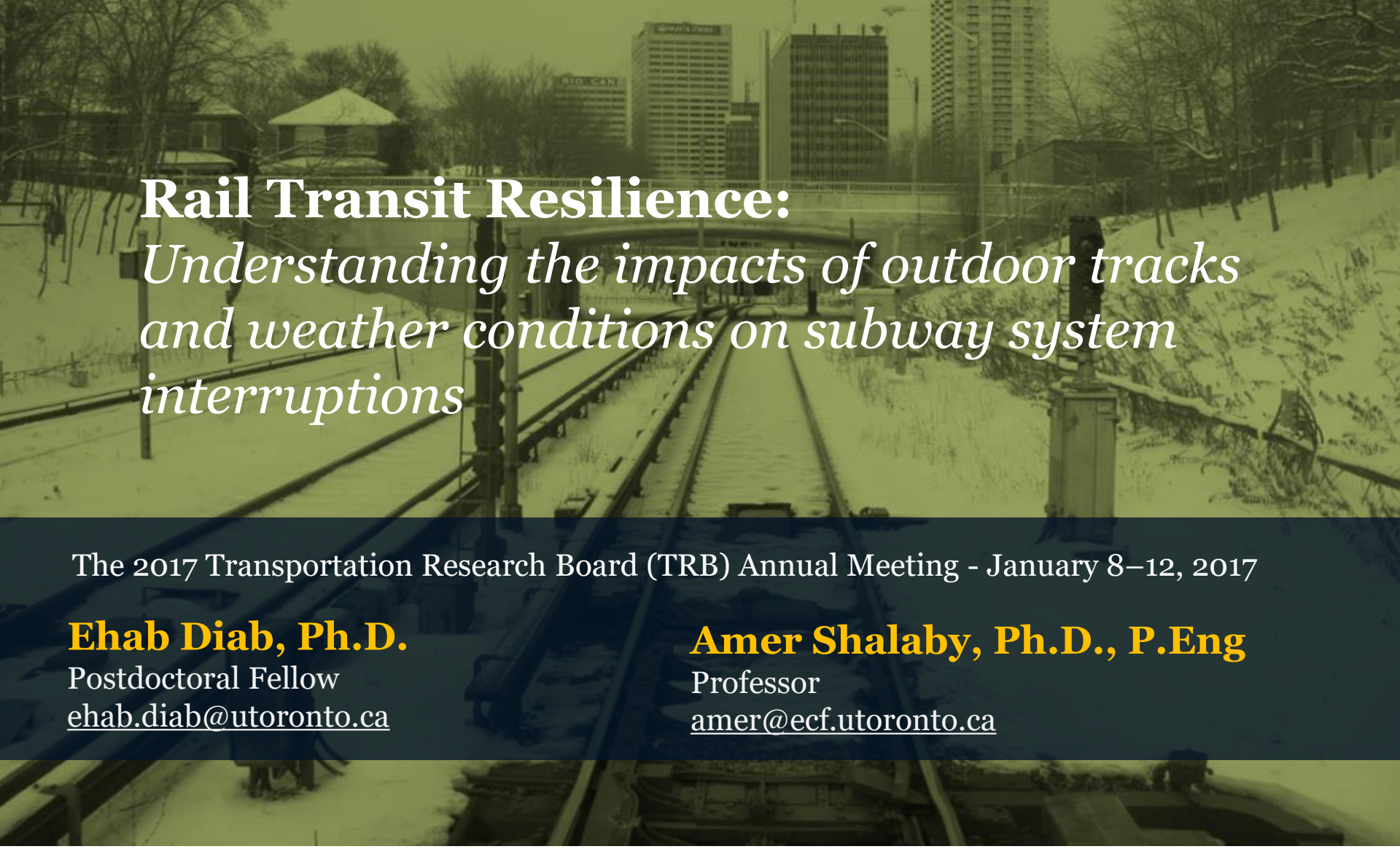


Rail Transit Resilience:
Understanding the impacts of outdoor tracks and weather conditions on subway system interruptions

The 2017 Transportation Research Board (TRB) Annual Meeting - January 8–12, 2017

Ehab Diab, Ph.D.
Postdoctoral Fellow
ehab.diab@utoronto.ca

Amer Shalaby, Ph.D., P.Eng
Professor
amer@ecf.utoronto.ca

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

Outline

- Context
- Research Objectives
- Case Study and Methodology
- Analysis
- Discussion and Conclusions

Research Gaps

- Most of the literature focuses on the impacts and the benefits of a new transport infrastructure does not account for the provided quality of service
  - by considering a consistent service with no service interruptions

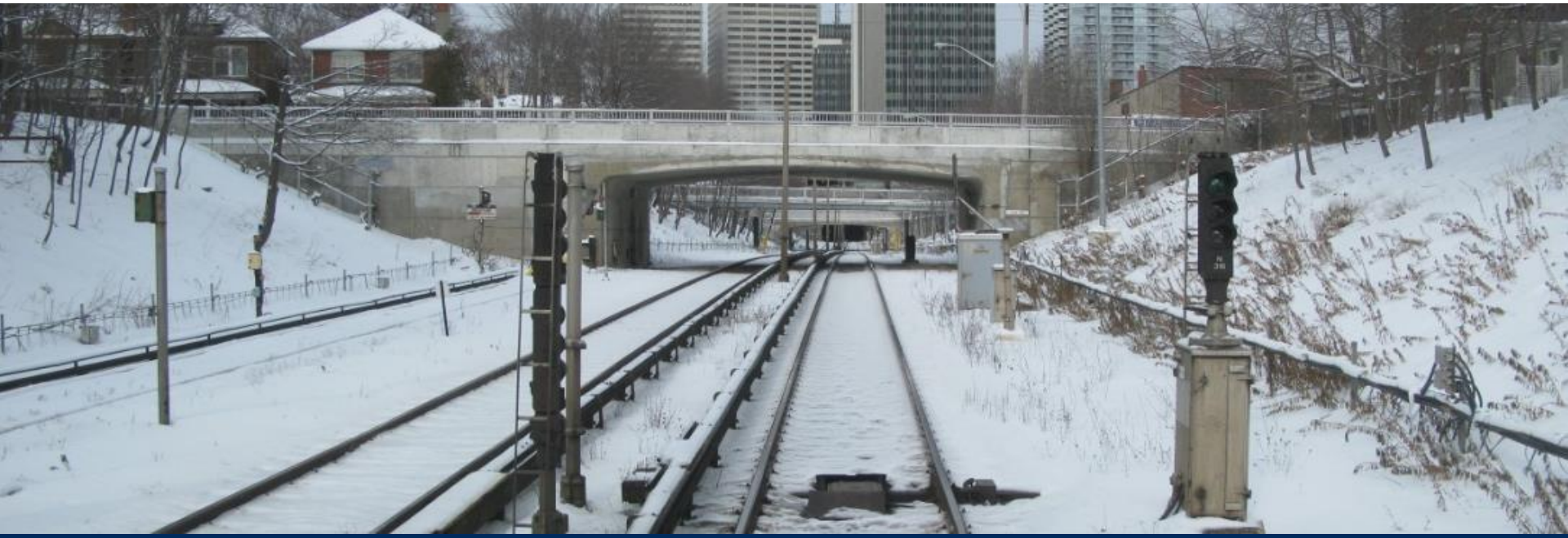
Research Gaps

- Measuring the impacts of weather conditions on service travel time and reliability
  - using automatic vehicle location (AVL) systems data

- Developing several modelling approaches to predict or account for the impact of incidents (i.e., vehicle failures) on the delay duration.

