Road Safety Analysis using Trajectory Data: At the Intersection of Naturalistic and Simulation Studies

WCTR 2022 virtual event
SIG C4: Traffic Safety Analysis and Policy

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July 29th 2022

POLYTECHNIQUE MONTRÉAL
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CIRRELT

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

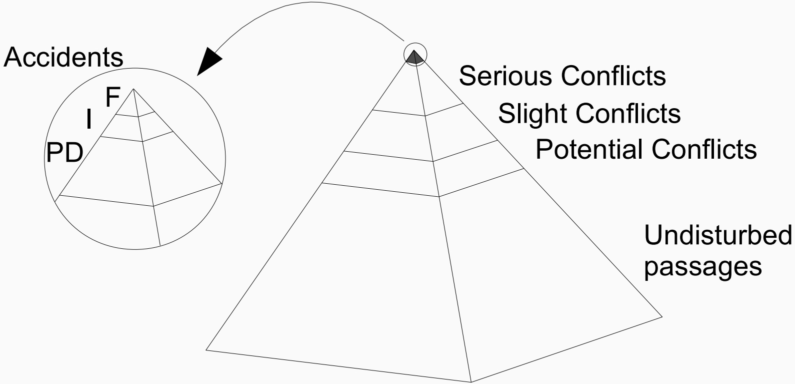
1. Accidents are reconstituted
    - traditional road safety analysis relying on historical collision data
    - vehicular accident reconstruction

Methods for Road Safety Analysis

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

1. Accidents are reconstituted
    - traditional road safety analysis relying on historical collision data
    - vehicular accident reconstruction
2. Road user behavior, interactions and accidents are directly observed
    - behavioural observations and surrogate measures of safety (SMoS)
    - data source: naturalistic (driving) studies, probe vehicles, site observations
        - manual to automated collection method

Foundation for Proactive Safety: the Safety Hierarchy



Outline

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Processing Steps

1. Video data collection
2. Data preparation
3. Road user detection, tracking and classification

Step 1: Video Data Collection

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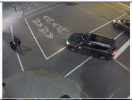
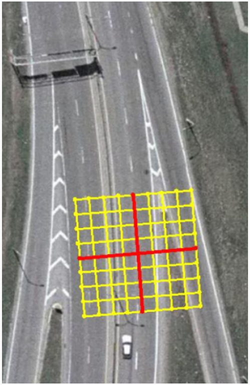
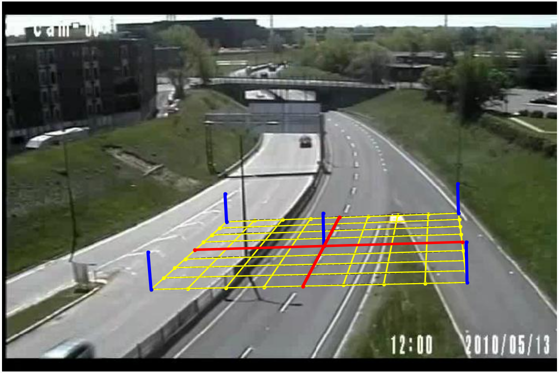
SAMPLE CAMERA VIEWS UNDER DIFFERENT LIGHTING CONDITIONS					
Daytime Conditions	**Thermal Camera**	**Regular Camera**	**Nighttime Conditions**	**Thermal Camera**	**Regular Camera**
Overcast			High visibility		
Sun, no shadows			Medium visibility		
Sun, strong shadows			Low visibility		

Step 2: Data Preparation

In particular, camera calibration: homography, distortion, etc.

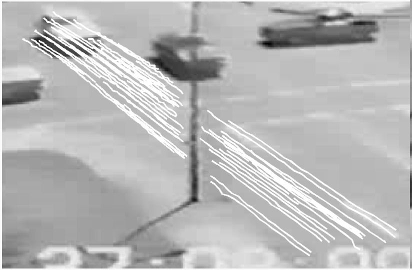




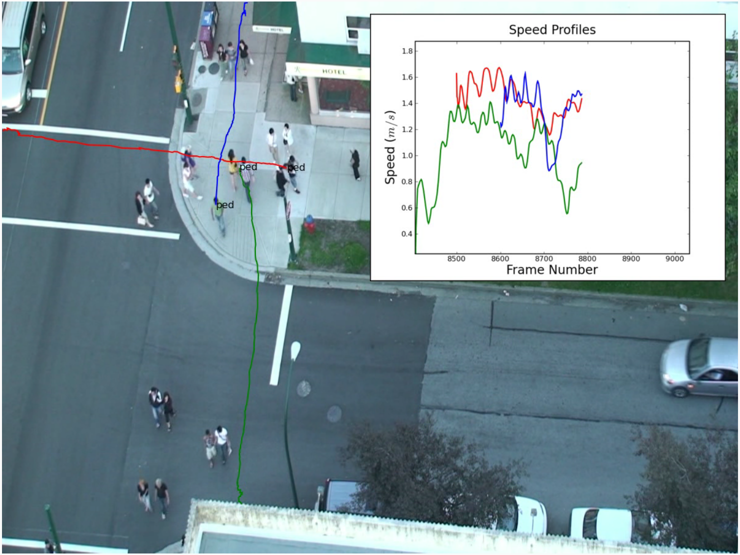
Step 2: Data Preparation

In particular, camera calibration: homography, distortion, etc.

