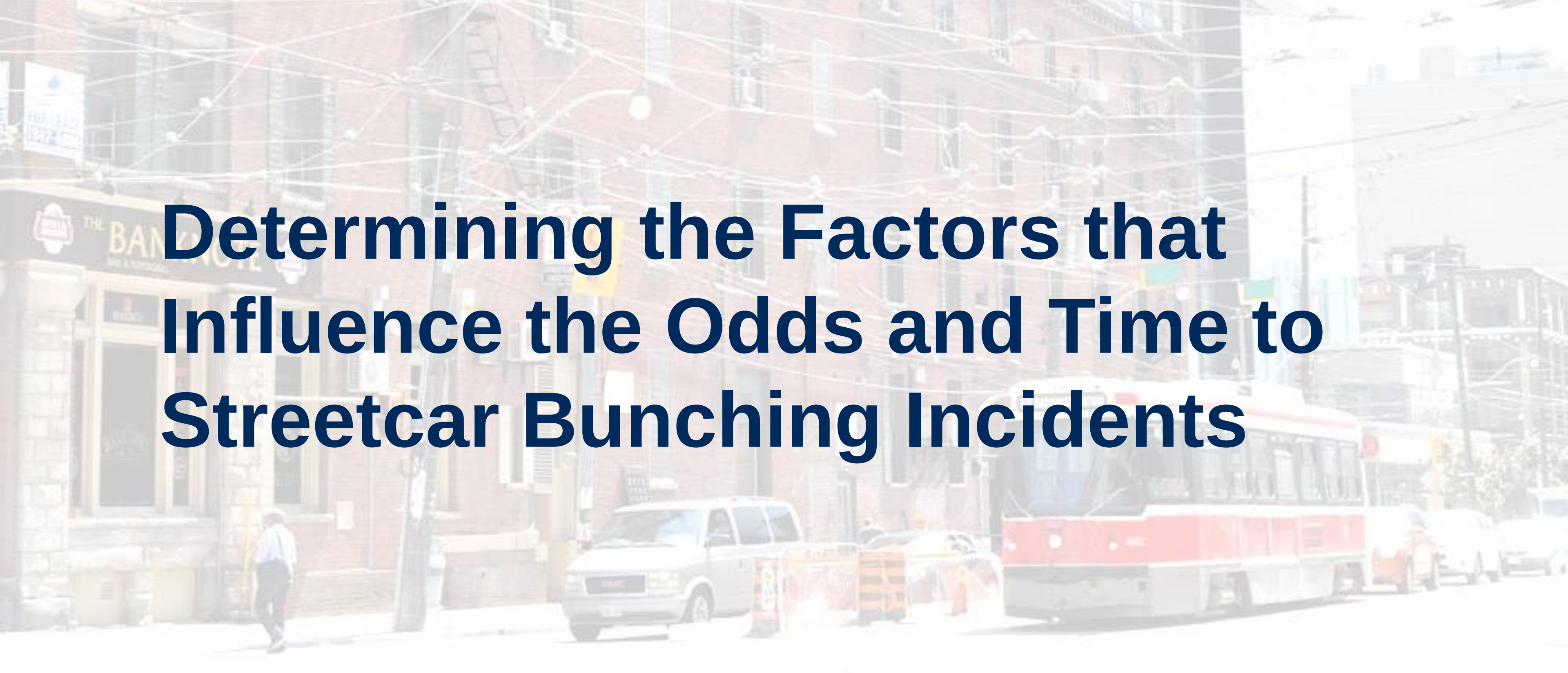


Determining the Factors that Influence the Odds and Time to Streetcar Bunching Incidents

Paula Nguyen (paula.nguyen@mail.utoronto.ca)
Dr. Ehab Diab (ehab.diab@utoronto.ca)
Professor Amer Shalaby (amer@ecf.utoronto.ca)

UNIVERSITY OF TORONTO
FACULTY OF APPLIED SCIENCE & ENGINEERING
Transportation Research Institute

Outline

- Introduction
- Study Objectives
- Data
- Methodology
- Models
- Conclusions

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

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)