Research Gaps

- There has been little effort to investigate the impacts of outdoor tracks and weather condition on transit service interruptions and delays.



Research Objective

- Evaluate the impacts of:
  - Outdoor track segments (or open-air sectors) of the subway system
  - Weather conditions on the frequency and duration of service interruptions at the stop-level of analysis

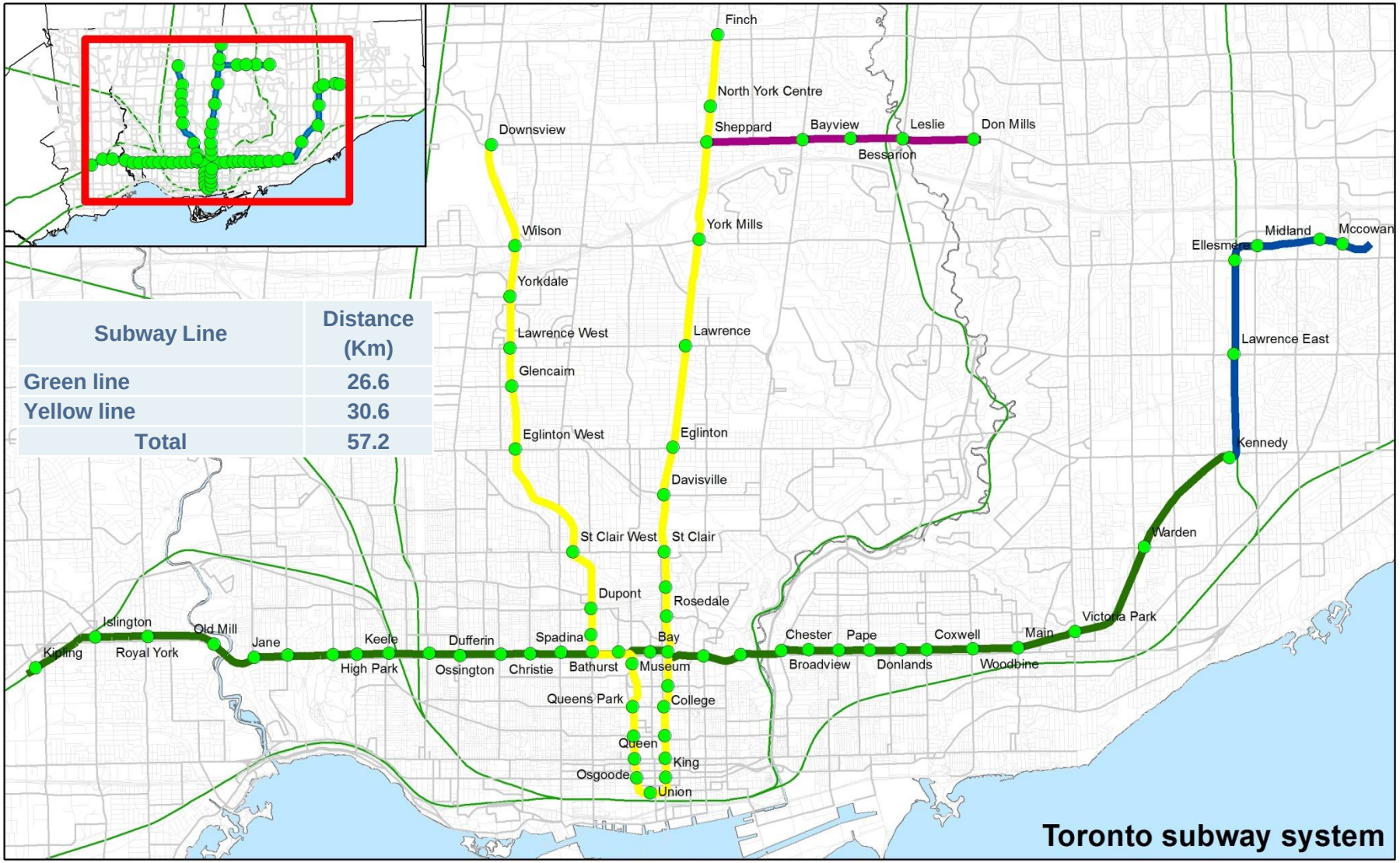
Methodology

- Using a detailed subway system interruption data collected in 2013 by the Toronto Transit Commission (TTC)
- Weather conditions data (Environment Canada)

Methodology

- A total of 12,000 subway incidents were reported at the stop 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, as well as a brief description of the incident and a code representing the incident type.



Subway Line	Distance (Km)
Green line	26.6
Yellow line	30.6
Total	57.2

Subway stops

TTC bus routes

Subway lines

Bloor-Danforth line (Green line)

Scarborough line (Blue line)

Sheppard line (Magenta line)

