Automated Methods for Traffic Data Collection and Surrogate Measures of Safety

Presentation at the Chair of Traffic Engineering and Control
Technische Universität München

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POLYTECHNIQUE MONTRÉAL
WORLD-CLASS ENGINEERING

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Outline

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A World Health Issue

Over 1.2 million people die each year on the world's roads, and between 20 and 50 million suffer non-fatal injuries. In most regions of the world this epidemic of road traffic injuries is still increasing.
(Global status report on road safety, World Health Organization, 2009)

A World Health Issue

TOTAL 2004

RANK	LEADING CAUSE	%
1	Ischaemic heart disease	12.2
2	Cerebrovascular disease	9.7
3	Lower respiratory infections	7.0
4	Chronic obstructive pulmonary disease	5.1
5	Diarrhoeal diseases	3.6
6	HIV/AIDS	3.5
7	Tuberculosis	2.5
8	Trachea, bronchus, lung cancers	2.3
9	Road traffic injuries	2.2
10	Prematurity and low birth weight	2.0
11	Neonatal infections and other	1.9
12	Diabetes mellitus	1.9
13	Malaria	1.7
14	Hypertensive heart disease	1.7
15	Birth asphyxia and birth trauma	1.5
16	Self-inflicted injuries	1.4
17	Stomach cancer	1.4
18	Cirrhosis of the liver	1.3
19	Nephritis and nephrosis	1.3
20	Colon and rectum cancers	1.1

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10	HIV/AIDS	2.0
11	Nephritis and nephrosis	1.9
12	Self-inflicted injuries	1.9
13	Liver cancer	1.7
14	Colon and rectum cancer	1.7
15	Oesophagus cancer	1.5
16	Violence	1.4
17	Alzheimer and other dementias	1.4
18	Cirrhosis of the liver	1.3
19	Breast cancer	1.3
20	Tuberculosis	1.1

Source: World health statistics 2008 (http://www.who.int/whosis/whostat/2008/en/index.html)

Methods for Road Safety Analysis

There are two main categories of methods, whether they are based on direct observation or not

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   - traditional road safety analysis relying on historical collision data
   - vehicular accident reconstruction

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   - traditional road safety analysis relying on historical collision data
   - vehicular accident reconstruction
2. Road user behaviour and accidents are directly observed
   - naturalistic driving studies
   - surrogate measures of safety

Main Issues with Traditional Methods for Road Safety Analysis

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2. Small data quantity
3. Limited quality of the data reconstituted after the event, with a bias towards more damaging collisions
4. Traditional road safety analysis is reactive
   - the following paradox ensues: safety analysts need to wait for accidents to happen in order to prevent them

Need for Proactive Methods for Road Safety Analysis

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- These methods should
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  - be related to traffic events that are more frequent than collisions and can be observed in the field
  - be correlated to collisions, logically and statistically

Automated Video Analysis

- One of the main issues of existing proactive methods is their reliance on manual data collection, which is costly and may not be reliable because of observer subjectivity and inter and intra-observer variability
- One solution is automated video analysis, which has several advantages
  - video sensors are easy to install (or can be already installed)
  - video sensors are inexpensive
  - video data can provide rich traffic description (e.g. road user tracking)
  - video sensors can cover large areas
  - video recording allows verification at a later stage
  - open source software provides many tools for computer vision

Automated Video Analysis

Video analysis enables various types of studies:

- road user behaviour: motorized and non-motorized users
- surrogate measures of safety
- “big data”

Remainder of the Talk

- Automated video analysis
- Automated, robust and generic probabilistic framework for surrogate safety analysis
- Case studies of automated video analysis

Outline

Automated Video Analysis

Image Sequence

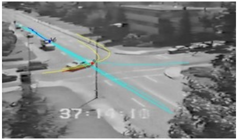
+

Camera Calibration

+

Labeled Images for Road User Type

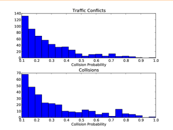
Road User Trajectories



Interactions

Applications

Motion patterns, volume, origin-destination counts, driver behavior



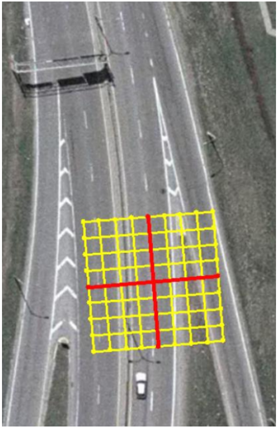
Traffic conflicts, exposure and severity measures, interacting behavior

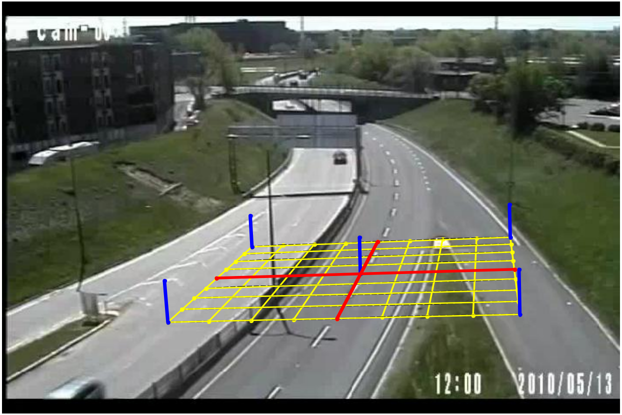
Step 1: Video Data Collection

[Jackson et al., 2013]

Step 2: Data Preparation

In particular, camera calibration: homography and distortion (if any)





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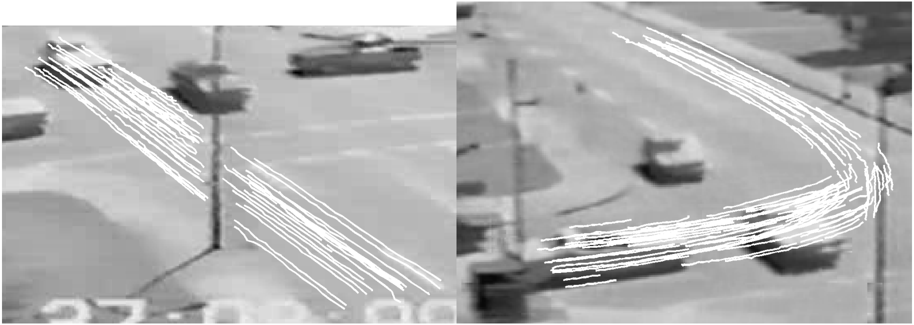
Step 3: Moving Road User Detection, Tracking and Classification



Good enough for safety analysis and other applications in busy urban road locations, including the study of pedestrians and pedestrian-vehicle interactions [Saunier and Sayed, 2006]

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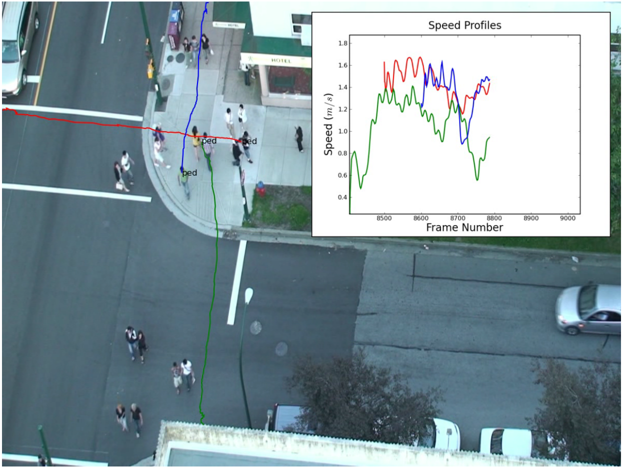

