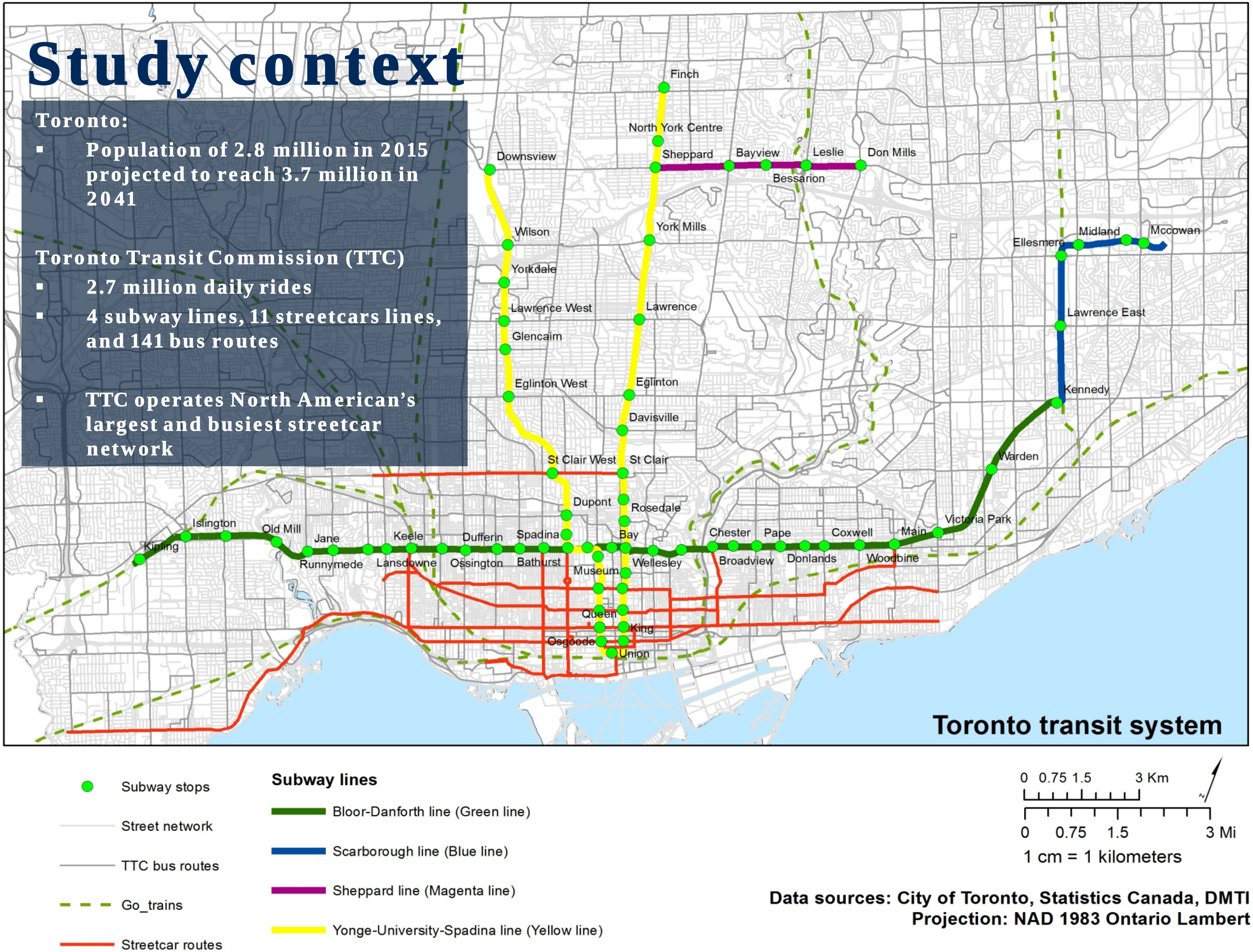
Study context

Toronto:

- Population of 2.8 million in 2015 projected to reach 3.7 million in 2041

Toronto Transit Commission (TTC)

- 2.7 million daily rides
- 4 subway lines, 11 streetcars lines, and 141 bus routes
- TTC operates North American's largest and busiest streetcar network



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

TTC Streetcar System

- 11 streetcar routes covering 338 km, serving over 60 million passengers a year
- 622 streetcar stops all inside Toronto