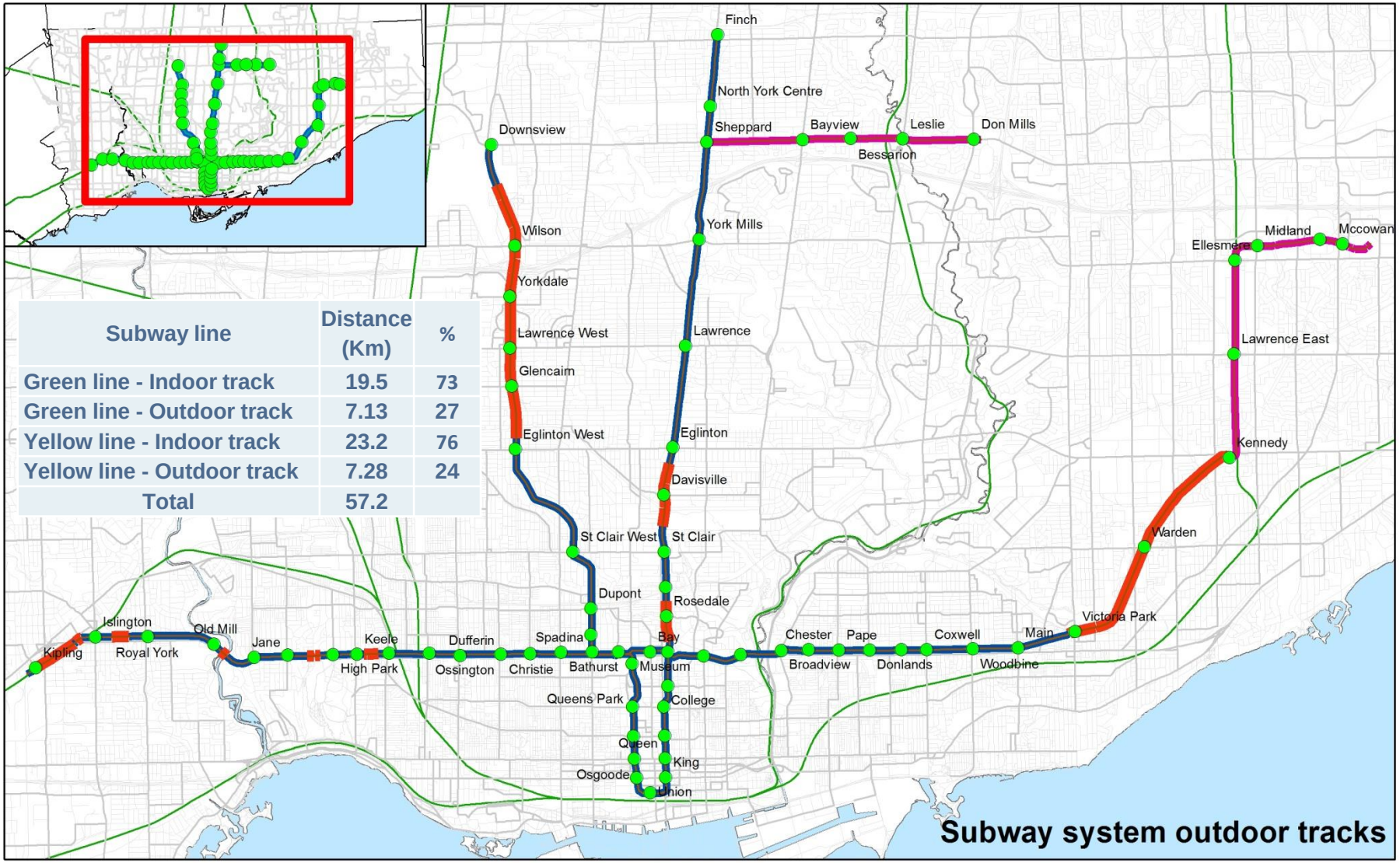
Yonge-University-Spadina line (Yellow line)

0 0.5 1 2 Km

0 0.5 1 2 Mi

1 cm = 1 kilometers

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



Subway line	Distance (Km)	%
Green line - Indoor track	19.5	73
Green line - Outdoor track	7.13	27
Yellow line - Indoor track	23.2	76
Yellow line - Outdoor track	7.28	24
Total	57.2	

Subway stops

Subway_Out_Dissolve

TTC bus routes

Subway system tracks

Indoor tracks

Outdoor tracks

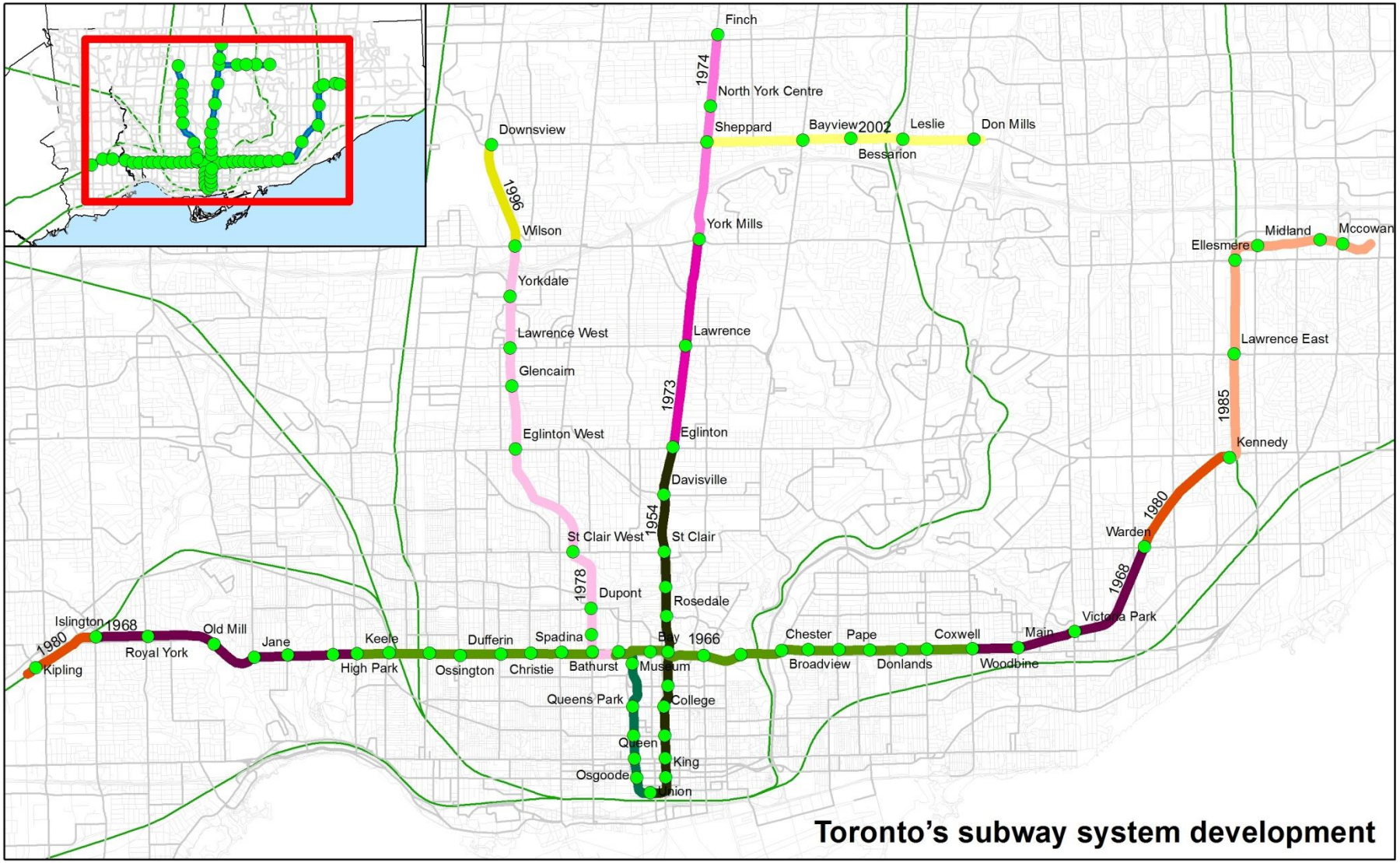
Not included in the analysis

0 0.5 1 2 Km

0 0.5 1 2 Mi

1 cm = 1 kilometers

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


Finch
1974
North York Centre
Sheppard
Bayview
2002
Leslie
Don Mills
Bessarion
Downsview
1996
Wilson
York Mills
Yorkdale
Lawrence West
Lawrence
Glencairn
1973
Eglinton West
Eglinton
Davisville
1954
St Clair West
St Clair
1978
Dupont
Rosedale
Islington
1968
1980
Old Mill
Royal York
Kipling
Jane
Keele
High Park
Dufferin
Ossington
Spadina
Christie
Bathurst
Bay
1966
Museum
Queens Park
College
Queen
King
Osgoode
Union
Chester
Pape
Coxwell
Broadview
Donlands
Main
Woodbine
Victoria Park
Warden
1980
1968
Kennedy
1985
Lawrence East
Ellesmere
Midland
Mccowan
Toronto’s subway system development
Subway stops
TTC bus routes
Opening year
1954
1963
1966
1968
1973
1974
1978
1980
1985
1987
1996
2002
0 0.5 1 2 Km
0 0.5 1 2 Mi
1 cm = 1 kilometers
Data sources: City of Toronto, Statistics Canada, DMTI
Projection: NAD 1983 Ontario Lambert