[Saunier et al., 2011]

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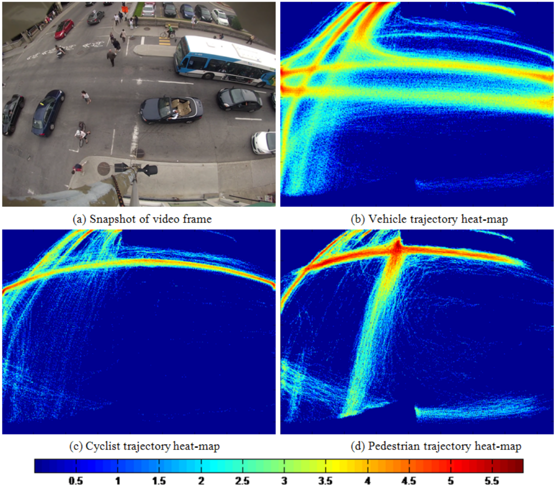


(a) Snapshot of video frame

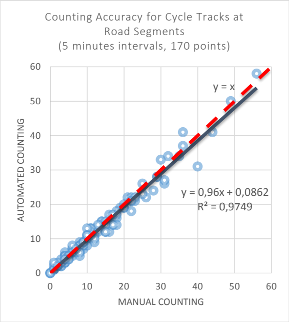
(b) Vehicle trajectory heat-map

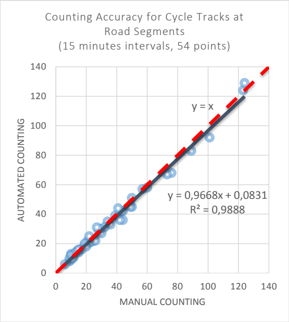
(c) Cyclist trajectory heat-map

(d) Pedestrian trajectory heat-map

(e) Scale used for trajectorie heat-maps (log-scale)

Validating Cyclist Counts in Mixed Traffic

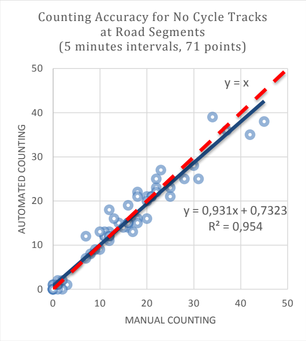


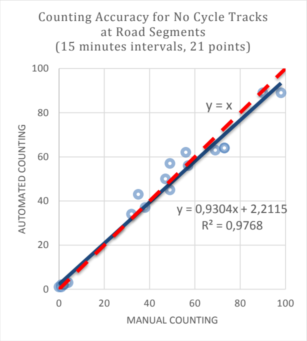


(a)

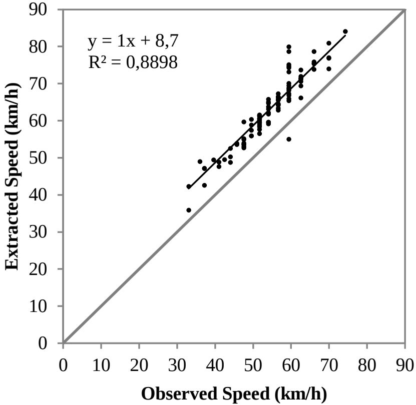
(b)

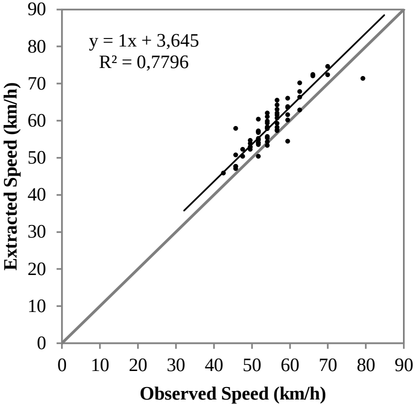
Validating Cyclist Counts in Mixed Traffic





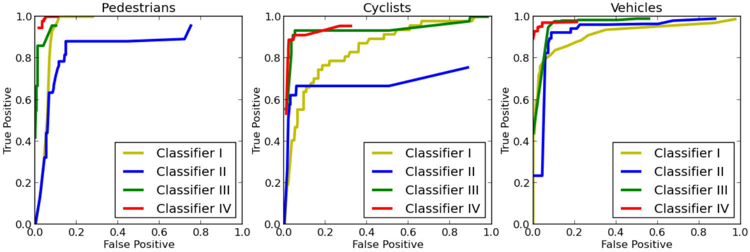
Disaggregated Vehicle Speed Validation





[Anderson-Trocme et al., 2015]

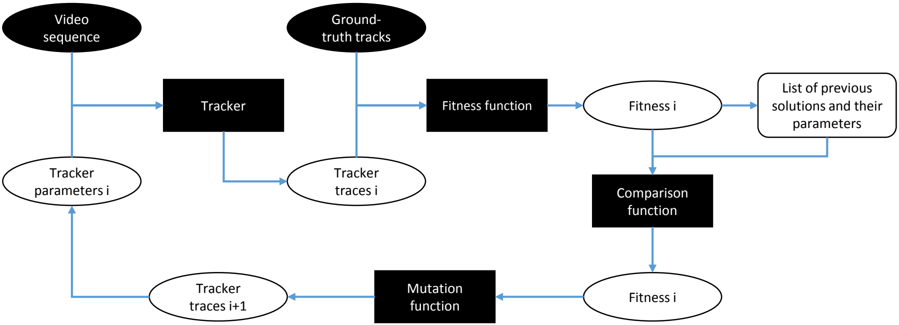
Road User Classification in Dense Mixed Traffic



ROC Curves

[Zangenehpour et al., 2014]

Tracking Parameter Optimization



[Ettehadieh et al., 2015]

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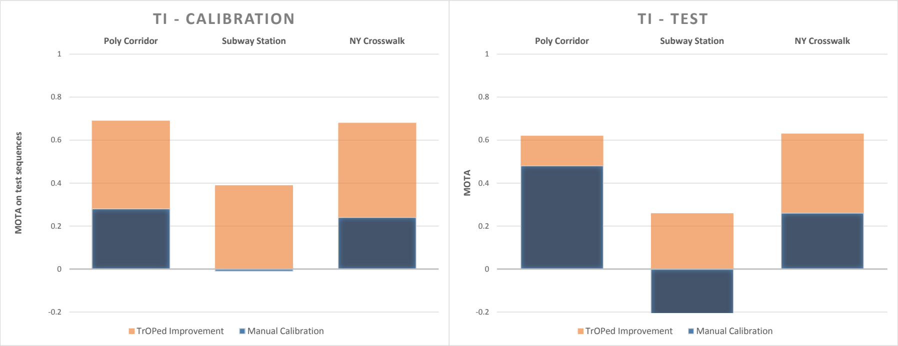