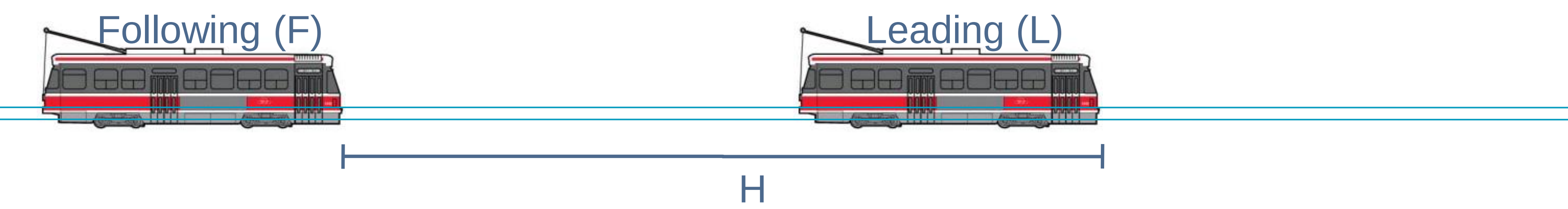
Motivation

1. Streetcar bunching is a well-known problem in Toronto
2. Streetcar bunching ≠ Bus bunching
   – Streetcars cannot overtake each other. This makes bunching incidents more critical to the reliability and service quality of streetcar systems
3. There is a lack of studies in the literature on streetcar performance and, more specifically, streetcar bunching.
4. Streetcar and light rail systems are slowly becoming more popular and more widely implemented around the world.

Research Objectives

- To understand the factors that impact the odds of streetcar bunching
- To determine the internal and external factors that impact the time to the initial bunching incident from terminal

Terminal



TTC Streetcar System

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

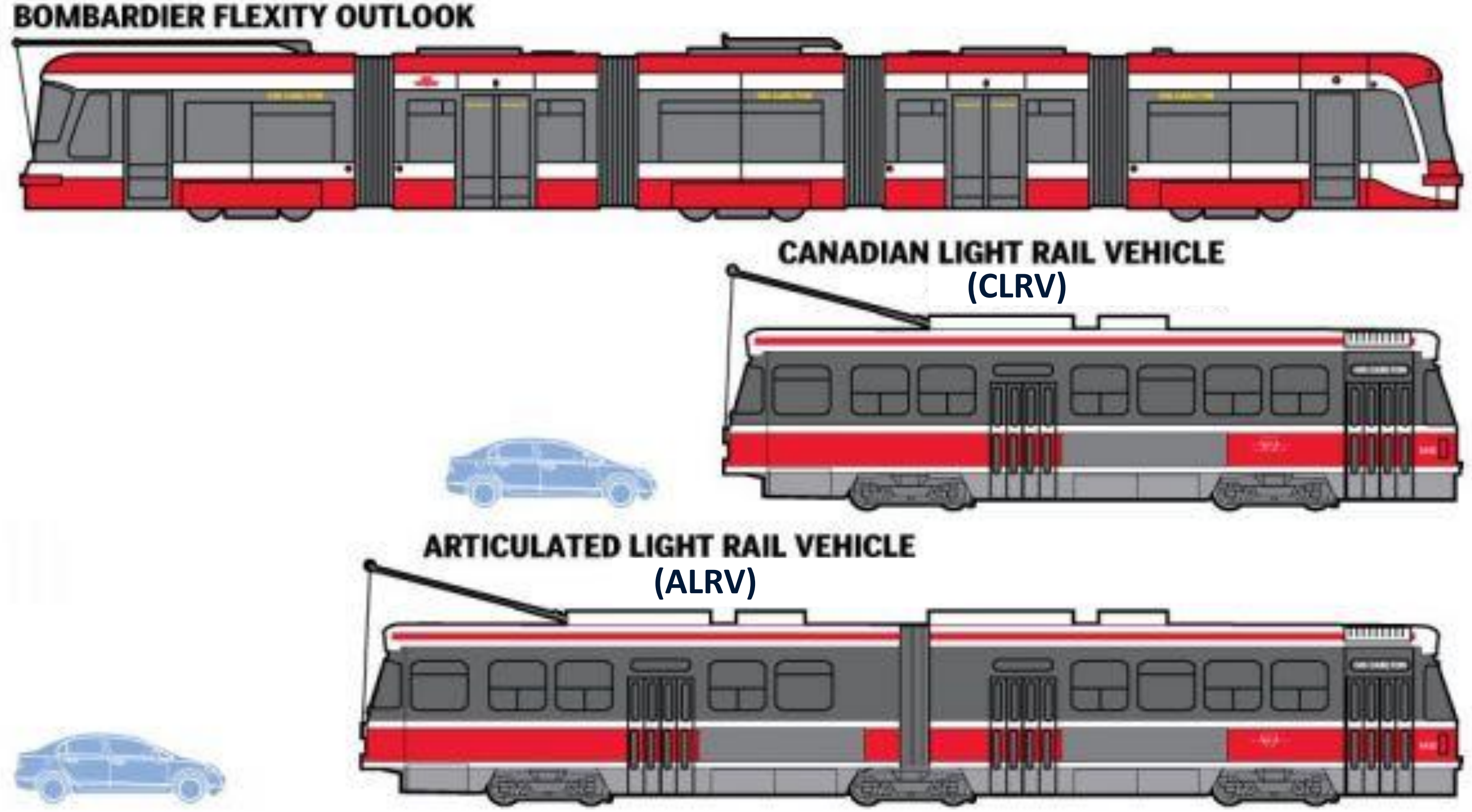
UNIVERSITY OF TORONTO
FACULTY OF APPLIED SCIENCE & ENGINEERING
Transportation Research Institute