Methodology

- Distinguishing the incidents that are suspected to be affected by the outdoor segments
- All incidents types, code and description were reviewed
  - To include: debris at track level, signal and switch problems, track circuit/track down, smoke or fire at the track, speed control/emergency brakes applied, and disabled train due to traction and propulsion problems.
  - To remove: passengers' activity issues (e.g., medical emergency, assault on employee), security aspects (e.g., bomb threats), employees availability, and train body problems (e.g., door closing problems).
- A total of 4,980 incidents are kept for the analysis

Methodology

- The data were aggregated according to the following criteria:
  - *Subway lin*
    uni d (e
    pre of
    and weathe

For example, all incidents occurred at the Yellow line, at Bloor/Yonge station, along the southbound direction that has an outdoor sector, and during a weather group (e.g., 2013 Winter) are aggregated into one category

- Weather groups:
  1. Seasons (Winter, Summer, Spring, Autumn)
  2. Snow on ground (No Snow, less than 7.5 cm, less than 15cm, more than 15 cm (Environment Canada warning criteria))
  3. Rainfall (No rain, less than 12.5 mm, less than 25 mm, more than 25 mm (Environment Canada warning criteria))

Methodology

- Descriptive statistics
- Six statistical models at the aggregate level using log of the number of incidents and log of total amount of delay per a group as dependent variables
  1. Two Seasonal Models
  2. Two Snow Models
  3. Two Rainfall Models

Methodology

Other variables were tested but were eliminated from the study due to their non-significance, such as:

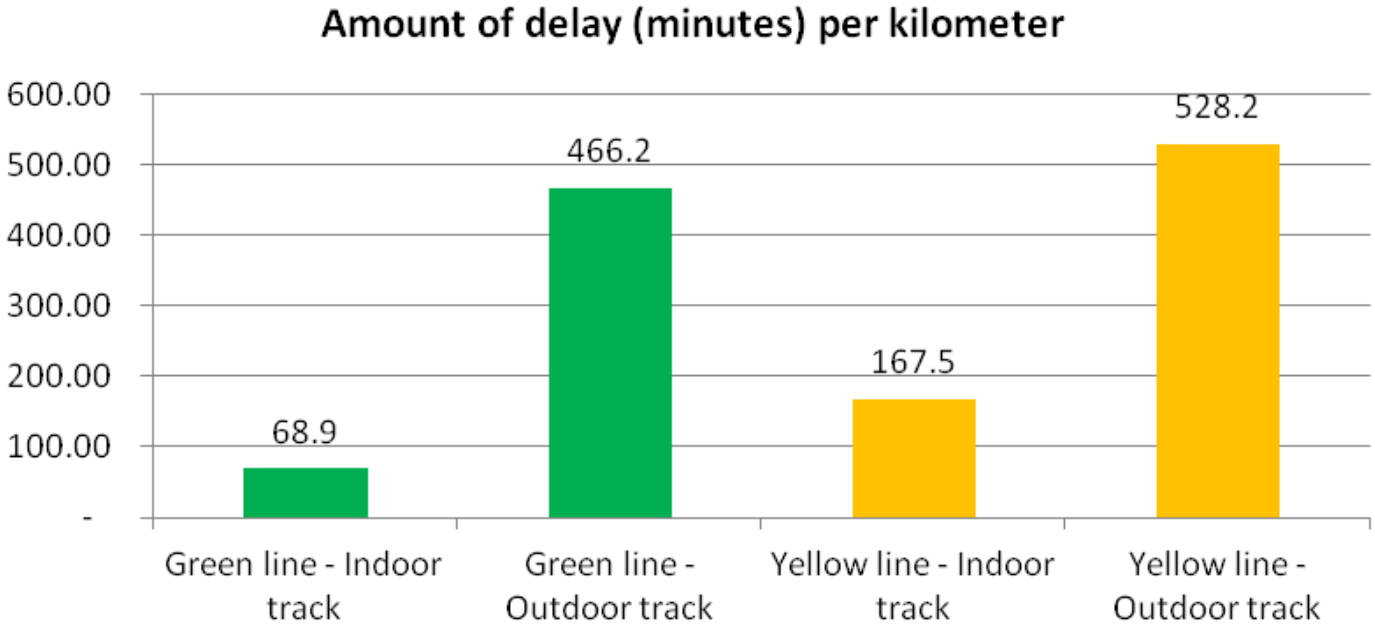
1. Transfer stations
2. Service frequency
3. Platform location (central or side platform)
4. Age of infrastructure
5. Circuity (the ratio of network distance to Euclidean distance between stations)

Variable Name
log of the number of incidents
log of the amount of delay
Yellow line
Layover stop
Toronto rocket train (TR) trains
Indoor track distance (KM)
Outdoor track distance (KM)
Season Models
Winter
Spring
Summer
Out* Winter
Snow Models
Snow less than 7 cm
Snow less than 15 cm
Snow with more than 15
Out* Snow less than 7 cm
Out* Snow less than 15 cm
Out* Snow with more than 15 cm
Rain Models
Rain less than 12.5 mm
Rain less than 25 mm
Rain with more than 25 mm
Out* Rain less than 12 mm
Out* Rain less than 25 mm
Out* Rain with more than 25 mm