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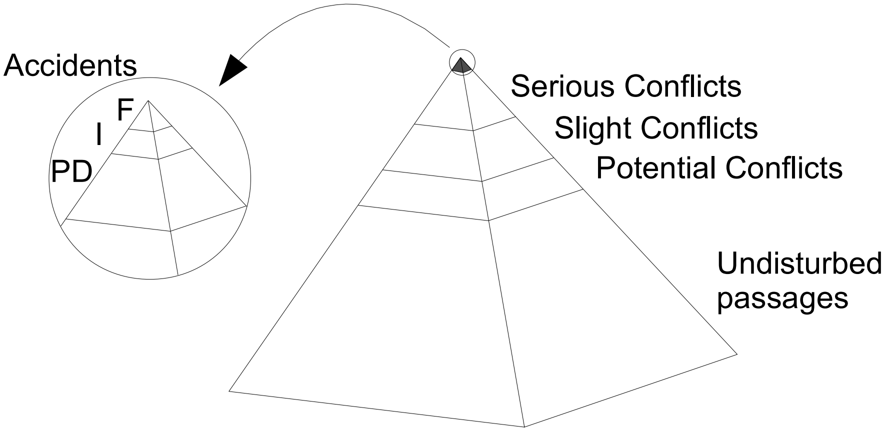
Outline

1. Motivation
2. Automated Video Analysis
3. Probabilistic Framework for Automated Road Safety Analysis
4. Case Studies
5. Ongoing Work
6. Conclusion

Traffic Conflicts

A traffic conflict is "an observational situation in which two or more road users approach each other in space and time to such an extent that a collision is imminent if their movements remain unchanged" [Amundsen and Hydén, 1977]

The Safety/Severity Hierarchy



Surrogate Measures of Safety

- Continuous measures
  - Time-to-collision (TTC)
  - Gap time (GT) (=predicted PET)
  - Deceleration to safety time (DST)
  - Speed-based indicators, etc.
- Unique measures per conflict
  - Post-encroachment time (PET)
  - Evasive action(s) (harshness), subjective judgment, etc.
- Number of traffic events, e.g. (serious) traffic conflicts

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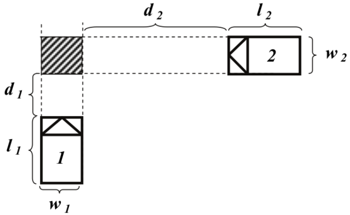
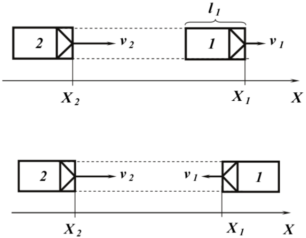
Which indicators are related to collision probability and/or severity?

Time-to-Collision





$$TTC = \frac{d_2}{v_2} \text{ if } \frac{d_1}{v_1} < \frac{d_2}{v_2} < \frac{d_1 + l_1 + w_2}{v_1}$$

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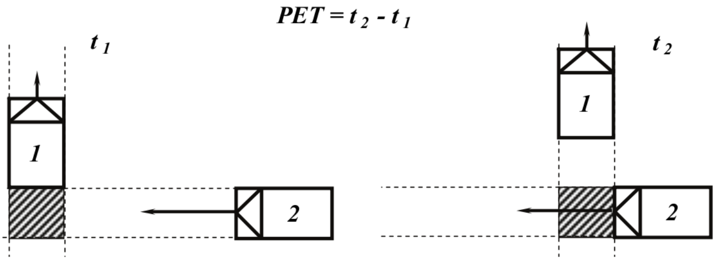
$$TTC = \frac{X_1 - X_2 - l_1}{v_1 - v_2} \text{ if } v_2 > v_1 \text{ (rear end)}$$

$$TTC = \frac{X_1 - X_2}{v_1 + v_2} \text{ (head on)}$$

Post-Encroachment Time (PET) and Predicted PET



- PET is the time difference between the moment an offending road user leaves an area of potential collision and the moment of arrival of a conflicted road user possessing the right of way
- pPET is calculated at each instant by extrapolating the movements of the interacting road users in space and time

Issues with Traffic Conflict Techniques

- Several methods for surrogate safety analysis exist ("old" and "new" traffic conflict techniques) but there is a lack of comparison and validation
- Issues related to the (mostly) manual data collection process
  - cost
  - reliability and subjectivity: intra- and inter-observer variability
- Mixed validation results (and unavailable literature)

Rethinking the Collision Course

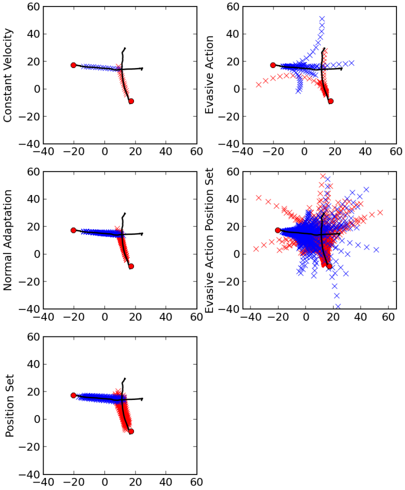
- A traffic conflict is "an observational situation in which two or more road users approach each other in space and time to such an extent that a collision is imminent if their movements remain unchanged"
- For two interacting road users, many chains of events may lead to a collision
- It is possible to estimate the probability of collision if one can predict the road users' future positions
  - the motion prediction method must be specified

Motion Prediction

- Predict trajectories according to various hypotheses
  - iterate the positions based on the driver input (acceleration and steering)
  - learn the road users' motion patterns (including frequencies), represented by actual trajectories called prototypes, then match observed trajectories to prototypes and re-sample
- Advantage: generic method to detect a collision course and measure safety indicators, as opposed to several cases and formulas (e.g. in [Gettman and Head, 2003])

[Saunier et al., 2007, Saunier and Sayed, 2008, Mohamed and Saunier, 2013, St-Aubin et al., 2014]

Various Methods for Motion Prediction



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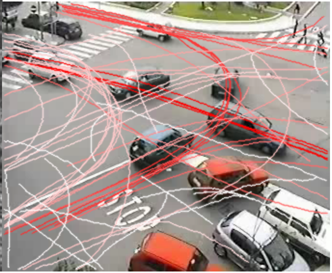