Service Summary

			Monday to Friday					Saturday				Sunday/holiday			
	All-Day, Every Day[1]	10-minute Service[2]	Morning Peak	Midday	Afternoon Peak	Early Evening	Late Evening	Morning	Afternoon	Early Evening	Late Evening	Morning	Afternoon	Early Evening	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

Streetcar Fleet

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

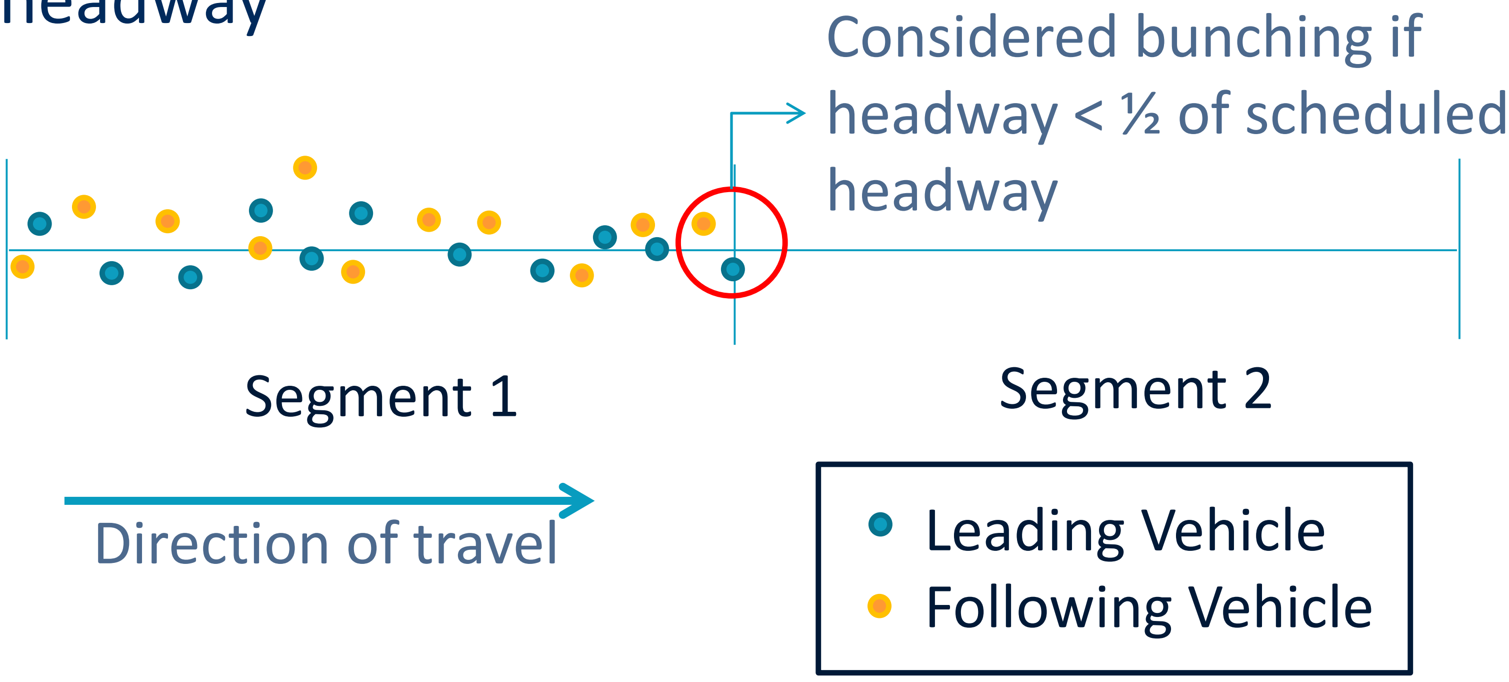


Data Processing

- 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
- Only 8 streetcar routes were included in the study