Analysis and Discussion

Descriptive statistics

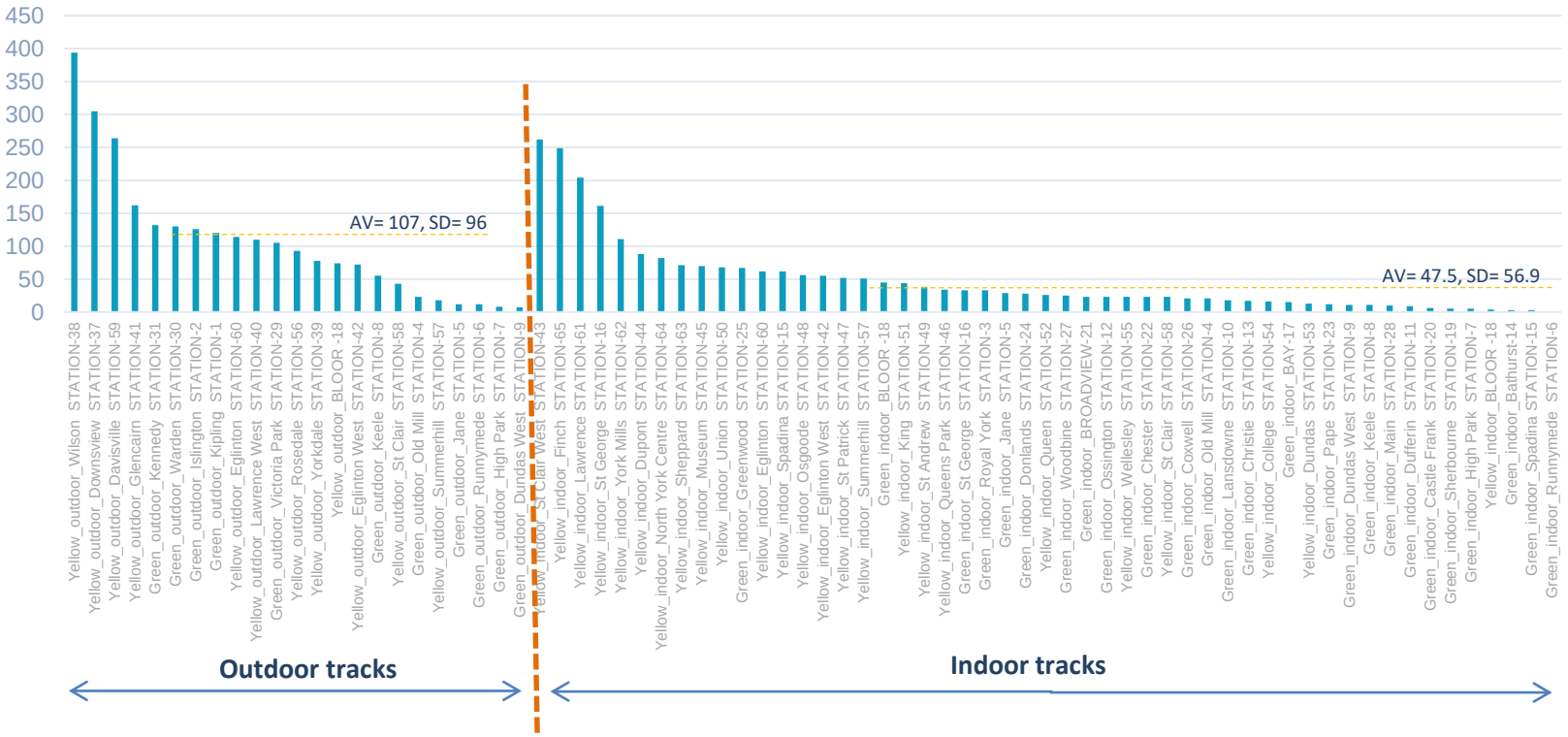
- Number of incidents and total delay per subway line, track type and distance (per kilometer)