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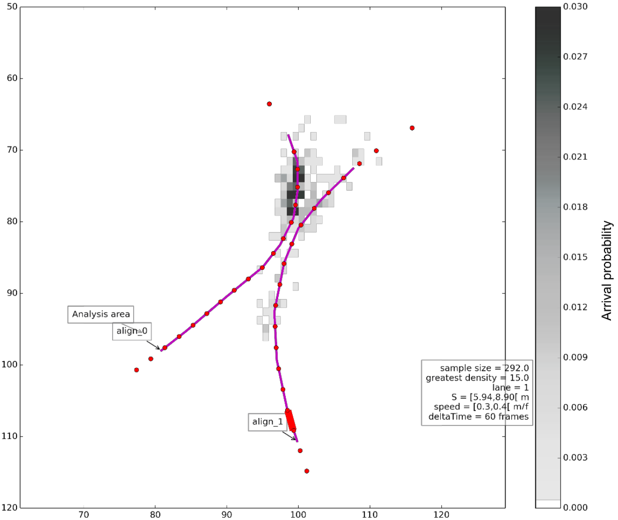
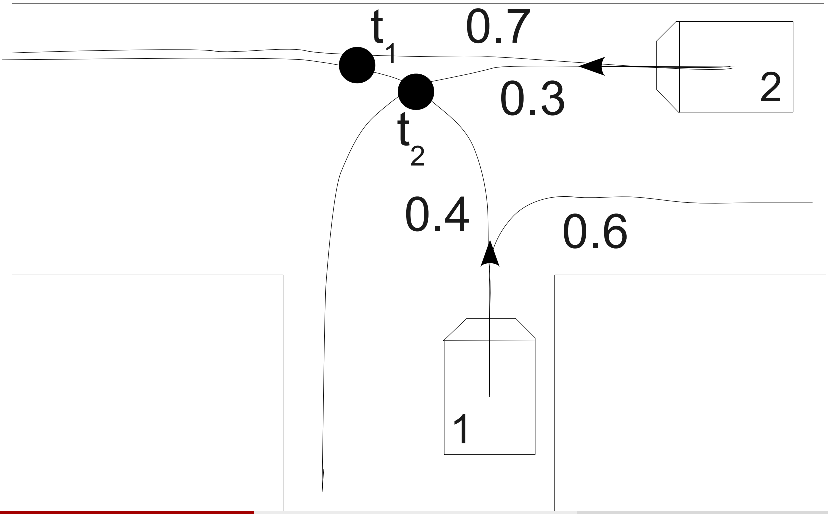


Predicting Potential Collision Points



Collision Points and Crossing Zones

Using of a finite set of predicted trajectories, enumerate the collision points CP_n and the crossing zones CZ_m. Safety indicators can then be computed:

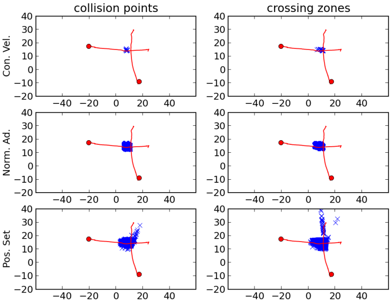
$$P(Collision(U_i, U_j)) = \sum_n P(Collision(CP_n))$$

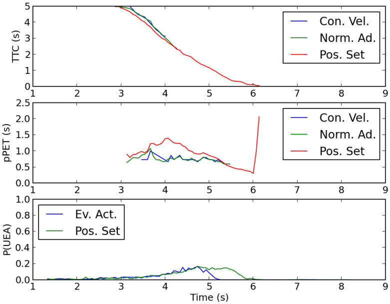
$$TTC(U_i, U_j, t_0) = \frac{\sum_n P(Collision(CP_n))\ t_n}{P(Collision(U_i, U_j))}$$

$$pPET(U_i, U_j, t_0) = \frac{\sum_m P(Reaching(CZ_m))\ |t_{i,m} - t_{j,m}|}{\sum_m P(Reaching(CZ_m))}$$

[Saunier et al., 2010, Mohamed and Saunier, 2013, Saunier and Mohamed, 2014]

Examples of Safety Indicators





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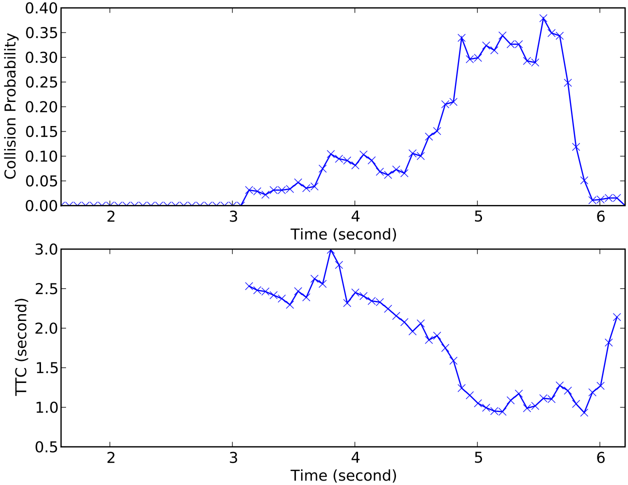

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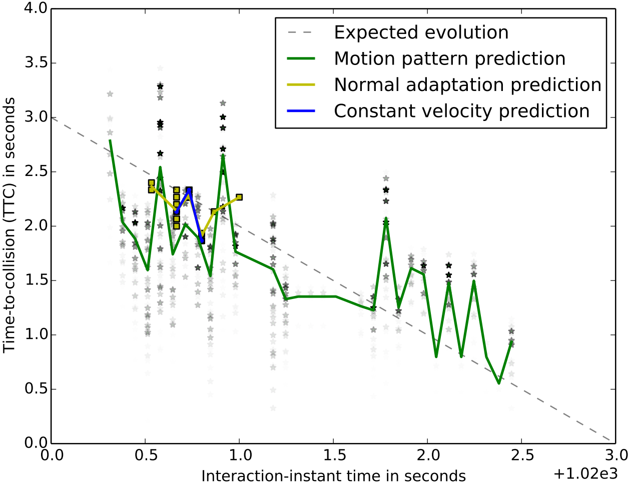
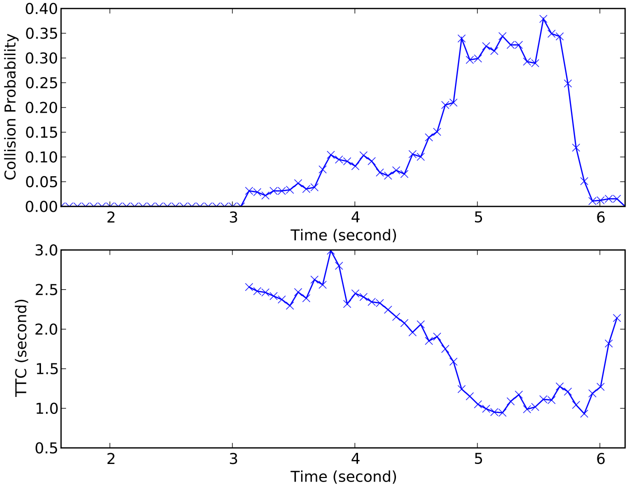


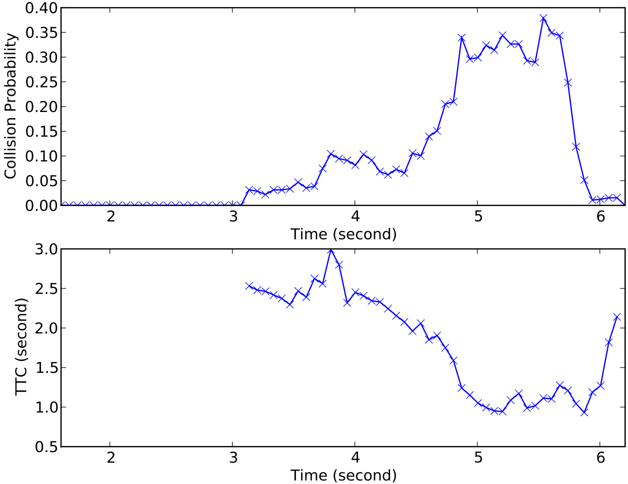
Interpretation?

For each interaction, we have



Interpretation?

How should data be aggregated?



Past research: The Whole Hierarchy

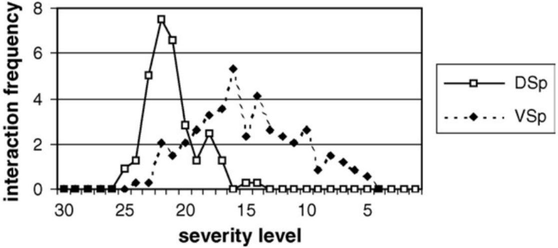


Fig. 6. Interaction frequency (interactions per observation hour) for different severity levels. Straight ahead driving vehicles versus pedestrians. The pedestrian is taking evasive action. A non-signalised intersection (DSp) and a signalised intersection (VSp).

[Svensson, 1998, Svensson and Hydén, 2006]

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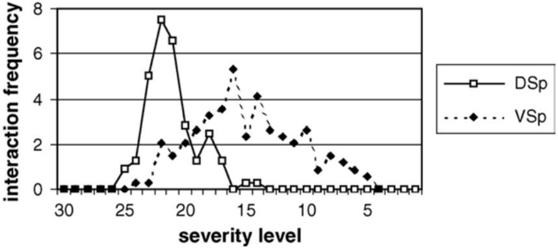
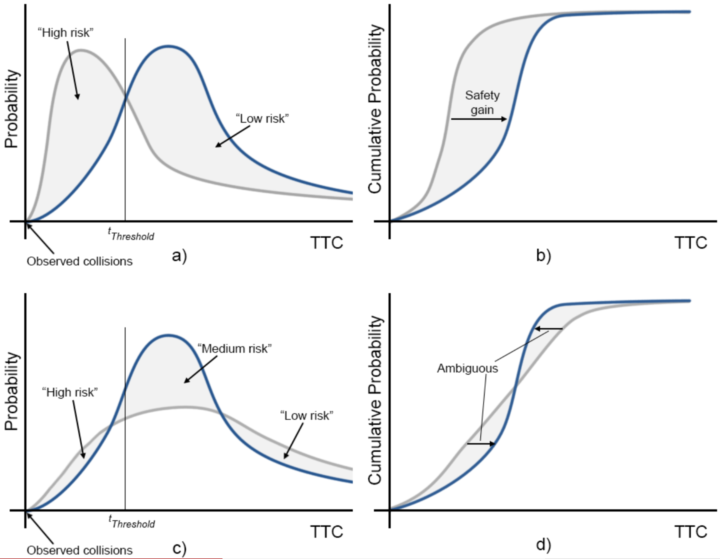


Fig. 6. Interaction frequency (interactions per observation hour) for different severity levels. Straight ahead driving vehicles versus pedestrians. The pedestrian is taking evasive action. A non-signalised intersection (DSp) and a signalised intersection (VSp).

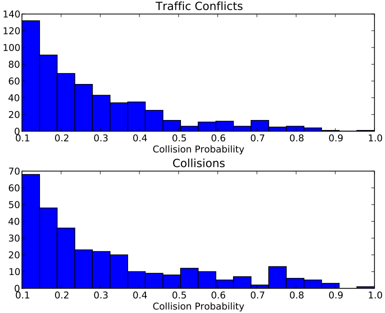
Feedback and learning process: collisions with injuries occurred at the signalized intersection [Svensson, 1998, Svensson and Hydén, 2006]

Various Interpretation Methods

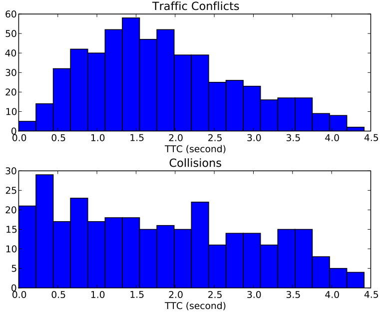


Various Interpretation Methods

Maximum Collision Probability



Minimum TTC



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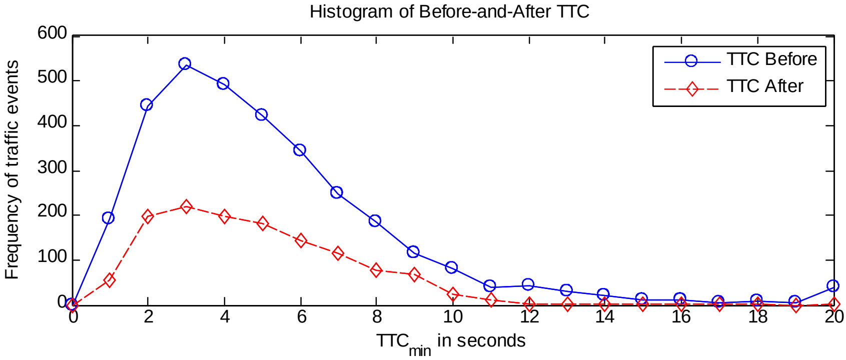

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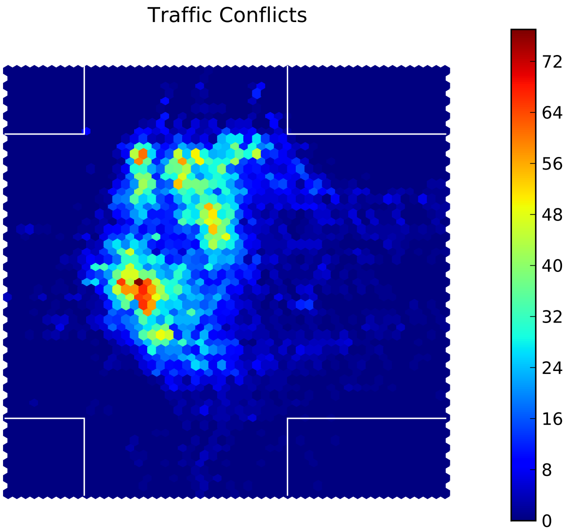
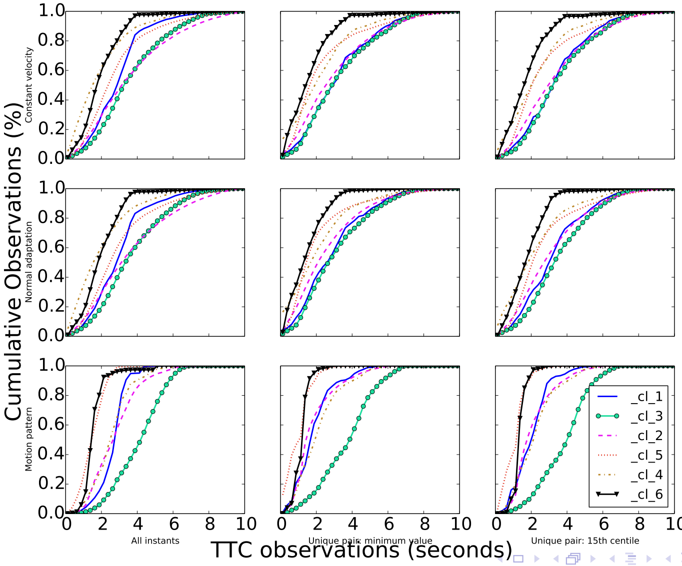


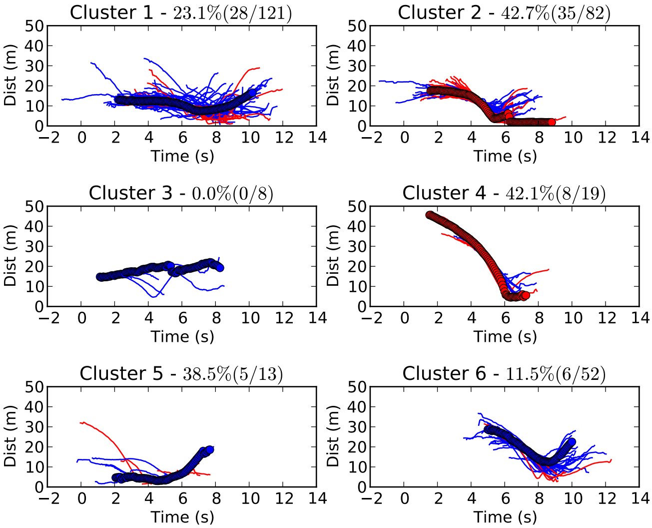
Various Interpretation Methods



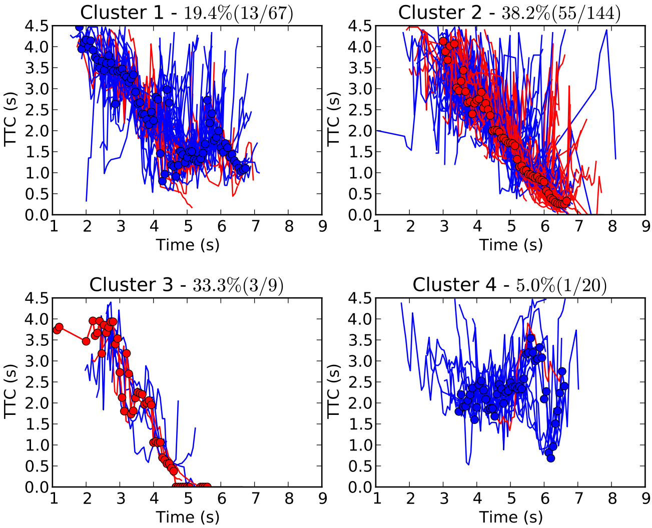
Various Interpretation Methods

Model I. Cycle track on the right vs. no cycle track						
Number of Observations = 2880			Log likelihood = -1420		Pseudo R^2 = 0.264	
	Coef.	Std. Err.	z	P > |z|	[95% Conf. Interval]	
Cycle Track on Right	0.4303	0.1297	3.32	0.001	0.1760	0.6846
Turning-Vehicle Flow for 15s before to 15s after	-1.4089	0.0551	-25.56	0.000	-1.5170	-1.3009
Number of Lane on the Main Road	-0.2354	0.0654	-3.60	0.000	-0.3636	-0.1073
Bus Stop	0.2658	0.1336	1.99	0.047	0.0039	0.5277
Cut-off 1	-6.6884	0.2836			-7.2443	-6.1326
Cut-off 2	-3.8927	0.1968			-4.2785	-3.5070
Cut-off 3	-2.5246	0.1812			-2.8798	-2.1695
Model II. Cycle track on the left vs. no cycle track						
Number of Observations = 4803			Log likelihood = -3241		Pseudo R^2 = 0.288	
	Coef.	Std. Err.	z	P > |z|	[95% Conf. Interval]	
Cycle Track on Left	-0.1618	0.1186	-1.36	0.172	-0.3941	0.0706
Bicycle Flow for 10s before	0.0827	0.0302	2.74	0.006	0.0235	0.1419
Turning-Vehicle Flow for 15s before to 15s after	-1.3938	0.0342	-40.79	0.000	-1.4608	-1.3268
Cut-off 1	-7.4890	0.2074			-7.8956	-7.0825
Cut-off 2	-3.5944	0.1243			-3.8380	-3.3509
Cut-off 3	-2.0168	0.1132			-2.2387	-1.7950
Model III. Cycle track on the right vs. cycle track on the left						
Number of Observations = 6567			Log likelihood = -4030		Pseudo R^2 = 0.291	
	Coef.	Std. Err.	z	P > |z|	[95% Conf. Interval]	
Cycle Track on Left	-0.5351	0.0921	-5.81	0.000	-0.7155	-0.3546
Bicycle Flow for 10s before	0.6000	0.0268	2.23	0.025	0.0074	0.1126
Turning-Vehicle Flow for 15s before to 15s after	-1.3544	0.0304	-44.52	0.000	-1.4141	-1.2948
Number of Lane on the Main Road	-0.1592	0.0660	-2.41	0.016	-0.2884	-0.0299
Number of Lane on the Turning Road	0.3855	0.1144	3.37	0.001	0.1613	0.6097
Cut-off 1	-7.7501	0.3077			-8.3532	-7.1471
Cut-off 2	-3.7916	0.2684			-4.3177	-3.2655
Cut-off 3	-2.2953	0.2650			-2.8148	-1.7758

Various Interpretation Methods



Various Interpretation Methods



Outline

Lane-Change Bans at Urban Highway Ramps

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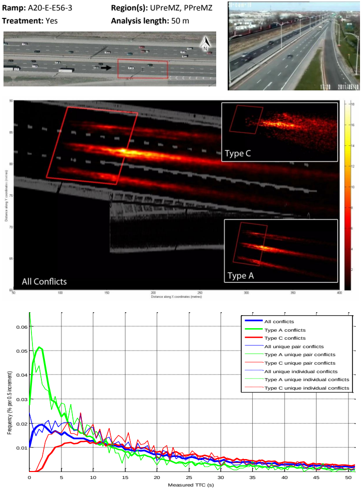


Figure 37 – Conflict analysis Cam20-16-Dorval (Treated).

Treated site (with lane marking) [St-Aubin et al., 2012, St-Aubin et al., 2013a]

Lane-Change Bans at Urban Highway Ramps

70

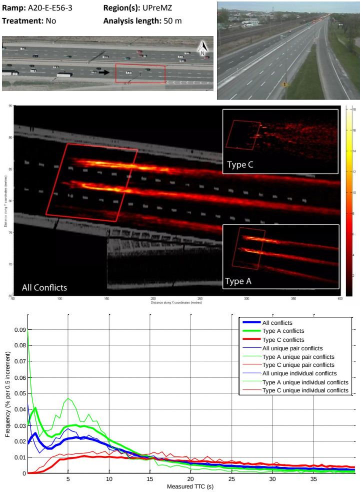
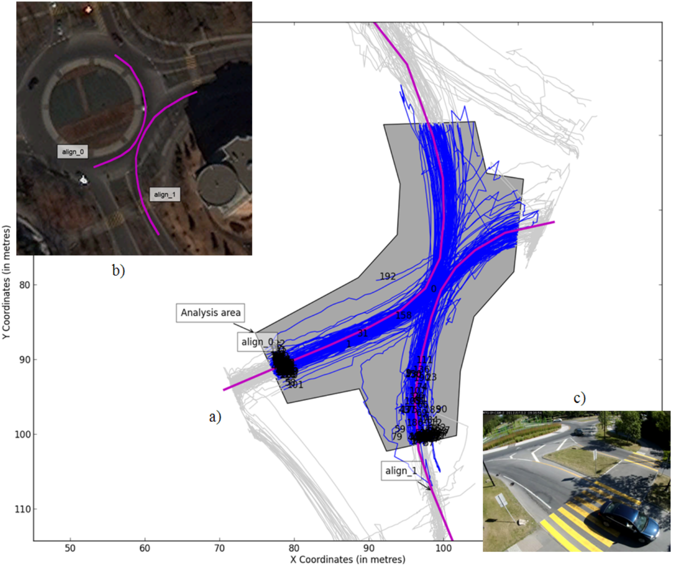


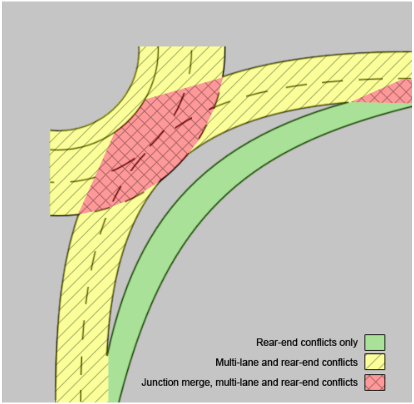
Figure 27 – Conflict analysis Cam20-16-Dorval (Untreated).

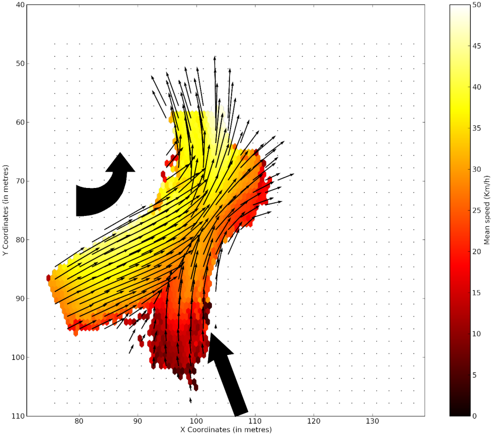
Untreated site (no lane marking)
[St-Aubin et al., 2012, St-Aubin et al., 2013a]

Big Data: Roundabout Safety in Québec



Speed Fields in Roundabouts



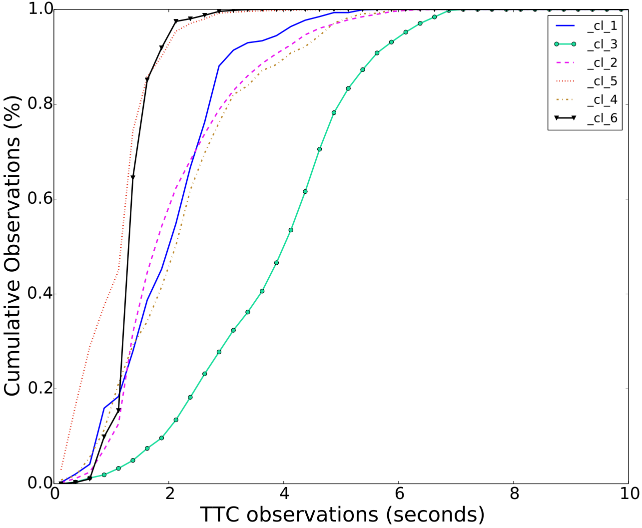


[St-Aubin et al., 2013b]

K-means cluster profile for TTC regression

#	Description	N_{zones}	N_{obs}
1	Small single and double lane residential collectors	11	4,200
2	Single-lane regional highways and arterials with speed limits of 70-90 km/h and mostly polarized flow ratios	16	26,243
3	2-lane arterials with very high flow ratios	5	13,307
4	Hybrid lane 1$-$ $>$2 2$-$ $>$1 arterials with very low flow ratios	3	4,809
5	Traffic circle converted to roundabout (2 lanes, extremely large diameters, tangential approach angle)	4	10,295
6	Single-lane regional highway with large-angle quadrants (140 degrees) and mixed flow ratios	2	2,235

TTC Distribution Comparison by Cluster



[St-Aubin et al., 2015]

Analysis of Bicycle Facilities in Montreal

- Bicycle boxes (only 4 in Montreal)

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  - video data collected at 2 sites, before and after the installation of a bicycle box, and 2 control sites without

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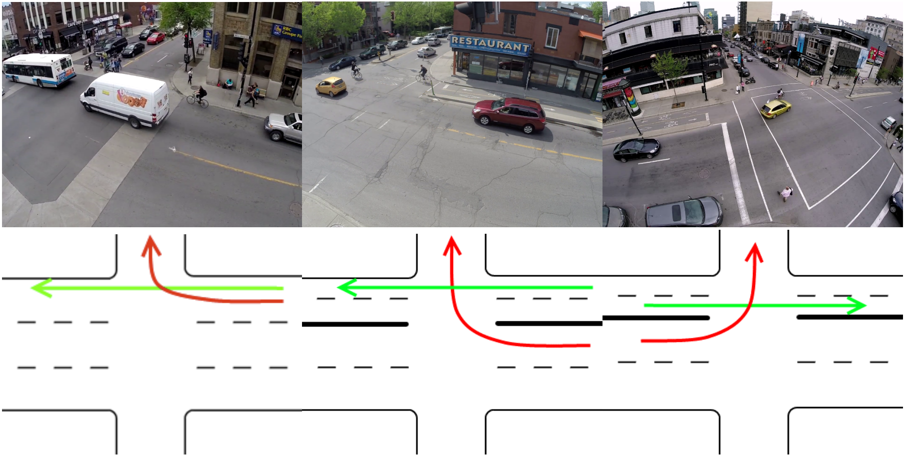
    - video data collected at 2 sites, before and after the installation of a bicycle box, and 2 control sites without
- Cycle tracks: 650 km of bicycle network in 2015

Model of Dangerous Interactions at Bicycle Boxes

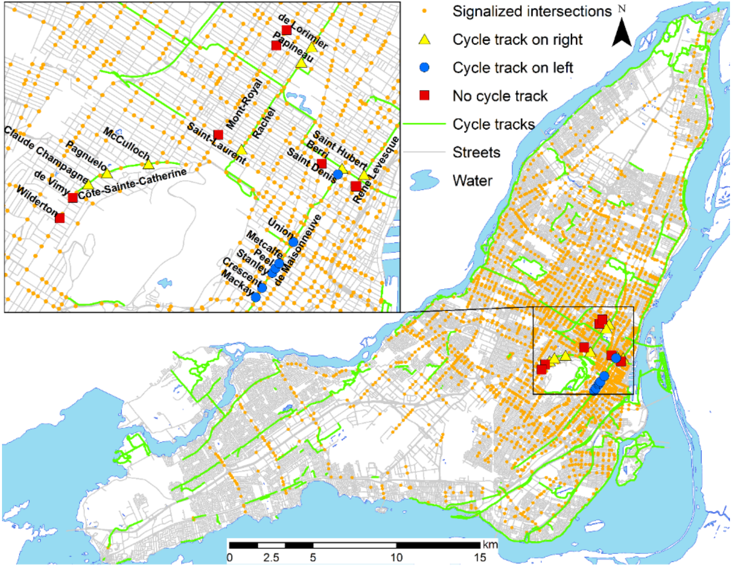
Explanatory variables	Interaction Type 1						Interaction Type 2					
	Interaction (PET < 5s)			Dangerous Interaction (PET < 1.5s)			Interaction (PET < 5s)			Dangerous Interaction (PET < 1.5s)		
	Coef.	p-val.	Elas.	Coef.	p-val.	Elas.	Coef.	p-val.	Elas.	Coef.	p-val.	Elas.
Constant	-0.559	0.00	-	-1.954	0.00	-	-2.994	0.00	-	-4.354	0.00	-
Bicycle Flow during 30s before	0.423	0.00	7.7 %	0.434	0.00	2.1 %	-	-	-	-	-	-
Vehicle Flow 1 during 30s before	0.091	0.00	1.6 %	0.040	0.04	0.2 %	0.063	0.00	0.4 %	-	-	-
Vehicle Flow 2 during 30s before	-0.086	0.00	-1.6 %	-0.082	0.01	-0.4 %	0.117	0.00	0.8 %	0.097	0.00	0.1 %
Presence of Bicycle Box	**-0.739**	**0.00**	**-14 %***	**-1.226**	**0.00**	**-7 %***	**-0.726**	**0.00**	**-5 %***	**-2.050**	**0.00**	**-2 %***
Observations	1054						1054					
Percentage of positive obs.	27.6 %			7.5 %			9.8 %			1.3 %		
Log-likelihood	-544.00			-251.48			-299.85			-66.44		
Pseudo R^2	0.133			0.109			0.117			0.110		

* Elasticity for discrete change of dummy variable from 0 to 1

Turning Vehicle Interactions with Cycle Tracks



Site Selection

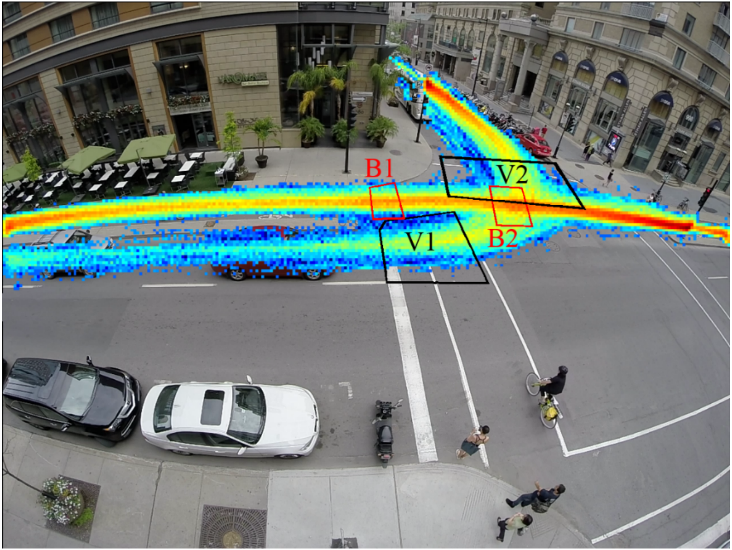


Site Selection

	# intersections	Duration
Cycle track on the right	8 intersections	37 h
Cycle track on the left	7 intersections	22 h
No cycle track	8 intersections	31 h
Total	23 intersections	90 h

Videos were collected on weekdays during the evening peak period from 3pm to 7pm

Road User Selection



Three PET Ordered Logit Models

	Model I. Cycle track on the right vs. no cycle track			Model II. Cycle track on the left vs. no cycle track			Model III. Cycle track on the right vs. cycle track on the left		
	Coef.	Std. Err.	Sig.	Coef.	Std. Err.	Sig.	Coef.	Std. Err.	Sig.
Cycle Track on Right	0.395	0.181	0.03	-	-	-	-	-	-
Cycle Track on Left	-	-	-	Not Significant			-0.513	0.131	0.00
Bicycle Flow for 5s before to 5s after	Not Significant			0.088	0.038	0.02	0.066	0.034	0.05
Turning-Vehicle Flow for 5s before to 5s after	-2.771	0.132	0.00	-3.265	0.090	0.00	-3.131	0.080	0.00
Number of Lanes on the Main Road	-0.151	0.078	0.05	Not Significant			Not Significant		
Number of Lanes on the Turning Road	Not Significant			0.324	0.146	0.03	0.457	0.178	0.01
Cut-off 1	-6.599	0.353	0.00	-7.372	0.301	0.00	-7.621	0.323	0.00
Cut-off 2	-4.233	0.273	0.00	-3.807	0.223	0.00	-4.125	0.265	0.00
Cut-off 3	-3.150	0.256	0.00	-2.102	0.211	0.00	-2.479	0.258	0.00
Number of Observations	2880			4803			6567		
Log likelihood	-804			-1876			-2330		

Outline

Framework for the Calibration and Validation of Traffic Micro-simulation

- Terrible state of practice (MULTITUDE project)

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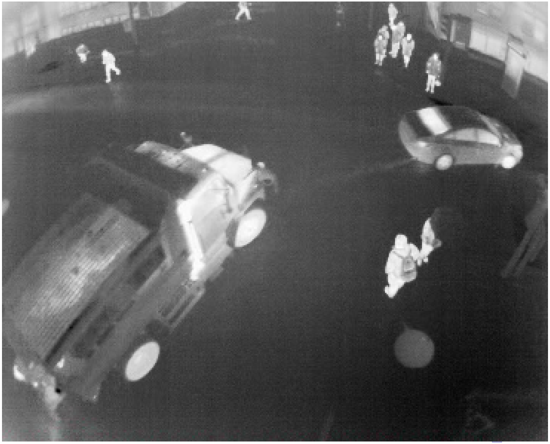
  - Fit distributions of microscopic measures (headway, number of lane changes)
  - Use derivative-free (“black box”) optimization software NOMAD
- Partnership with WSP (consulting company)

Night-time Safety

- Study of the link between lighting and safety [Nabavi Niaki et al., 2014]
- Night-time observations: video data from thermal camera



Outline

Conclusion

- Surrogate methods for safety analysis are complementary methods to understand collision processes and better diagnose safety

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- Surrogate methods for safety analysis are complementary methods to understand collision processes and better diagnose safety
- The challenge is to propose a simple and generic framework for surrogate safety analysis

Open Questions

- How can we aggregate indicators over time and space (and severity), without hiding information?

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- How can we aggregate indicators over time and space (and severity), without hiding information?
- How can we compare the various methods and indicators?
- How do we validate the methods? With respect to what?
- How do we account for exposure? Conflicts are, by definition, not exposure [Hauer, 1982]

Other Interests

- Traffic monitoring, probe data
- Naturalistic driving studies
- Advanced Driver Assistance Systems and vehicle automation: senior associate of the Canadian Automated Vehicles Centre of Excellence (CAVCOE)

Researchers Need to Share More

- Principle of independent reproducibility
- Need to share data and tools used to produce the results
  - public datasets and benchmarks [Saunier et al., 2014]
  - public / open source software: adoption and contributions by researchers and practitioners
- Traffic Intelligence open source project https://bitbucket.org/Nicolas/trafficintelligence

- Collaboration with Tarek Sayed (UBC), Karim Ismail (Carleton), Mohamed Gomaa Mohamed, Paul St-Aubin, Matin Nabavi Niaki (Polytechnique Montréal), Luis Miranda-Moreno, Sohail Zangenehpour, Joshua Stipancic (McGill), Aliaksei Laureshyn (Lund)
- Funded by the Natural Sciences and Engineering Research Council of Canada (NSERC), the Québec Research Fund for Nature and Technology (FRQNT) and the Québec Ministry of Transportation (MTQ), City of Montreal

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