Service Summary

	All-Day, Every Day[1]	10-minute Service[2]	Monday to Friday: Morning Peak	Monday to Friday: Midday	Monday to Friday: Afternoon Peak	Monday to Friday: Early Evening	Monday to Friday: Late Evening	Saturday: Morning	Saturday: Afternoon	Saturday: Early Evening	Saturday: Late Evening	Sunday/holiday: Morning	Sunday/holiday: Afternoon	Sunday/holiday: Early Evening	Sunday/holiday: Late Evening
Streetcar Routes															
501 Queen	•	•	5	6	5	6	9	7	5	7	10	8	6	9	10
502 Downtowner			12	10	12										
503 Kingston Rd			12		12										
504 King	•	•	2	4	2	4	6	6	5	7	8	5	6	10	10
505 Dundas	•	•	6	6	6	8	10	7	5	10	10	8	6	10	10
506 Carlton	•	•	4	6	6	8	9	8	6	9	10	10	8	10	10
508 Lake Shore			Temporarily Suspended												
509 Harbourfront	•	•	5	6	4	5	8	6	4	9	9	6	4	9	9
510 Spadina	•	•	4	3	3	3	7	4	4	4	7	4	4	5	7
511 Bathurst	•	•	4	5	4	6	6	5	4	6	6	6	5	8	8
512 St Clair	•	•	3	5	3	6	6	5	4	6	8	6	6	6	9

Notes:

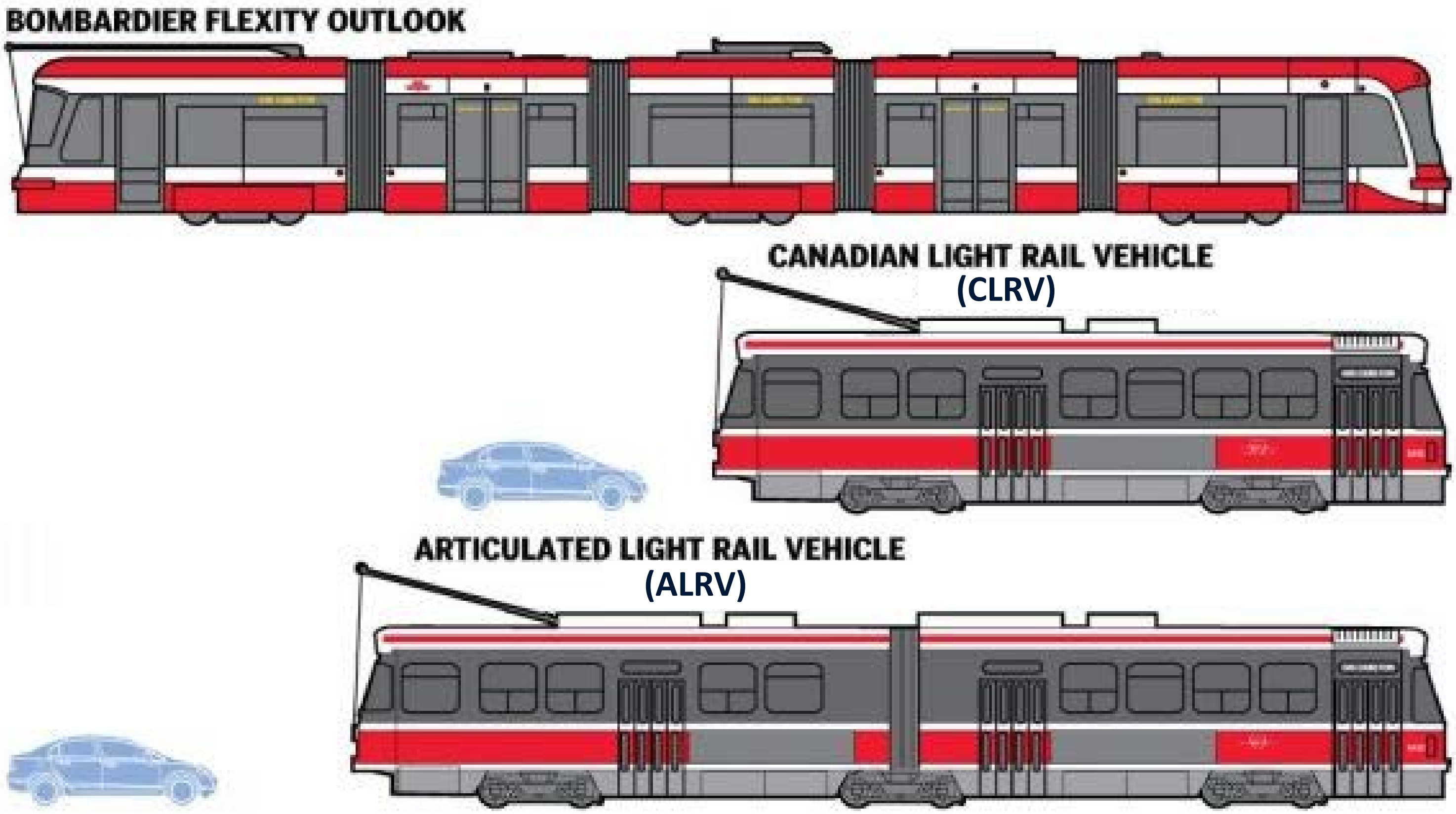
[1] All-Day, Every Day: route operates at all times, seven days a week over all or portions of the route.

[2] 10-Minute Service: route operates every ten minutes or better at all times the route is operated, over all or portions of the route.

Dark Gray highlight indicates periods of frequent service of 10 minutes or better over all or portions of the route.

Streetcar Fleet

- TTC runs approximately 241 streetcar vehicles
  - 165 CLRV, 43 ALRV, 33 Flexity Outlook



70 seated
130 max

46 seated
74 max

61 seated
108 max

TTC Daily Performance Report

Report for Wednesday, May 17, 2017

	Service:	Our objective:	Our target:	Actual:	How we did:
1	Yonge-University	Deliver a punctual service[1]	96%	98%	✓
2	Bloor-Danforth	Deliver a punctual service[1]	97%	96%	✗
4	Sheppard	Deliver a punctual service[1]	98%	99%	✓
3	Scarborough	Deliver a punctual service[1]	96%	84%	✗
	Bus	On time departures from end terminals [3]	90%	72%	✗
	Streetcar	On time departures from end terminals [3]	90%	58%	✗
	Elevator	Provide easy access[2]	98%	100%	✓
	Escalator	Provide easy access[2]	97%	97%	✓

Legend

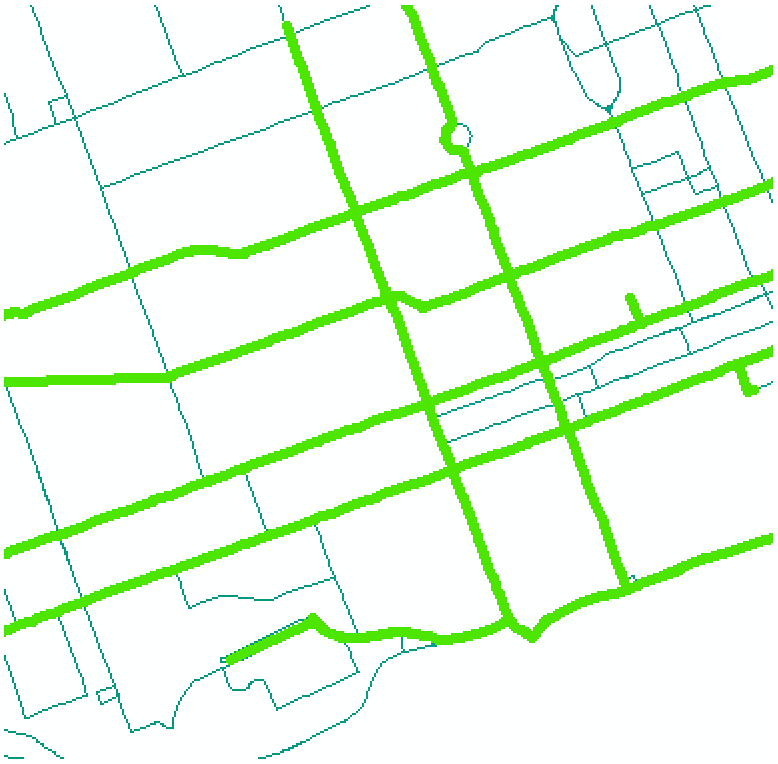
[1] % of Service (up to Headway + 3 minutes)