Amount of delay per kilometer (minutes)
68.89
466.22
167.45
528.15

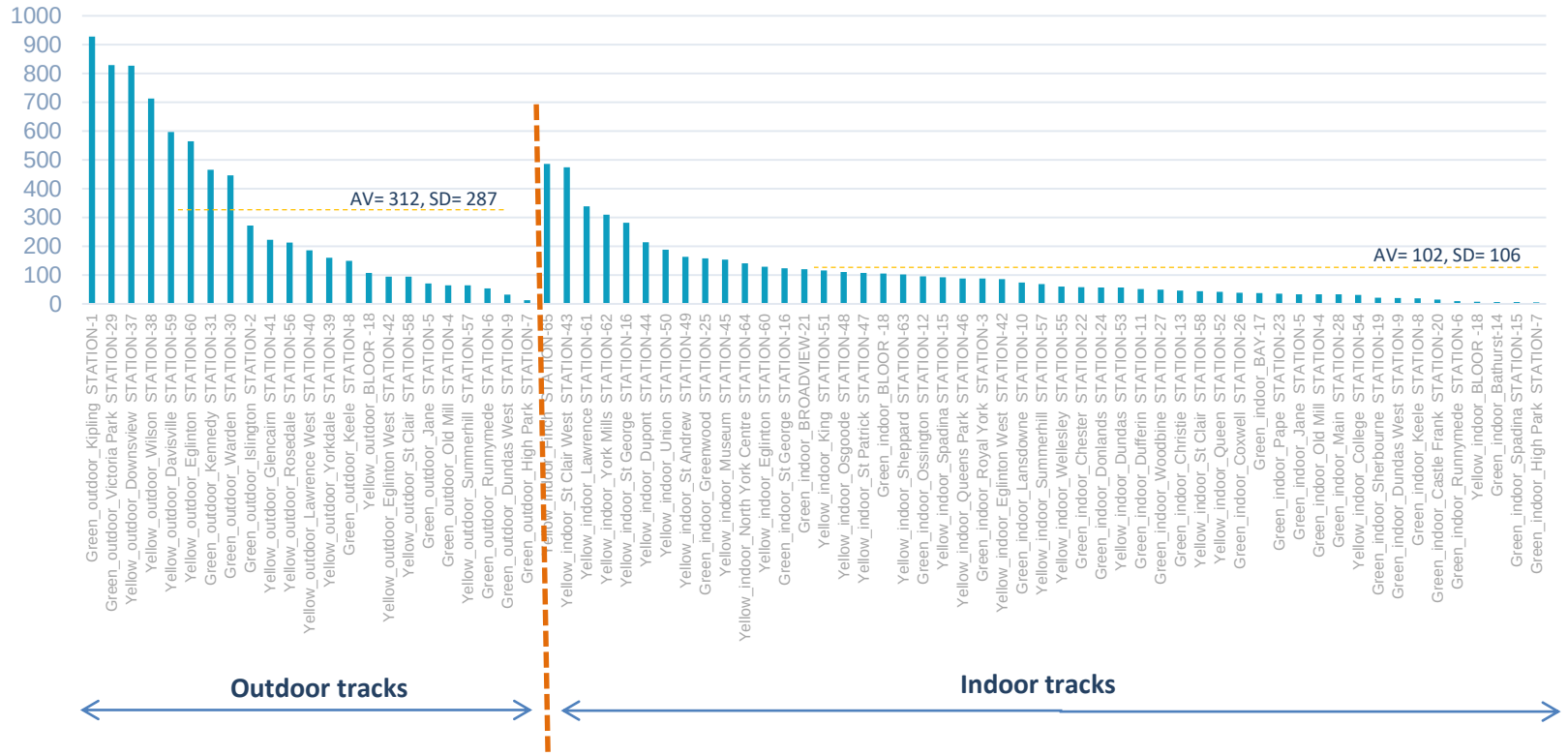
Descriptive statistics

- Number of incidents by station and track type



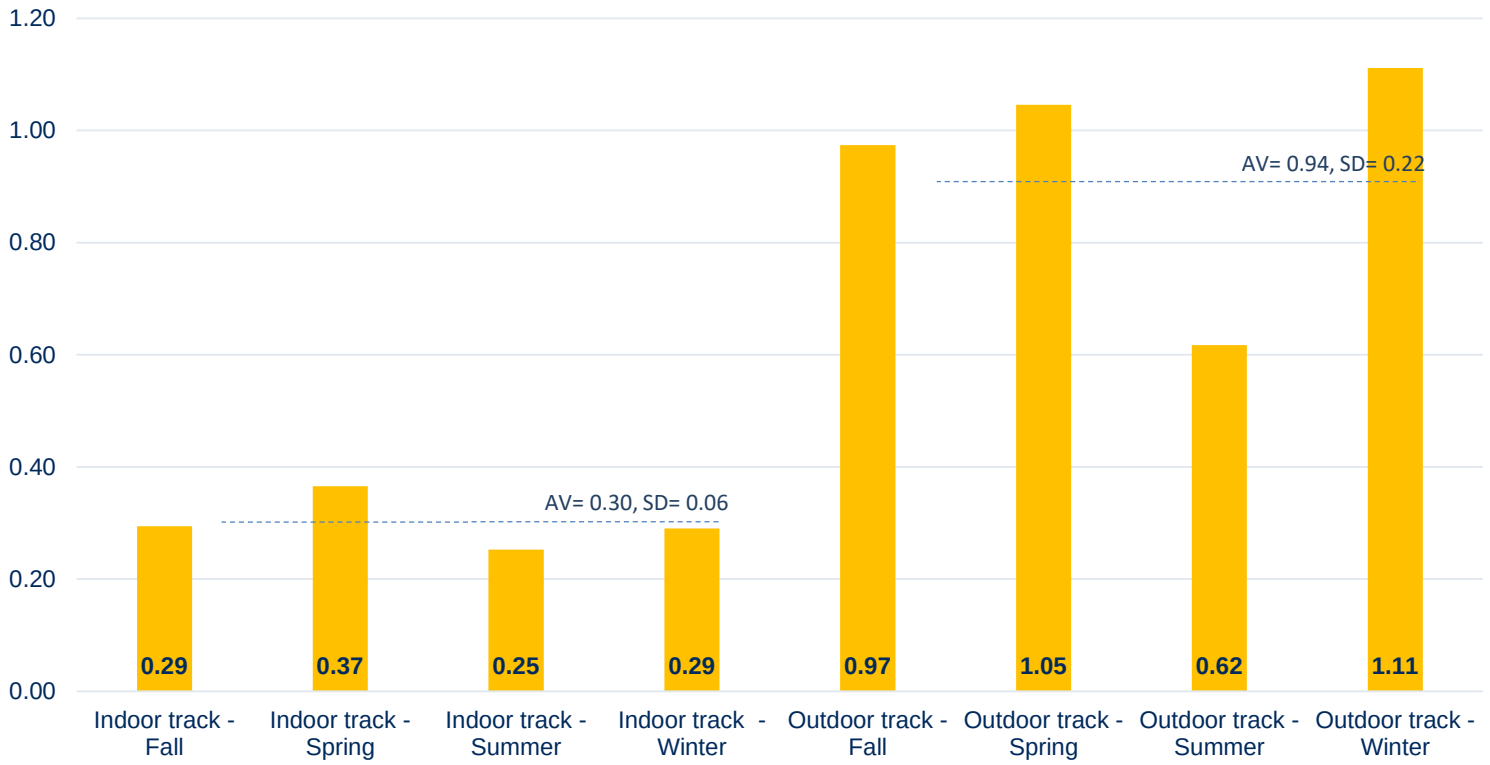
Descriptive statistics

- Total delay by station and track type



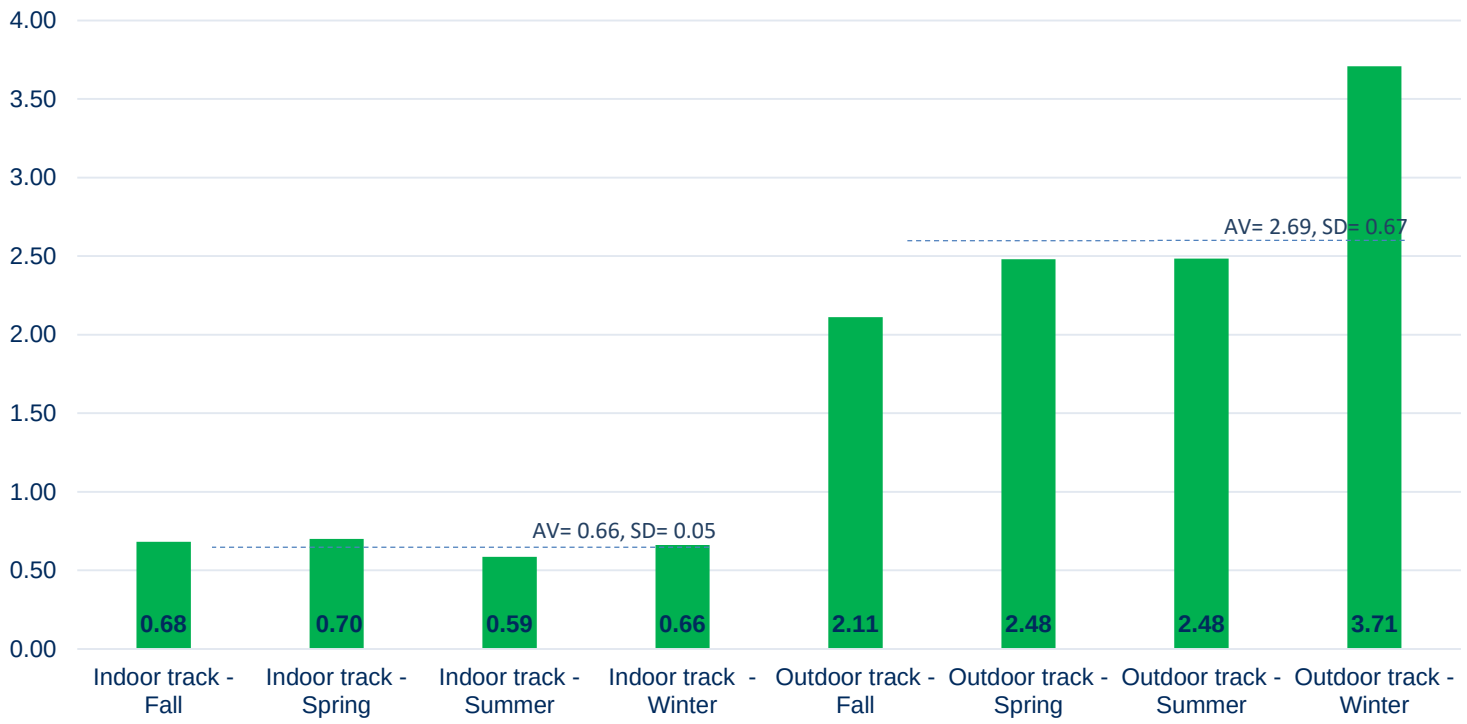
Descriptive statistics

- Number of incidents per kilometre, season, day and track type.



Descriptive statistics

- Amount of delay per kilometre, season, day and track type.