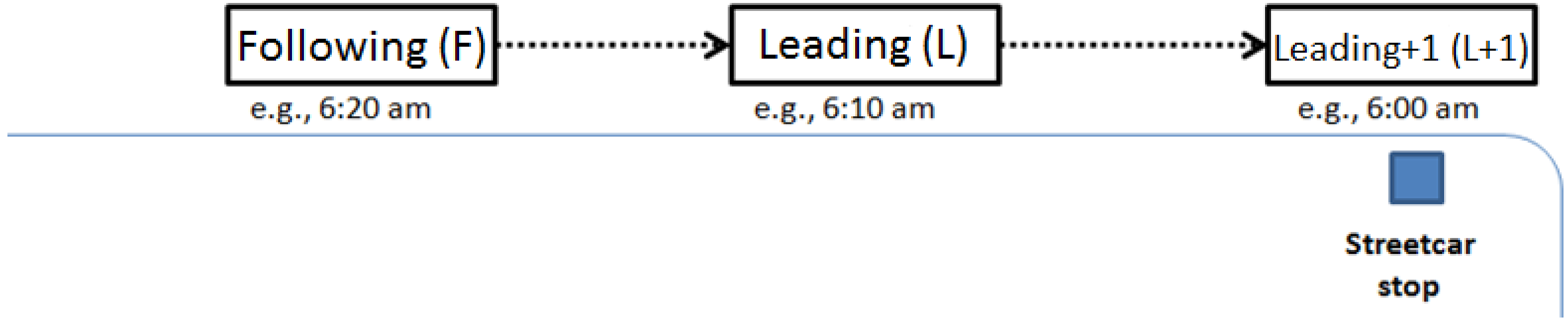
Data Processing

- Bunching incidents were isolated at segment level when actual headway was less than half of scheduled headway



Data Processing

- 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



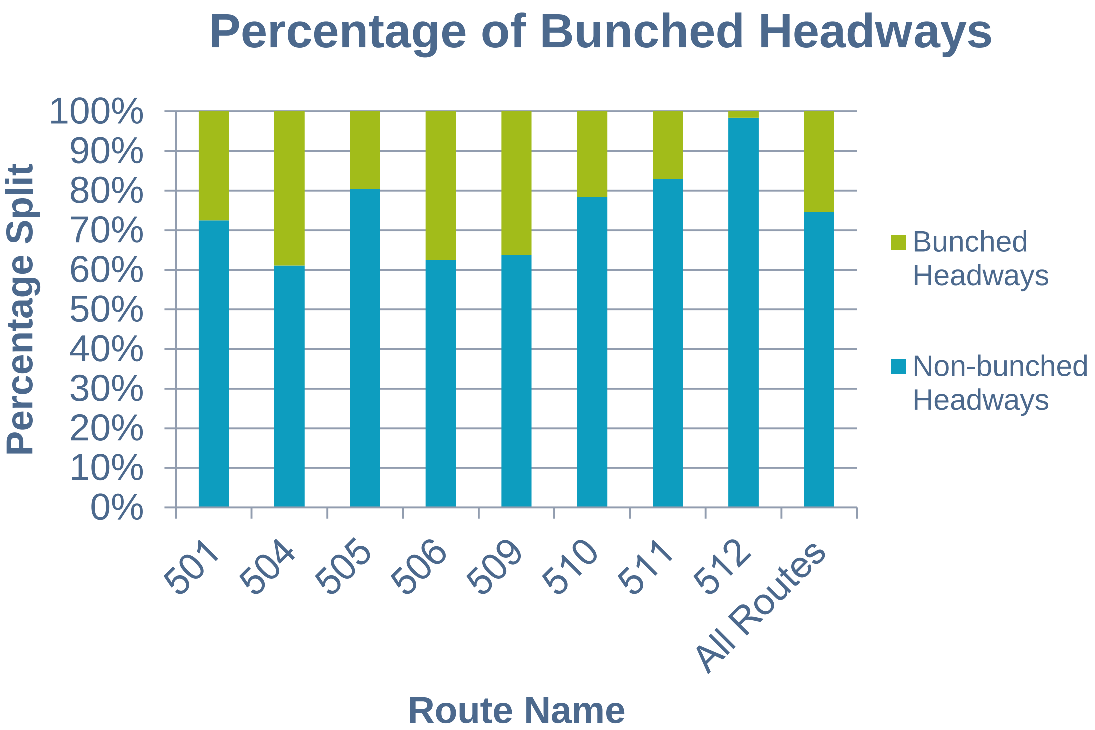
Methodology

- Descriptive statistics and visualizations were used
  - This assisted in showing magnitude of the bunching problem and any trends in the data
- 2 statistical models were used to achieve study objectives
  - Binary Logit Model
  - Accelerated Failure Time (AFT) Model
- 3 types of variables: control, internal, external

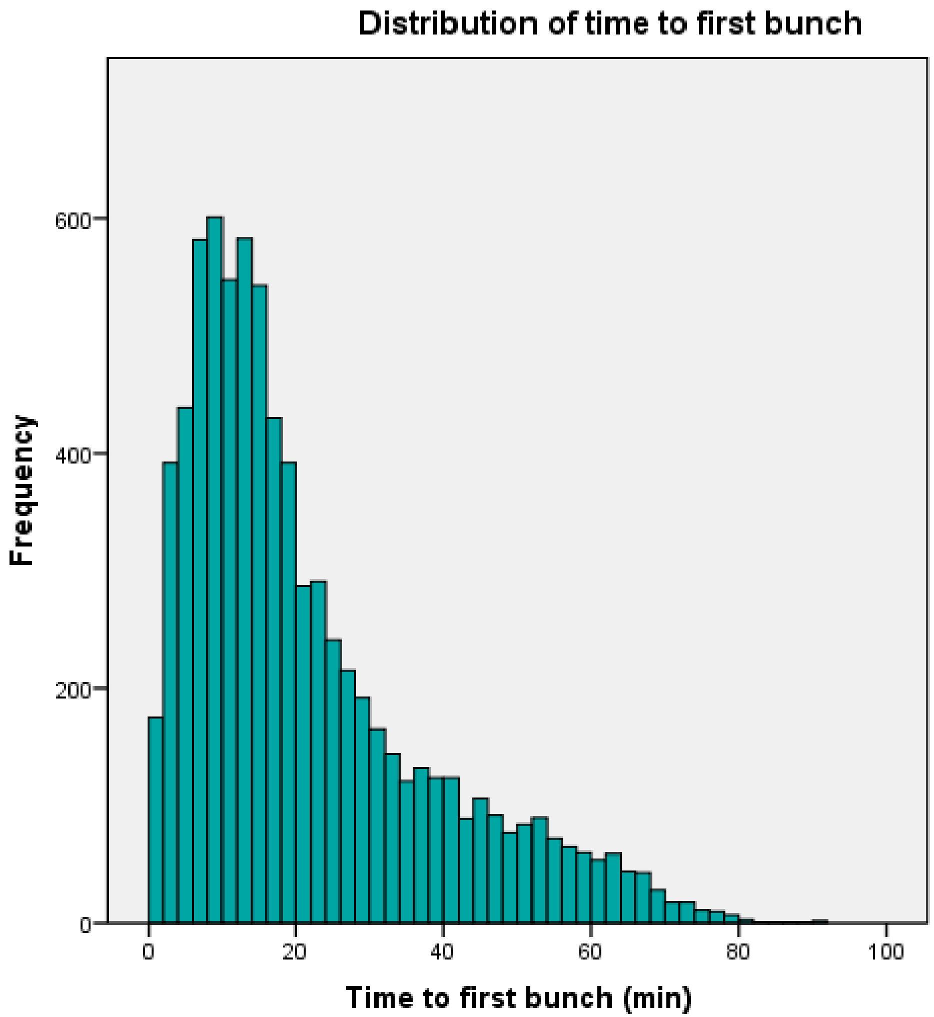
Statistics for All Headways

- Number of Headways and % of bunched headways:

Route	Total # of Headways	Bunch Cases	% bunch
501	7774	2141	27.5%
504	5580	2171	38.9%
505	2592	508	19.6%
506	2234	839	37.6%
509	2422	877	36.2%
510	3426	741	21.6%
511	2439	415	17.0%
512	4038	65	1.6%
Grand Total	30505	7757	25.4%



Distribution of Time to First Bunch



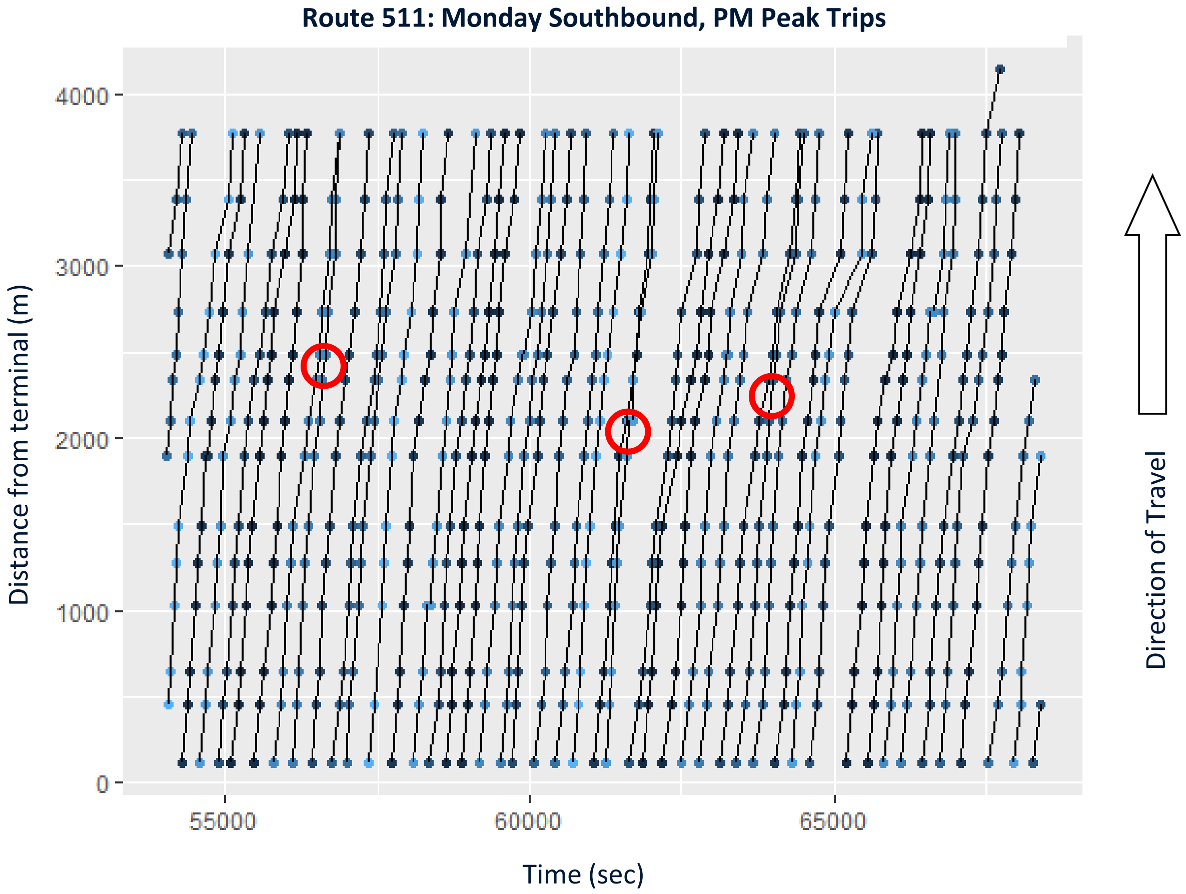
Mean: 21.20

Median: 16.00

Mode: 6.67

Std Dev: 16.58

Actual Time Distance Diagram



Binary Logistic Regression Model

- Used to investigate the effects of various factors on the odds of streetcar bunching, irrespective of location of bunching incident
- Also used to benchmark against previous bus bunching research
- This model was chosen because the dependent variable of interest, whether the headway will bunch or not, is dichotomous
- If bunching occurred, it was coded as 1. Otherwise, it was coded a value of 0

Accelerated Failure Time (AFT) Model

- AFT model assumes that the effect of the independent variables acts directly on the survival time
- Used to understand the impact of external and internal factors on time to the initial bunching incident
- The time to bunching is calculated from the time the following vehicle leaves the terminal to the time the following vehicle first bunched with the leading vehicle.
- Only bunched trips were used in the model

Headway Deviation Combination Variables

- Short: <80% of scheduled headway
- On Time: 80%-120% of scheduled headway
- Long: > 120% of scheduled headway

Following Vehicle	Leading Vehicle
Short	Short
Short	On Time
Short	Long
On Time	Short
On Time	On Time
On Time	Long
Long	Short
Long	On Time
Long	Long

Analysis: Logit Full Model

Nagelkerke R Square
0.592

	Coefficient	Wald	Significance	Odds Ratio	95% Confidence Interval	
					Lower	Upper
Wkday	2.15	2450.65	0.00	8.62	7.92	9.39
Trip direction	0.32	72.73	0.00	1.37	1.28	1.47
Lshort	-1.02	253.45	0.00	0.36	0.32	0.41
Vehicle Combination	(Reference to same vehicle type for both following and leading vehicles)					
FVehCap > LVehCap	-0.27	18.60	0.00	0.76	0.67	0.86
FVehCap < LVehCap	0.33	32.36	0.00	1.39	1.24	1.56
Time Period	(Reference to AM Peak)					
Mid Day	0.78	183.44	0.00	2.19	1.95	2.45
PM Peak	0.18	10.17	0.00	1.20	1.07	1.34
Evening	0.94	145.62	0.00	2.56	2.19	2.98
Route Number	(Reference to Route 512)					
Route 501	8.16	2121.09	0.00	3494.14	2469.15	4944.62
Route 504	3.12	547.37	0.00	22.62	17.42	29.37
Route 505	3.88	696.07	0.00	48.58	36.40	64.82
Route 506	4.94	1190.14	0.00	139.23	105.19	184.31
Route 509	3.88	747.04	0.00	48.53	36.73	64.10
Route 510	2.03	212.45	0.00	7.61	5.79	9.99
Route 511	2.49	305.49	0.00	12.05	9.11	15.92
Scheduled Headway	-0.59	938.62	0.00	0.56	0.53	0.58
Headway Deviation Combination	(Reference to On Time/On Time)					
Short/Short	0.00	0.00	0.96	1.00	0.83	1.22
Short/On Time	0.18	2.68	0.10	1.20	0.97	1.48
Short/Long	0.38	14.26	0.00	1.46	1.20	1.77
On Time/Short	-0.04	0.11	0.74	0.96	0.78	1.20
On Time/Long	0.05	0.18	0.67	1.05	0.84	1.32
Long/Short	-0.68	40.58	0.00	0.51	0.41	0.63
Long/On Time	-0.51	16.88	0.00	0.60	0.47	0.77
Long/Long	-0.27	6.26	0.01	0.76	0.62	0.94
Route 501 x Short/Short	-24.59	0.00	0.96	0.00	0.00	na
Constant	-0.45	6.29	0.01	0.64	na	na

Logit Model Analysis – Control Factors

Variable	Coef.	Std. Err.	z	P>z	[95% Conf. Interval]	
Wkday	2.15	2450.65	0.00	8.62	7.92	9.39
Trip direction	0.32	72.73	0.00	1.37	1.28	1.47
Time Period	(Reference to AM Peak)					
Mid Day	0.78	183.44	0.00	2.19	1.95	2.45
PM Peak	0.18	10.17	0.00	1.20	1.07	1.34
Evening	0.94	145.62	0.00	2.56	2.19	2.98
Route Number	(Reference to Route 512)					
Route 501	8.16	2121.09	0.00	3494.14	2469.15	4944.62
Route 504	3.12	547.37	0.00	22.62	17.42	29.37
Route 505	3.88	696.07	0.00	48.58	36.40	64.82
Route 506	4.94	1190.14	0.00	139.23	105.19	184.31
Route 509	3.88	747.04	0.00	48.53	36.73	64.10
Route 510	2.03	212.45	0.00	7.61	5.79	9.99
Route 511	2.49	305.49	0.00	12.05	9.11	15.92

Logit Model Analysis – Internal Factors

Variable	Coef.	Std. Err.	z	P>z	[95% Conf. Interval]	
Lshort	-1.02	253.45	0.00	0.36	0.32	0.41
Vehicle Combination	(Reference to same vehicle type for both following and leading vehicles)					
FVehCap > LVehCap	-0.27	18.60	0.00	0.76	0.67	0.86
FVehCap < LVehCap	0.33	32.36	0.00	1.39	1.24	1.56

Logit Model Analysis – Internal Factors

Variable	Coef.	Std. Err.	z	P>z	[95% Conf. Interval]	
Scheduled Headway	-0.59	938.62	0.00	0.56	0.53	0.58
Headway Deviation Combination	(Reference to On Time/On Time)					
Short/Short	0.00	0.00	0.96	1.00	0.83	1.22
Short/On Time	0.18	2.68	0.10	1.20	0.97	1.48
Short/Long	0.38	14.26	0.00	1.46	1.20	1.77
On Time/Short	-0.04	0.11	0.74	0.96	0.78	1.20
On Time/Long	0.05	0.18	0.67	1.05	0.84	1.32
Long/Short	-0.68	40.58	0.00	0.51	0.41	0.63
Long/On Time	-0.51	16.88	0.00	0.60	0.47	0.77
Long/Long	-0.27	6.26	0.01	0.76	0.62	0.94
Route 501 x Short/Short	-24.59	0.00	0.96	0.00	0.00	na

Analysis: AFT Full model

Variable	Coef.	Std. Err.	z	P>z	[95% Conf. Interval]	
wkday	-0.038	0.024	-1.550	0.121	-0.085	0.010
Ftripdir	0.044	0.015	2.990	0.003	0.015	0.074
TimePeriod	(Reference to AM Peak)					
Midday	0.129	0.022	5.890	0.000	0.086	0.172
PM Peak	0.154	0.021	7.280	0.000	0.113	0.196
Evening	0.066	0.026	2.540	0.011	0.015	0.116
Route	(Reference to Route 512)					
501	-0.196	0.100	-1.970	0.049	-0.392	-0.001
504	0.639	0.093	6.870	0.000	0.456	0.821
505	0.286	0.107	2.680	0.007	0.077	0.495
506	0.109	0.105	1.040	0.299	-0.097	0.315
509	-0.180	0.098	-1.840	0.066	-0.371	0.012
510	0.162	0.095	1.710	0.088	-0.024	0.348
511	-0.078	0.102	-0.770	0.440	-0.278	0.121
VehCombination	(Reference to same vehicle type for both)					
Follow veh > Lead veh	-0.079	0.021	-3.670	0.000	-0.121	-0.037
Follow veh < Lead veh	-0.084	0.020	-4.300	0.000	-0.122	-0.046
SchedHead	0.101	0.046	2.220	0.026	0.012	0.191
SchedHead2	-0.011	0.003	-3.160	0.002	-0.017	-0.004
FLHeadRatio	0.002	0.000	18.040	0.000	0.002	0.002
LL1HeadRatio	0.000	0.000	-0.440	0.663	0.000	0.000
CumTSP	0.077	0.003	23.790	0.000	0.071	0.084
StopComb	-0.373	0.131	-2.840	0.005	-0.631	-0.115
CumPedCross	-0.030	0.004	-7.090	0.000	-0.038	-0.022
CumSigApp	-0.006	0.001	-10.970	0.000	-0.007	-0.005
Vehicle Volume Cat	(Reference to low vehicle volume category)					
Medium Volume	-0.012	0.016	-0.740	0.461	-0.043	0.019
High Volume	0.267	0.039	6.840	0.000	0.190	0.343
_cons	1.909	0.159	11.970	0.000	1.596	2.221

AFT Analysis – Control Factors

Variable	Coef.	Std. Err.	z	P>z	[95% Conf. Interval]	
wkday	-0.038	0.024	-1.550	0.121	-0.085	0.010
Ftripdir	0.044	0.015	2.990	0.003	0.015	0.074
TimePeriod	(Reference to AM Peak)					
Midday	0.129	0.022	5.890	0.000	0.086	0.172
PM Peak	0.154	0.021	7.280	0.000	0.113	0.196
Evening	0.066	0.026	2.540	0.011	0.015	0.116
Route	(Reference to Route 512)					
501	-0.196	0.100	-1.970	0.049	-0.392	-0.001
504	0.639	0.093	6.870	0.000	0.456	0.821
505	0.286	0.107	2.680	0.007	0.077	0.495
506	0.109	0.105	1.040	0.299	-0.097	0.315
509	-0.180	0.098	-1.840	0.066	-0.371	0.012
510	0.162	0.095	1.710	0.088	-0.024	0.348
511	-0.078	0.102	-0.770	0.440	-0.278	0.121

AFT Analysis – Internal Factors

Variable	Coef.	Std. Err.	z	P>z	[95% Conf. Interval]	
VehCombination	(Reference to same vehicle type for both)					
Follow veh > Lead veh	-0.079	0.021	-3.670	0.000	-0.121	-0.037
Follow veh < Lead veh	-0.084	0.020	-4.300	0.000	-0.122	-0.046
SchedHead	0.101	0.046	2.220	0.026	0.012	0.191
SchedHead2	-0.011	0.003	-3.160	0.002	-0.017	-0.004
FLHeadRatio	0.002	0.000	18.040	0.000	0.002	0.002
LL1HeadRatio	0.000	0.000	-0.440	0.663	0.000	0.000
CumTSP	0.077	0.003	23.790	0.000	0.071	0.084
StopComb	-0.373	0.131	-2.840	0.005	-0.631	-0.115

AFT Analysis – External Factors

Variable	Coef.	Std. Err.	z	P>z	[95% Conf. Interval]	
CumPedCross	-0.030	0.004	-7.090	0.000	-0.038	-0.022
CumSigApp	-0.006	0.001	-10.970	0.000	-0.007	-0.005
Vehicle Volume Cat	(Reference to low vehicle volume category)					
Medium Volume	-0.012	0.016	-0.740	0.461	-0.043	0.019
High Volume	0.267	0.039	6.840	0.000	0.190	0.343

Key Findings

- Longer scheduled headways are found to decrease odds to bunching as well as delay onset of bunching
- Regardless of headway adherence of leading vehicle:
  - When the following vehicle has an actual headway that is shorter than the scheduled headway, the odds of bunching is increased
  - When the following vehicle has an actual headway that is longer than the scheduled headway, the odds of bunching is reduced
- Odds of bunching are increased in the midday, PM peak, and evening time periods but the time to bunching is shorter in the AM peak
- Short turning is found to be effective in reducing bunching odds

Key Findings

- Different combinations of vehicle types and of stop placements are found to accelerate the time to bunching and increase odds of bunching
- The implementation of TSP at multiple intersections seem to delay the onset of bunching
- The cumulative number of pedestrian crossings and signalized approaches have been found to accelerate the time to bunching
- Heavy traffic volume delays the onset of bunching (dedicated right of ways will accelerate time to bunching)

Future Work

- Study using an extended time period to capture impact of construction, special events, and weather
- Time to bunch study for bus bunching
- Prediction of bunching odds and time to bunching in real-time applications for streetcars

Acknowledgements

- Ontario Research Fund (ORF) for funding
  - Project 2.3 (Transit Management) within iCity project
- TTC for providing the data used in the analysis

Thank you!

Determining the Factors that Influence the Odds and Time to Streetcar Bunching Incidents

Paula Nguyen (paula.nguyen@mail.utoronto.ca)
Dr. Ehab Diab (ehab.diab@utoronto.ca)
Professor Amer Shalaby (amer@ecf.utoronto.ca)

UNIVERSITY OF TORONTO
FACULTY OF APPLIED SCIENCE & ENGINEERING
Transportation Research Institute