Step 3: Road User Detection, Tracking and Classification

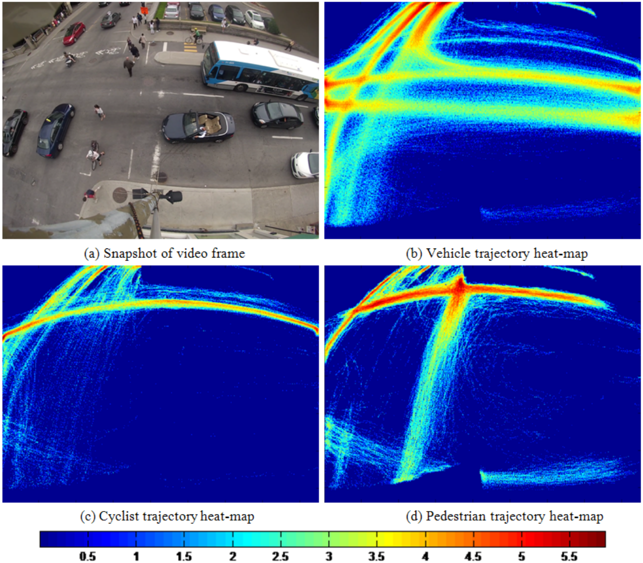


Step 3: Road User Detection, Tracking and Classification



Video

Step 3: Road User Detection, Tracking and Classification



(a) Snapshot of video frame

(b) Vehicle trajectory heat-map

(c) Cyclist trajectory heat-map

(d) Pedestrian trajectory heat-map

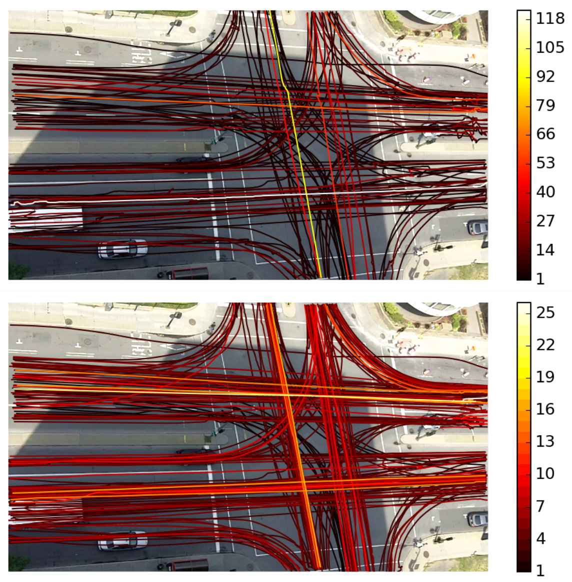
(e) Scale used for trajectorie heat-maps (log-scale)

Outline

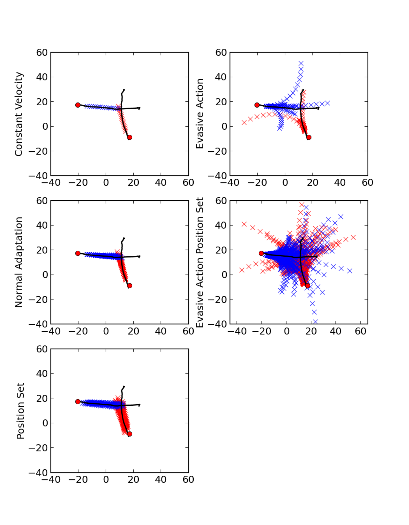
Processing Steps

4. Motion pattern learning
5. Motion prediction
6. Safety indicators
7. Interpretation (SMoS)

Step 4: Motion Pattern Learning

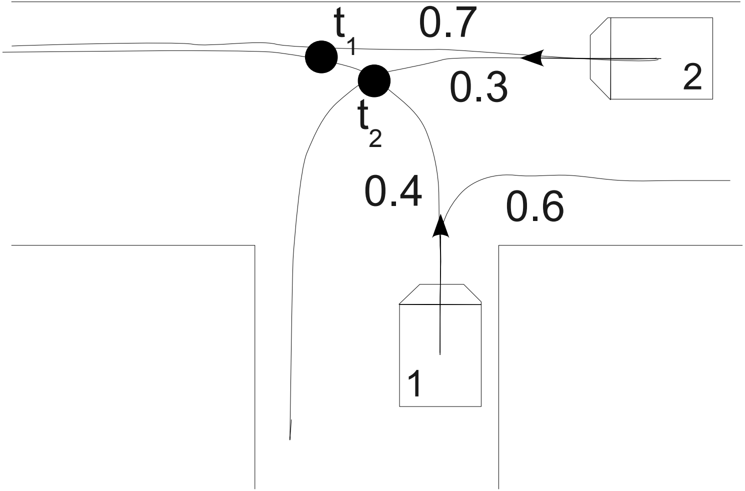


Step 5: Motion Prediction



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”

Step 5: Motion Prediction



Step 5: Motion Prediction

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Step 6: Safety Indicators

- Continuous measures
  - