Automated Methods for Surrogate Safety Analysis

Webinar for the District Department of Transportation

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POLYTECHNIQUE MONTRÉAL
WORLD-CLASS ENGINEERING

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Outline

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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

Methods for Road Safety Analysis

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1. Accidents are reconstituted
   - traditional road safety analysis relying on historical collision data
   - vehicular accident reconstruction
2. Road user behavior and accidents are directly observed
   - naturalistic driving studies
   - surrogate safety analysis

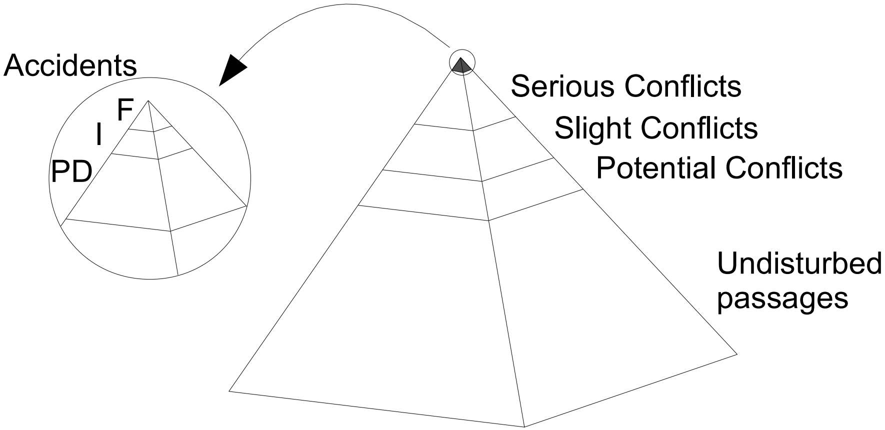
Need for Proactive (Surrogate) Methods for Road Safety Analysis

Because of the shortcomings of the traditional approaches, there is a need for methods that do not require to wait for accidents to happen

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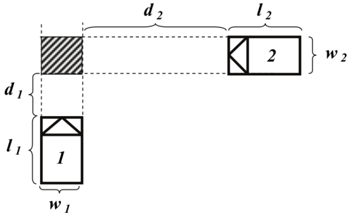
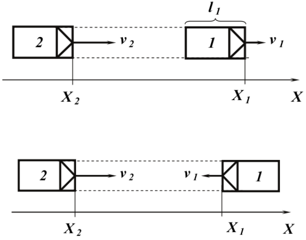
Which indicators related to collision probability and/or severity?

Time-to-Collision





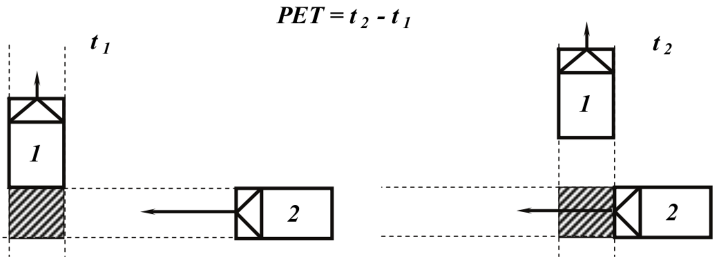
$$TTC = \frac{d_2}{v_2} \textit{ if } \frac{d_1}{v_1} < \frac{d_2}{v_2} < \frac{d_1 + l_1 + w_2}{v_1}$$

$$TTC = \frac{d_1}{v_1} \textit{ if } \frac{d_2}{v_2} < \frac{d_1}{v_1} < \frac{d_2 + l_2 + w_1}{v_2} \; (side)$$

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

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

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 traffic conflict techniques exist ("old" and "new") 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

Objectives

- Develop an automated and robust probabilistic framework for surrogate safety analysis
- Better understand collision processes and the similarities between interactions with and without a collision
- Validate the surrogate measures of safety
- Apply the method to several case studies: urban intersections, vulnerable road users, highways, roundabouts

Outline

Rethinking the Collision Course

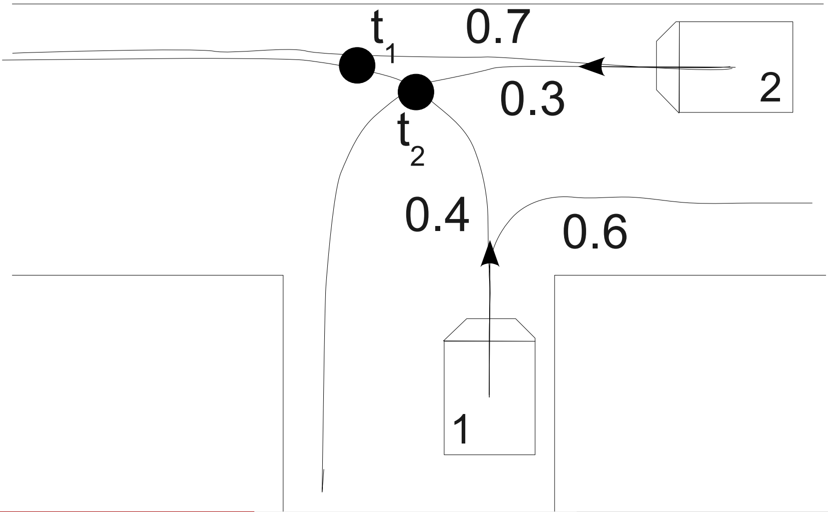
- A traffic conflict is “an observational situation in which two or more road users approach each other in space and time to such an extent that a collision is imminent if their movements remain unchanged”
- For two interacting road users, many chains of events may lead to a collision
- It is possible 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 resample
- 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]

A Simple Example



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]

Automated Video Analysis

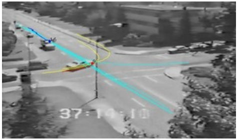
Image Sequence
+

Camera Calibration

+

Labeled Images for Road User Type

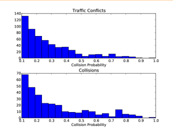
Road User Trajectories



Interactions

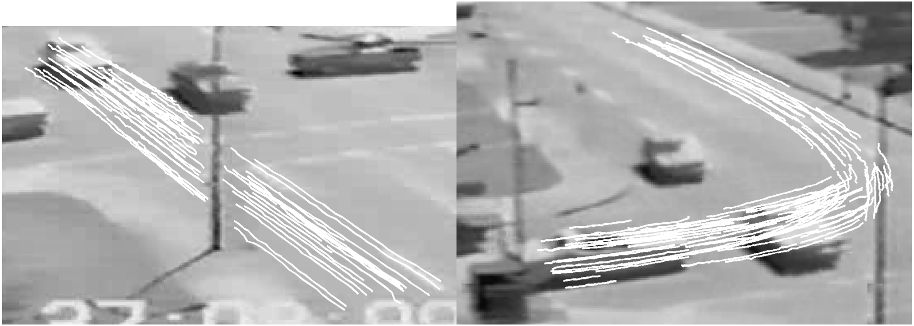
Applications

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



Traffic conflicts, exposure and severity measures, interacting behavior

Feature-based Road User Tracking in Video Data

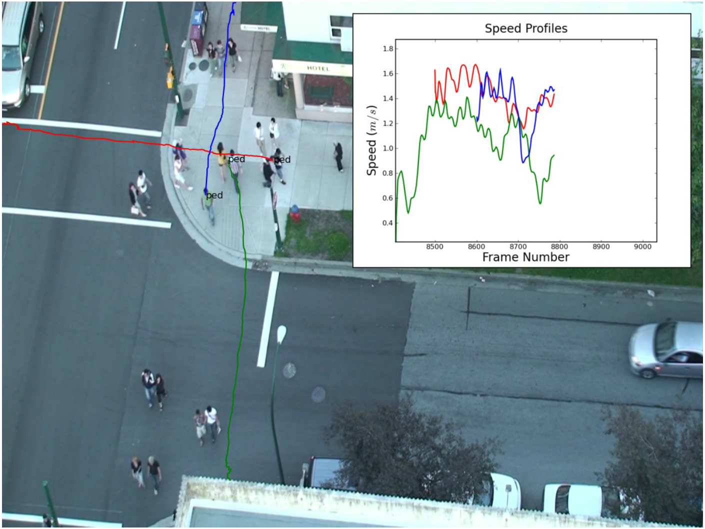


Good enough for safety analysis and other applications in busy urban road locations, including the study of pedestrians and pedestrian-vehicle interactions [Saunier and Sayed, 2006]

Flexible Mobile Video Data Collection Unit

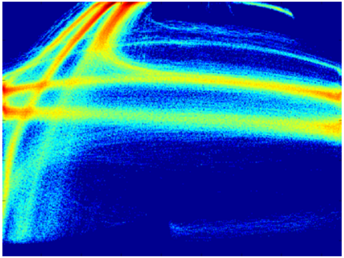
[Jackson et al., 2013]

Road User Classification [Saunier et al., 2011]

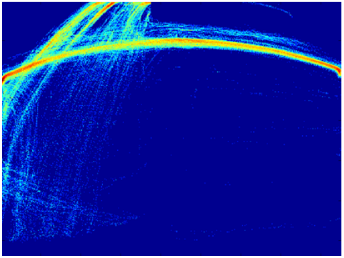


Road User Classification [Zangenehpour et al., 2014]

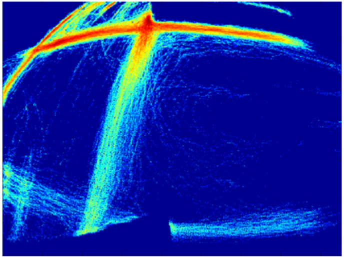
(a) Snapshot of video frame



(b) Vehicle trajectory heat-map



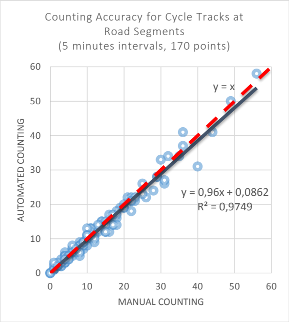
(c) Cyclist trajectory heat-map



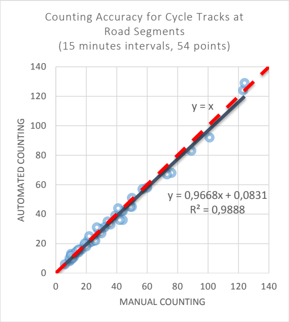
(d) Pedestrian trajectory heat-map

Outline

Validating Cyclist Counts in Mixed Traffic

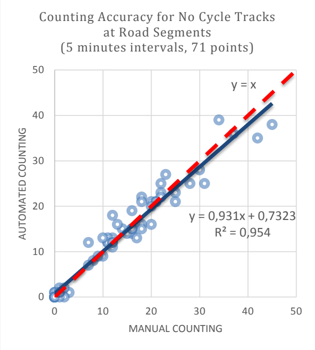


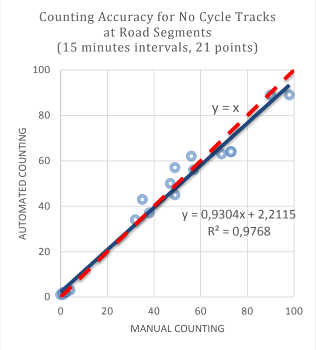
(a)

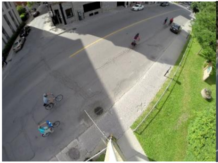


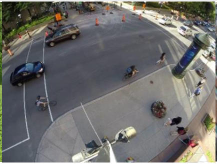
(b)

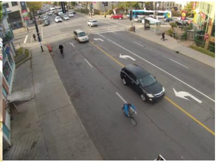
Validating Cyclist Counts in Mixed Traffic









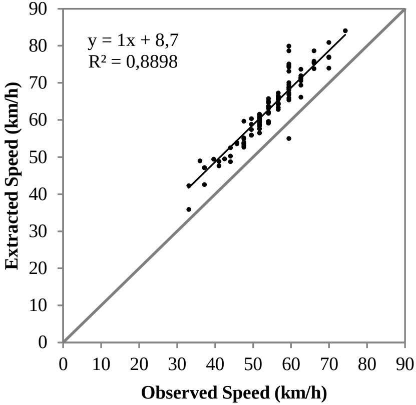


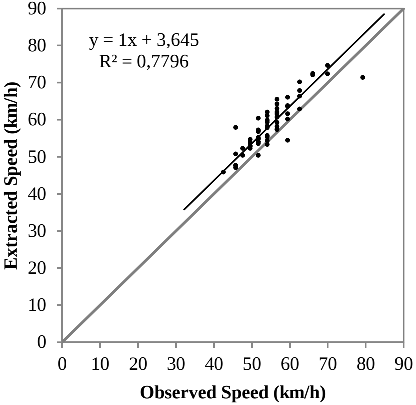
Validating Cyclist Counts in Mixed Traffic

Environment Type	Counting Interval (minutes)	Average Flow	Linear Coefficient, a*	Linear Constant, b*	Linear R^2	RMSD	MAPD	SDPD
Road segments with cycle track	5	11.3	0.96	0.09	0.97	1.59	10 %	5 %
	15	33.8	0.97	0.08	0.99	3.10	7 %	1 %
Intersections with cycle track	5	15.0	0.81	1.01	0.94	3.92	17 %	6 %
	15	44.3	0.83	2.56	0.97	9.33	12 %	3 %
Road segments without cycle track	5	12.3	0.93	0.73	0.95	2.40	13 %	7 %
	15	40.8	0.93	2.21	0.98	4.77	11 %	6 %
Intersections without cycle track	5	3.1	0.80	0.33	0.55	1.47	37 %	32 %
	15	9.4	0.78	1.44	0.68	2.32	19 %	6 %

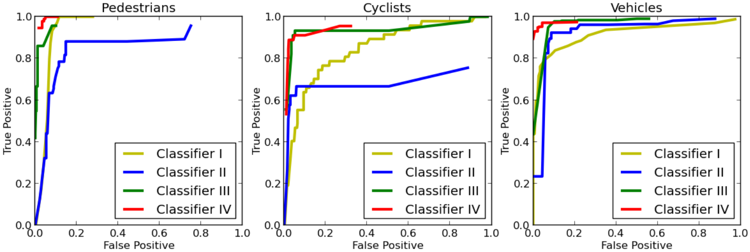
* in "Manual Count = a * Automated Count + b"

Disaggregated Vehicle Speed Validation





Road User Classification in Dense Mixed Traffic



ROC Curves

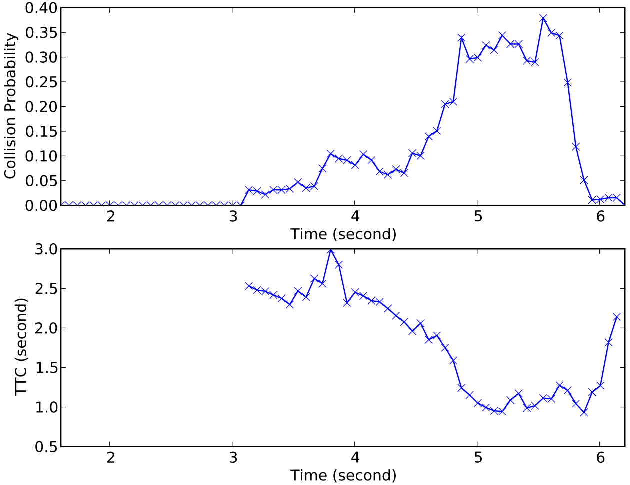
Road User Tracking (Kentucky Dataset)

Motion Prediction

Motion Prediction

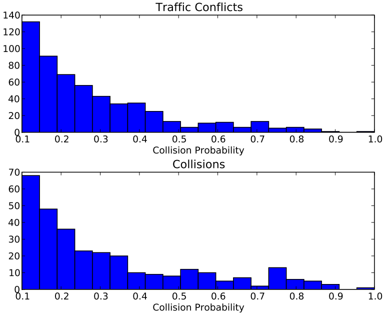
Motion Prediction

Safety Indicators

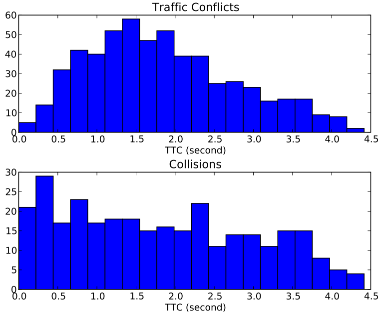


Distribution of Indicators (Event Aggregation)

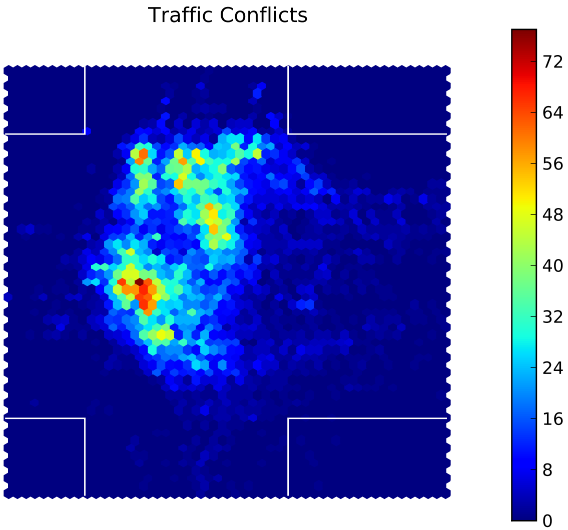
Maximum Collision Probability



Minimum TTC



Spatial Distribution of the Collision Points



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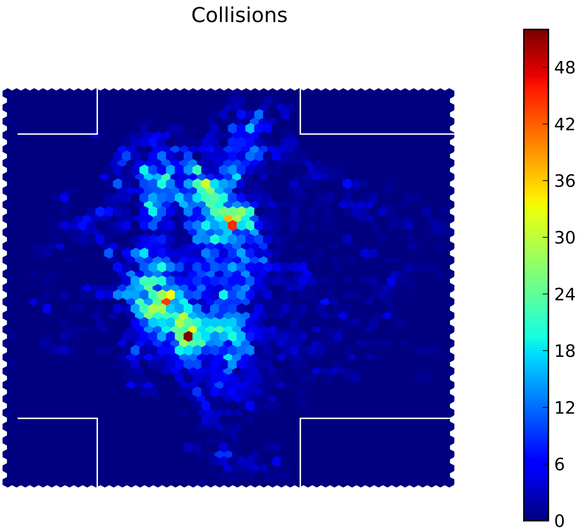
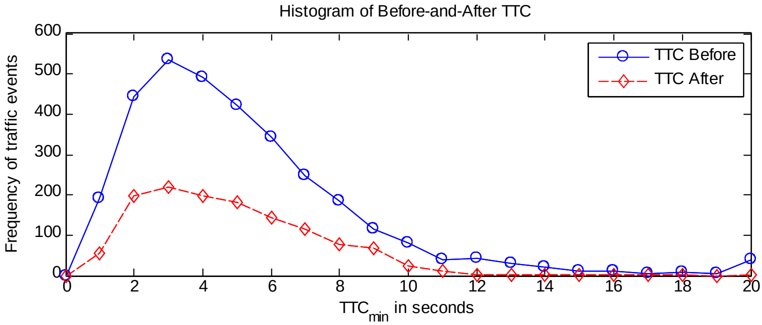


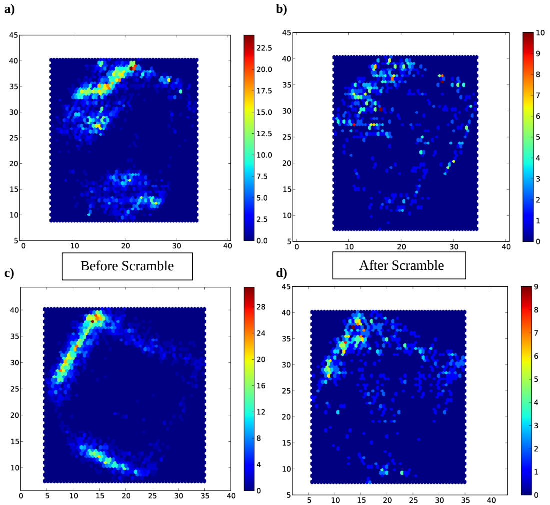
Before and After Study: Introduction of a Scramble Phase

Data collected in Oakland, CA [Ismail et al., 2010]

Distribution of Safety Indicators



Before and After Distribution of the Collision Points



Lane-Change Bans at Urban Highway Ramps

86

Ramp: A20-E-E56-3 **Region(s):** UPreMZ, PPreMZ
Treatment: Yes **Analysis length:** 50 m

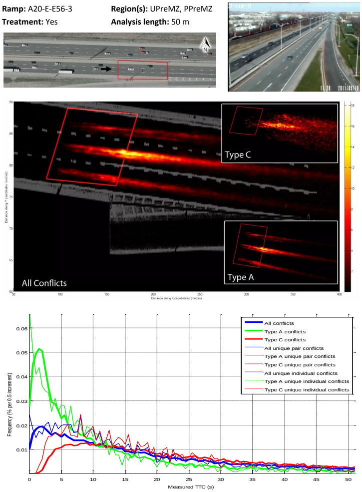


Figure 37 – Conflict analysis Cam20-16-Dorval (Treated).

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

Lane-Change Bans at Urban Highway Ramps

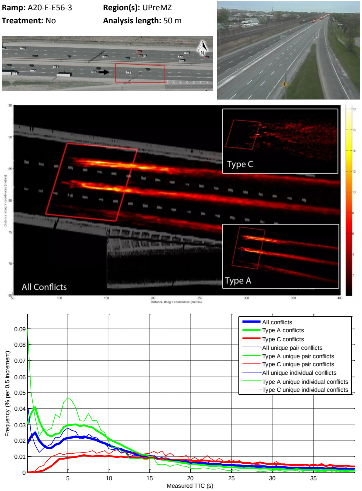
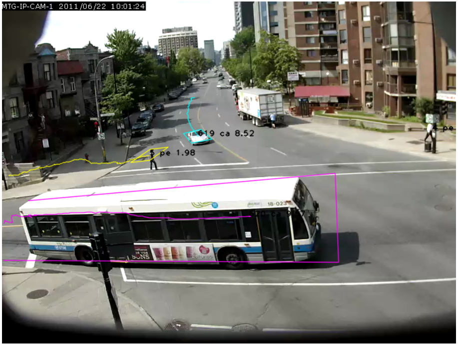
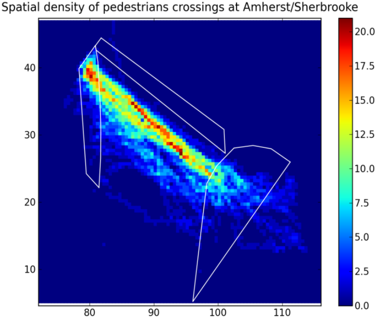


Figure 27 – Conflict analysis Cam20-16-Dorval (Untreated).

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

Dangerous Pedestrian Crossings and Violations at Signalized Intersections





[Brosseau et al., 2013]

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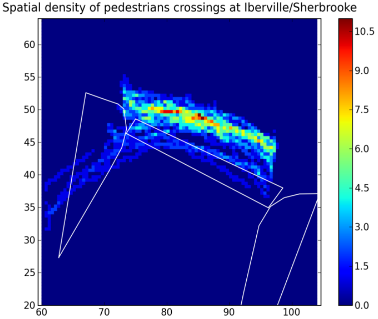
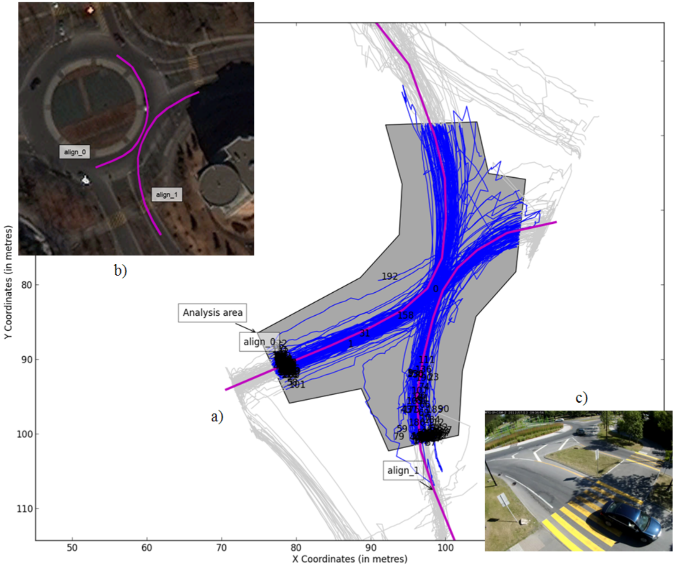
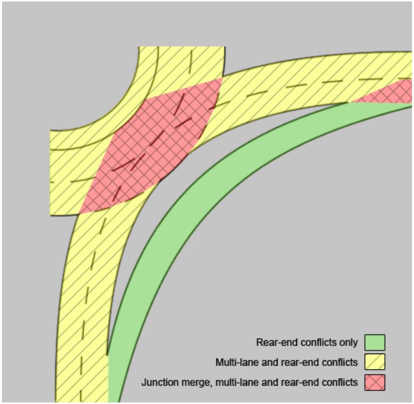


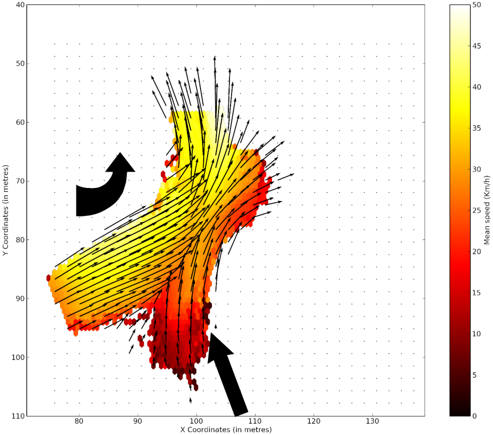
[Brosseau et al., 2013]

Big Data: Roundabout Safety in Québec



Speed Fields in Roundabouts



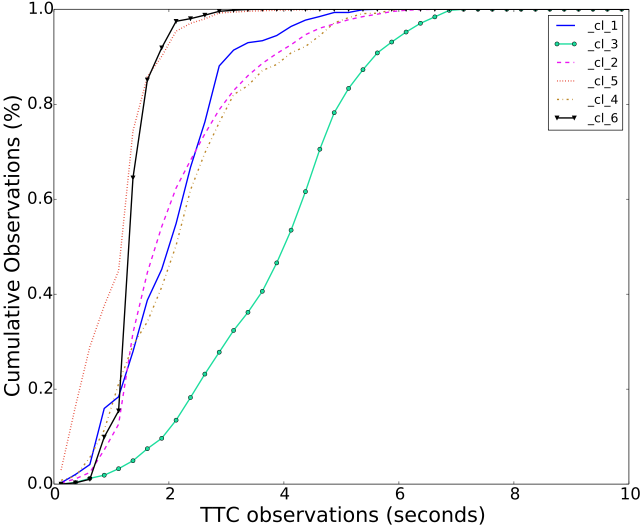


[St-Aubin et al., 2013b]

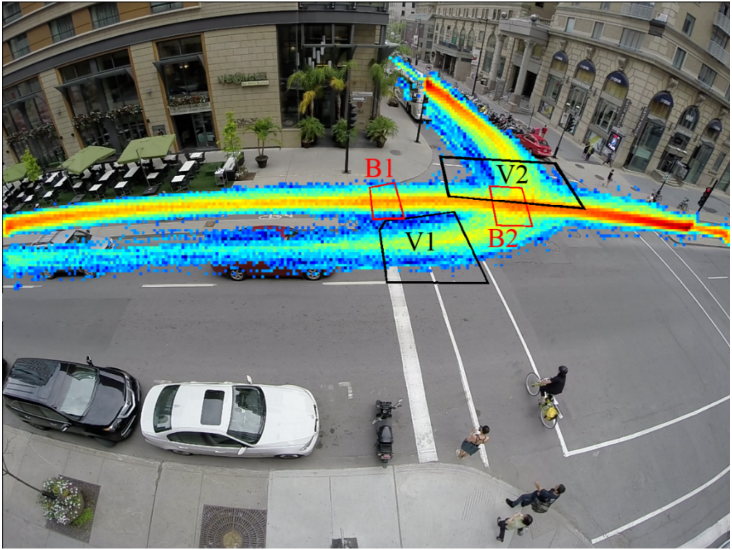
K-means cluster profile for TTC regression

#	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 polarised 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



Cycle Track Safety (TRB 2015)



Cycle Track Safety (TRB 2015)

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

Outline

Conclusion

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

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

Perspectives

- Improve computer vision for all road users in busy urban locations

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- Validation of surrogate methods for road safety analysis

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- Validation of surrogate methods for road safety analysis
    - 20 roundabout sites with video observations and accident records
- Understanding and modelling of collision processes: collect more data
- Pedestrian modelling: automated tracking parameter optimization (Bilal Farooq)

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`

Questions

1. What is a key difference between traditional safety analysis methods and the new proactive methods?
2. What are some of the benefits of video analysis for safety?
3. Cite a motion prediction method used to compute time to collision.
4. Cite some of the differences of post-encroachment time with time to collision.
5. Can surrogate methods of safety be applied to vulnerable road users?

- Collaboration with Tarek Sayed (UBC), Karim Ismail (Carleton), Marilyne Brosseau, Mohamed Gomaa Mohamed, Paul St-Aubin (Polytechnique Montréal), Luis Miranda-Moreno, Sohail Zangenehpour (McGill), Aliaksei Laureshyn (Lund)
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