[2] % of devices available

[3] % of service (end terminal departures between +1 minute early and -5 minutes late)

Methodology - Data

- More than 6 million observations were collected from the TTC's AVL system for 10 streetcar routes for the days between January 24 and 30, 2016
  - The selected week had a mild and clear weather, with minimal streetcar track construction, closures or service diversions
- TTC's AVL system records vehicle location at 20-second intervals



Methodology - Variables

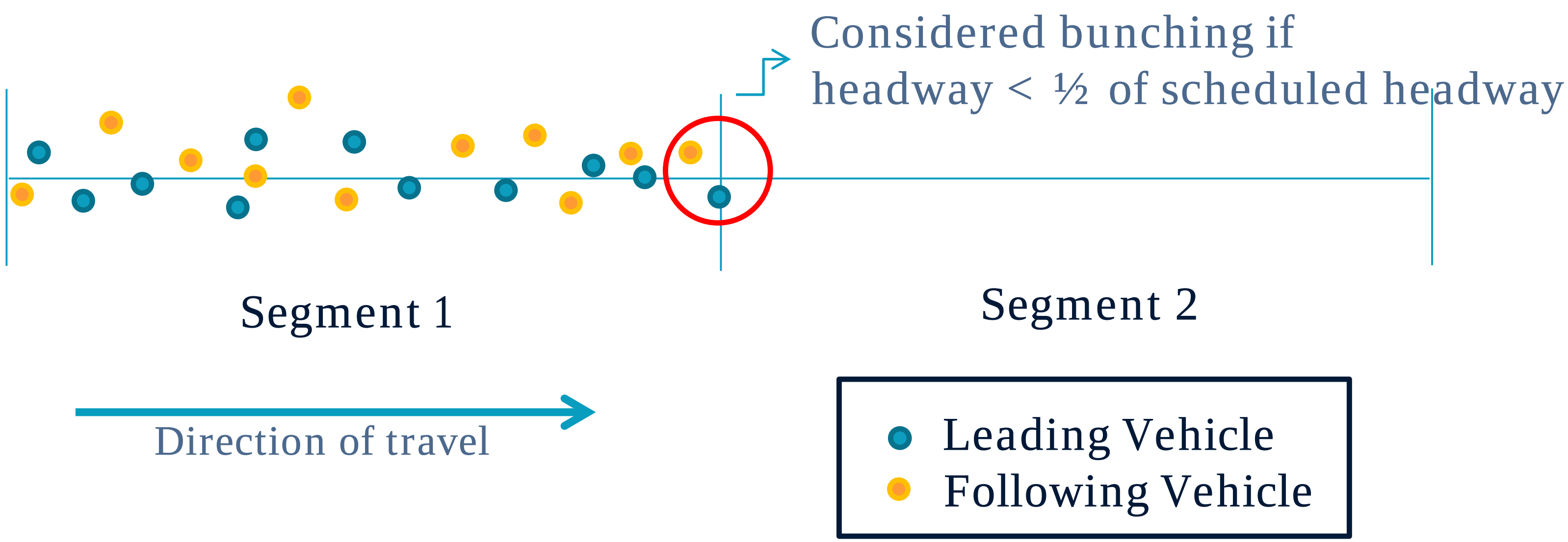
- Dependent variable: Time to first bunching incident (in Following Vehicle)
- Three types of independent variables*:

Control	Internal	External
Time Period	Right of Way	Number of Left Turns
Route Length	Number of TSP	Number of Right Turns
Average Stop Distance	Nearside/Farside Stop	Number of Through Intersections
Route #	Following & Lead Headway Ratio	Number of Signalized Intersections
Trip Direction	Lead & Lead+1 Headway Ratio	Number of Pedestrian Crossings
Weekday/Weekend	Scheduled Headway	Average Vehicle Volume
	Vehicle Type	Average Pedestrian Volume

** All variables were tested but some were removed due to insignificance or collinearity*

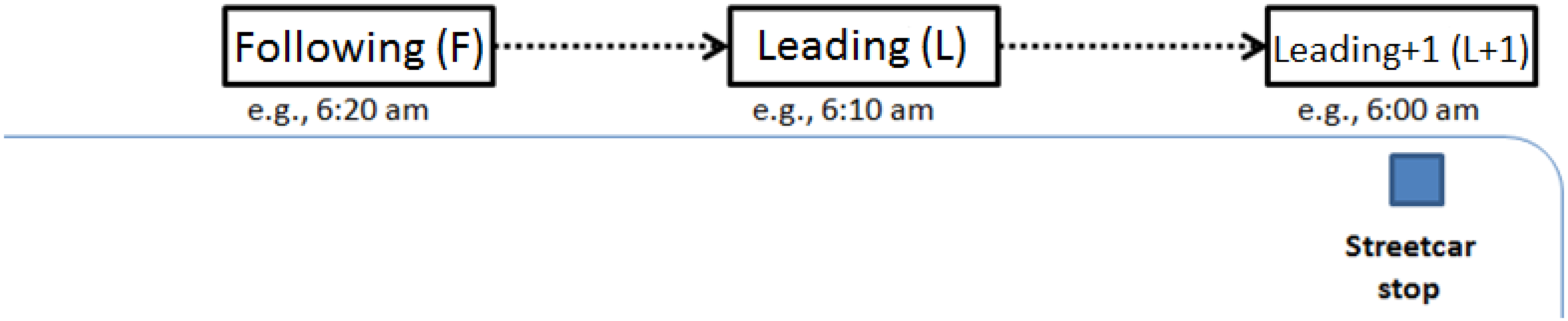
Methodology – Data Processing

- Python script was used to clean the data and identify trips
- Bunching incidents were isolated at segment level when actual headway was less than half of scheduled headway



Methodology – Data Processing

- Only bunching incidents are used in this study
- For each observation, data from the previous scheduled trip (L) and from the one prior (L+1) are used to better understand the streetcar bunching phenomenon



Methodology

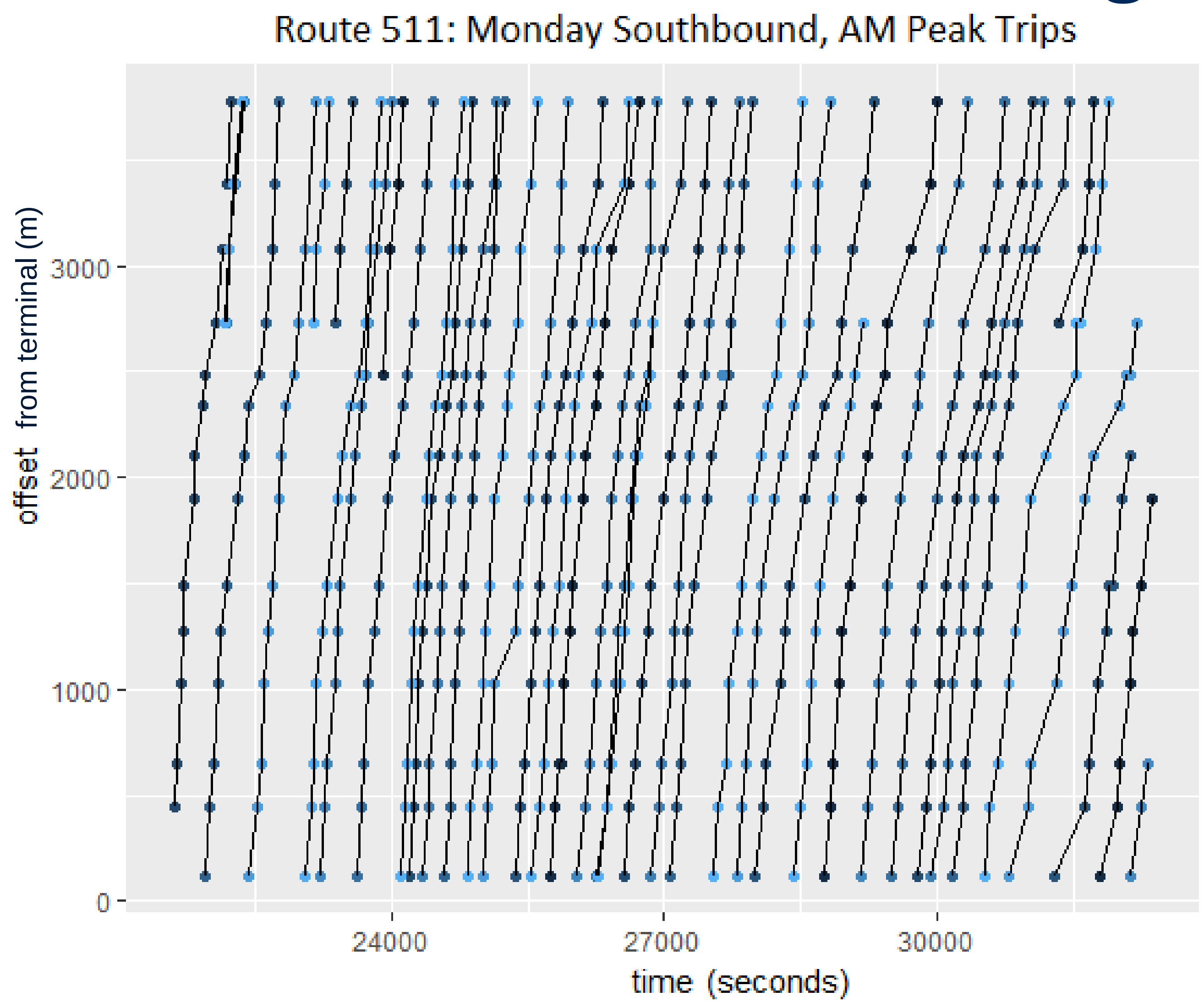
- Attempted Statistical Models
  - Linear Regression
    - Resulted in very low R^2 value
  - Ordinal Logit Model
    - Also resulted in very low ρ^2 value
  - Survival Analysis – Accelerated Failure Time (AFT) Model

Results - Statistics for All Trips

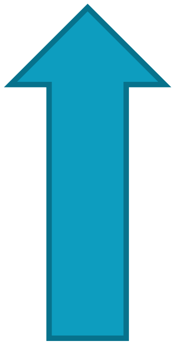
- Number of trips and % of bunched trips:

	Direction		Day		Time Period						
Route	EB/SB	WB/NB	Weekend	Weekday	AM Peak	Midday	PM Peak	Evening	Grand Total	Bunch Cases	% bunch
501	3894	3880	1006	6768	1282	2242	1602	2648	7774	2141	27.5%
504	2918	2662	543	5037	1156	1367	1284	1773	5580	2171	38.9%
505	1313	1279	399	2193	423	791	505	873	2592	508	19.6%
506	1154	1080	260	1974	482	750	470	532	2234	839	37.6%
509	1212	1210	409	2013	331	732	610	749	2422	877	36.2%
510	1711	1715	554	2872	430	1213	779	1004	3426	741	21.6%
511	1242	1197	354	2085	432	724	483	800	2439	415	17.0%
512	2034	2004	468	3570	742	1183	864	1249	4038	65	1.6%
Grand Total	15478	15027	3993	26512	5278	9002	6597	9628	30505	7757	25.4%
	50.7%	49.3%	13.1%	86.9%	17.3%	29.5%	21.6%	31.6%			

Results – Time Distance Diagram



Direction of travel



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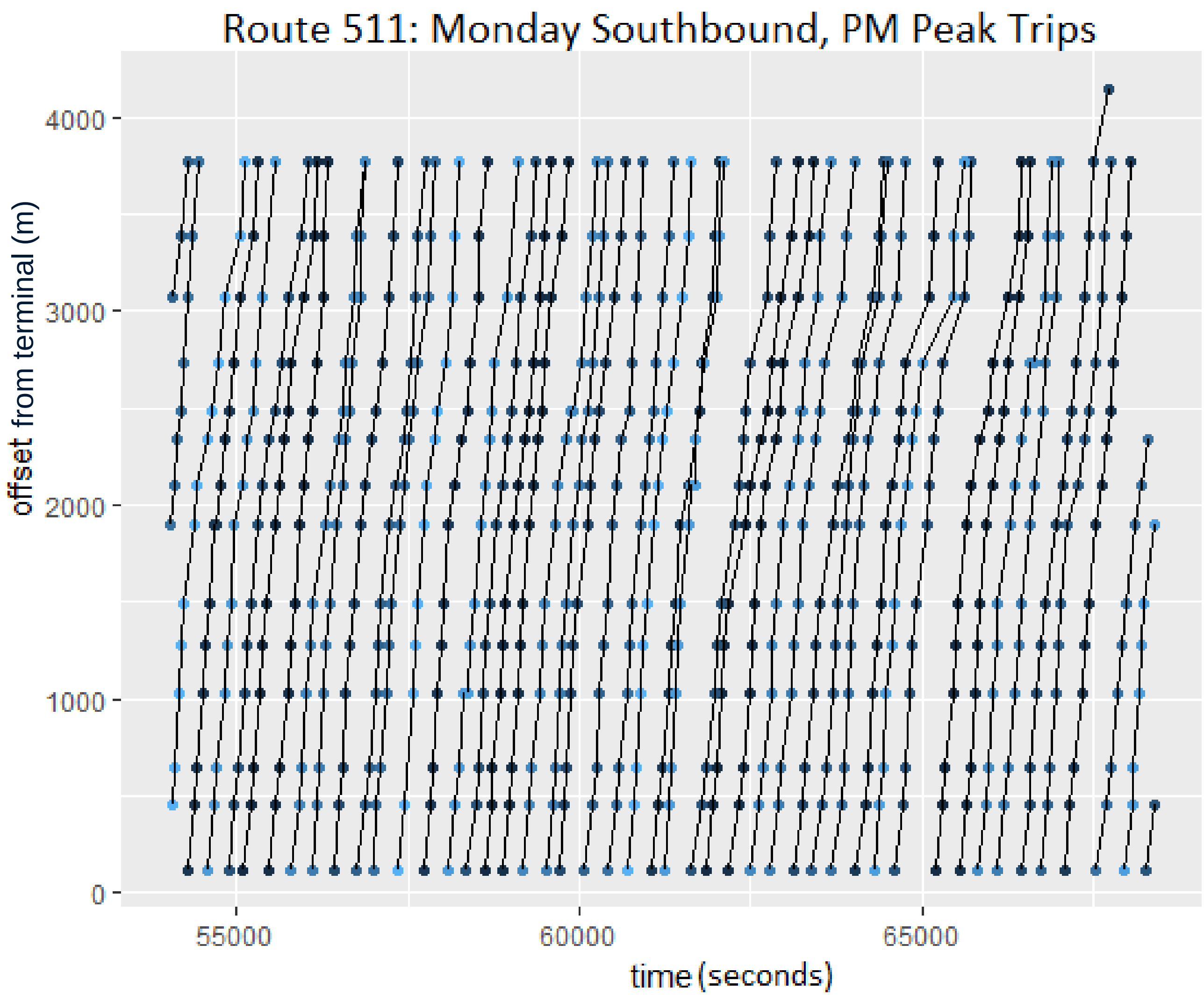
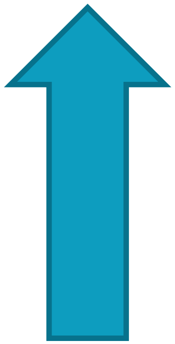


Direction of travel



Variables used in AFT Model

Variable Name	Variable Type	Description
wkday	Dummy	Weekday(1) or weekend(0)
Ftripdir	Dummy	EB/SB (0) or WB/NB (1)
VehCombination	Categorical	0=F & L are same vehicle type, 1= Fveh capacity>Lveh capacity 2= Fveh capacity < Lveh capacity
TimePeriod	Categorical	1=AM Peak, 2=Midday, 3=PM Peak 4=Evening
Route	Categorical	Streetcar route number
FLHeadRatio	Continuous	Ratio of F, L veh headway and scheduled headway
LL1HeadRatio	Continuous	Ratio of L, L+1 veh headway and scheduled headway
CumThru	Continuous	Cumulative number of through intersections
CumTSP	Continuous	Cumulative number of TSP
CumPedCross	Continuous	Cumulative number of pedestrian crossings
CumSigApp	Continuous	Cumulative number of signalized intersections
StopComb	Dummy	Same stop placement(0), Combination of near and far side stops (1)

Conclusions

- Headway deviation from schedule should be minimized at terminal, particularly during AM peaks on weekdays
- The implementation of TSP at multiple intersections seem to delay the onset of bunching
- Different combinations of vehicle types and of stop placements seem to accelerate the time to bunching
- The more the signalized intersections and pedestrian crossings there are, the quicker it will take streetcars to bunch
- Heavy traffic volume delays the onset of bunching

Ongoing Work

- Estimating a logit model to examine odds of bunching occurrence in a headway
- Prediction of bunching odds and time to bunching in real-time applications for streetcars

Thank you!

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