Regression models

Seasonal Models

	A) Log of the number of incidents				B) Log of the amount of delay			
Variable	Coeff.	Z	95% Conf. Interval Lower Bound	Upper Bound	Coeff.	Z	95% Conf. Interval Lower Bound	Upper Bound
Constant	**-0.86**	**-19.0 *****	**-0.95**	**-0.77**	**-0.44**	**-6.70 *****	**-0.57**	**-0.31**
Yellow line	0.00	-0.01	-0.07	0.07	**-0.14**	**-2.69 *****	**-0.25**	**-0.04**
Layover stop	**0.14**	**2.71 *****	**0.04**	**0.24**	**0.26**	**3.44 *****	**0.11**	**0.41**
Toronto rocket train	**0.02**	**12.03 *****	**0.02**	**0.02**	**0.02**	**8.14 *****	**0.01**	**0.02**
Indoor track distance (KM)	0.03	1.28	-0.02	0.09	0.01	0.16	-0.07	0.08
Outdoor track distance (KM)	**0.18**	**6.23 *****	**0.13**	**0.24**	**0.19**	**4.32 *****	**0.10**	**0.27**
Winter	-0.07	-1.62	-0.17	0.02	-0.02	-0.35	-0.16	0.11
Spring	**-0.10**	**-2.67 ****	**-0.18**	**-0.03**	**-0.10**	**-1.70 ***	**-0.21**	**0.02**
Summer	**-0.14**	**-3.62 *****	**-0.22**	**-0.06**	-0.09	-1.50	-0.20	0.03
Interactions								
Out * Winter	**0.12**	**2.00 ****	**0.00**	**0.24**	**0.19**	**2.19 ****	**0.02**	**0.37**
N	**175.00**				**175.00**			
Adjusted R Square	**0.68**				**0.52**			
F statistics	**(9, 165) 42.7**				**(9, 165) 22.1**			
F significance (Prob > F)	**0.00**				**0.00**			

Bold indicates statistical significance

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

Regression models

Snow Models

	A) Log of the number of incidents				B) Log of the amount of delay			
Variable	Coeff.	Z	95% Conf. Interval Lower Bound	Upper Bound	Coeff.	Z	95% Conf. Interval Lower Bound	Upper Bound
Constant	**1.06**	**20.8 *****	**0.96**	**1.16**	**1.51**	**22.4 *****	**1.38**	**1.64**
Yellow line	**0.21**	**4.20 *****	**0.11**	**0.31**	0.06	0.85	-0.08	0.19
Layover stop	**0.16**	**1.87 ****	**-0.01**	**0.32**	**0.27**	**2.49 ****	**0.06**	**0.49**
Toronto rocket train	**0.01**	**6.71 *****	**0.01**	**0.01**	**0.01**	**4.66 *****	**0.00**	**0.01**
Indoor track distance (KM)	**0.10**	**2.44 ****	**0.02**	**0.19**	**0.11**	**2.03 ****	**0.00**	**0.22**
Outdoor track distance (KM)	**0.28**	**5.73 *****	**0.19**	**0.38**	**0.31**	**4.76 *****	**0.18**	**0.44**
Snow less than 7 cm	0.08	1.05	-0.07	0.22	0.01	0.15	-0.17	0.20
Snow less than 15 cm	**-0.47**	**-6.91 *****	**-0.60**	**-0.34**	**-0.47**	**-5.18 *****	**-0.64**	**-0.29**
Interactions								
Out* Snow less than 7 cm	-0.08	-0.77	-0.30	0.13	0.03	0.20	-0.26	0.32
Out * Snow less than 15 cm	**1.00**	**6.40 *****	**0.69**	**1.31**	**1.12**	**5.44 *****	**0.72**	**1.53**
Out * Snow above 15 cm	**-0.88**	**-6.27 *****	**-1.16**	**-0.60**	**-1.00**	**-5.39 *****	**-1.37**	**-0.64**
N	157.00				157.00			
Adjusted R Square	0.69				0.56			
F statistics	(10, 146) 34.9				(10, 146) 20.7			
F significance (Prob > F)	0.00				0.00			

Bold indicates statistical significance

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

Regression models

Rainfall Models

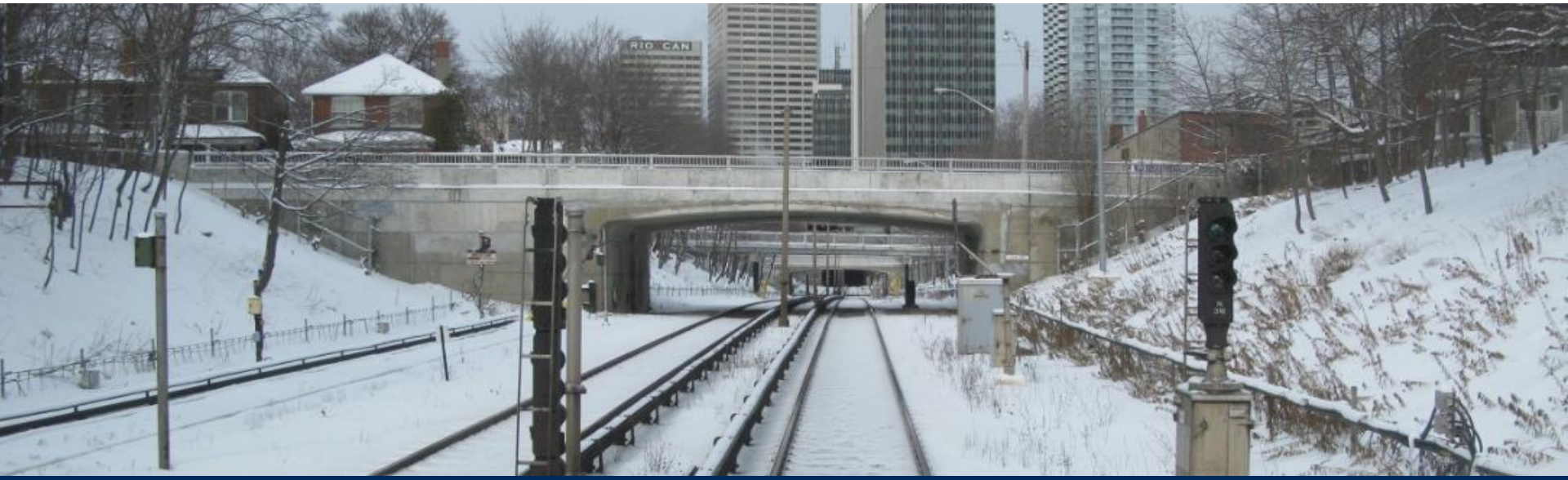
	A) Log of the number of incidents				B) Log of the amount of delay			
			95% Conf. Interval				95% Conf. Interval	
Variable	Coeff.	Z	Lower Bound	Upper Bound	Coeff.	Z	Lower Bound	Upper Bound
Constant	**1.03**	**21.4 *****	**0.93**	**1.12**	**1.51**	**22.3 *****	**1.37**	**1.64**
Yellow line	**0.11**	**2.42 ****	**0.02**	**0.21**	-0.08	-1.26	-0.22	0.05
Layover stop	0.11	1.57	-0.03	0.24	0.22	2.29	0.03	0.41
Toronto rocket train	**0.01**	**8.79 *****	**0.01**	**0.02**	**0.01**	**6.52 *****	**0.01**	**0.02**
Indoor track distance (KM)	0.05	1.22	-0.03	0.13	0.02	0.30	-0.10	0.13
Outdoor track distance (KM)	**0.26**	**5.88 *****	**0.17**	**0.35**	**0.24**	**3.77 *****	**0.11**	**0.36**
Rain less than 12 mm	**0.35**	**3.31 *****	**0.14**	**0.56**	**0.39**	**2.65 ****	**0.10**	**0.68**
Rain less than 25 mm	0.10	0.63	-0.21	0.41	0.28	1.25	-0.16	0.71
Rain with above than 25 mm	**-0.43**	**-3.21 ****	**-0.69**	**-0.16**	**-0.63**	**-3.39 ****	**-1.00**	**-0.26**
Interactions								
Out* Rain less than 12 mm	0.12	0.91	-0.15	0.39	-0.14	-0.74	-0.52	0.24
Out * Rain less than 25 mm	-0.13	-0.63	-0.53	0.28	-0.16	-0.56	-0.73	0.41
Out * Rain above than 25 mm	0.04	0.26	-0.29	0.37	**0.41**	**1.76 ***	**-0.05**	**0.87**
N		140.00				140.00		
Adjusted R Square		0.70				0.53		
F statistics		(11, 128) 30.7				(11, 128) 15.3		
F significance (Prob > F)		0.00				0.00		

Bold indicates statistical significance

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

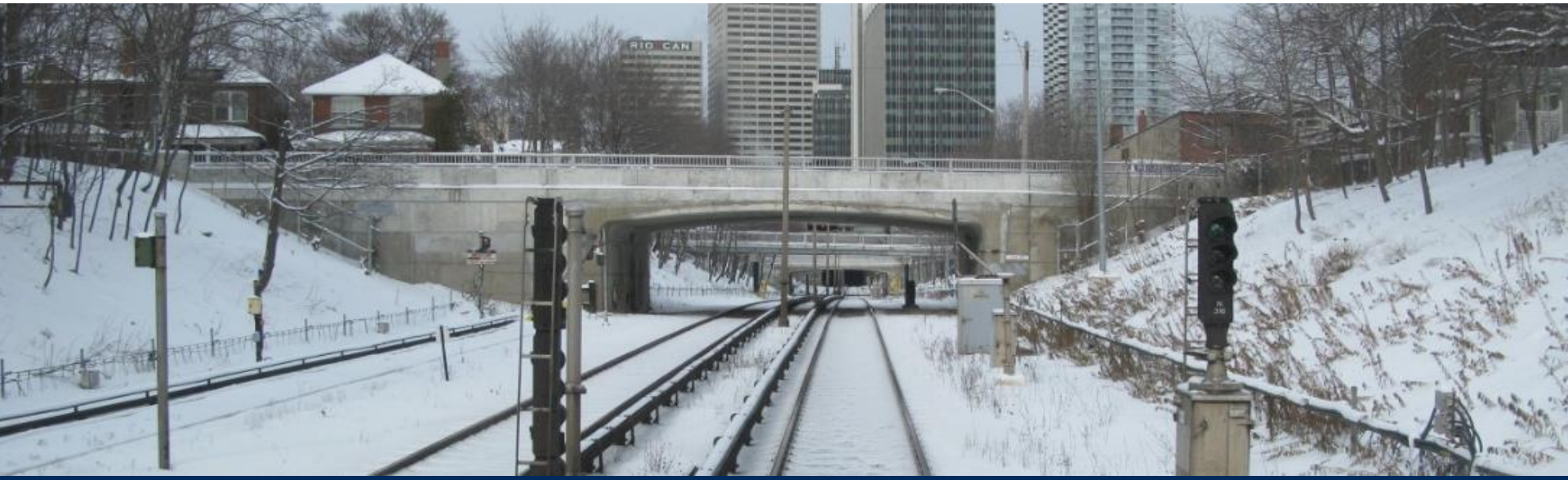
Discussion and conclusion

- Outdoor tracks have a statistically significant association with subway system's service interruptions
- Longer outdoor track distances are linked to both higher frequencies and delays of service interruptions



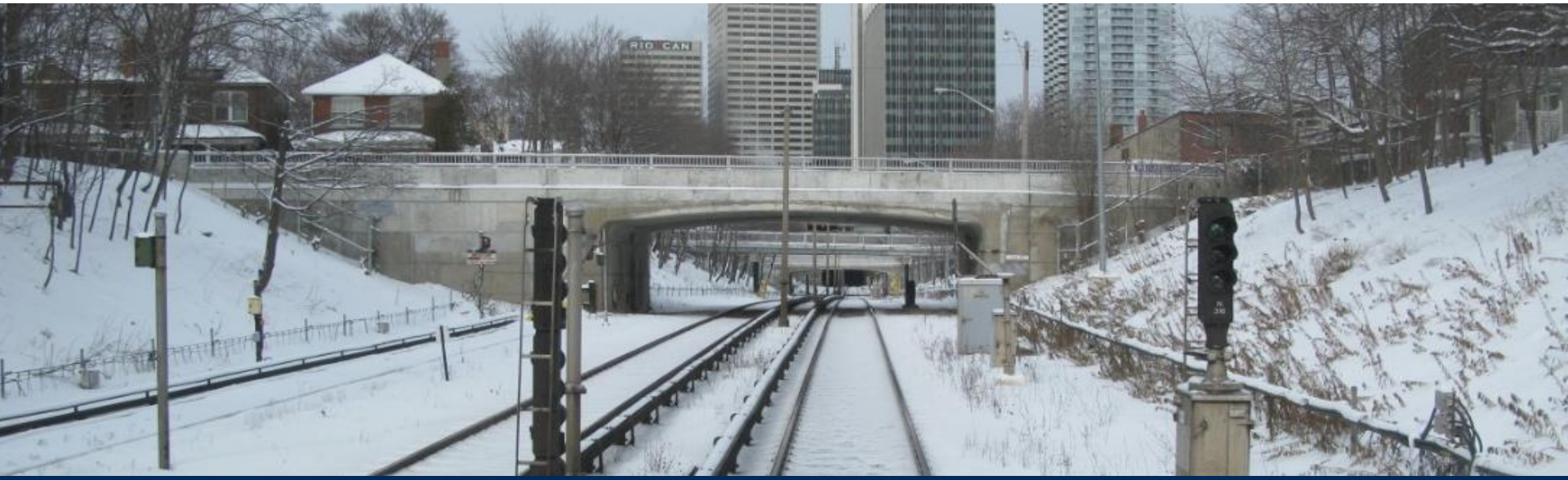
Discussion and conclusion

- Weather conditions, in terms of the amount of snow on the ground and rainfall interactions with outdoor tracks, have also a significant association with the frequency and duration of service interruptions



Discussion and conclusion

- The study provides policy makers with effective information related to the impact of outdoor tracks and weather conditions on subway system interruptions
- Support planning for a resilient public transport system and to justify increases in capital costs for infrastructure.



The End…

Thank you!

The 2017 Transportation Research Board (TRB) Annual Meeting - January 8–12, 2017

Ehab Diab, Ph.D.
Postdoctoral Fellow
ehab.diab@utoronto.ca

Amer Shalaby, Ph.D., P.Eng
Professor
amer@ecf.utoronto.ca

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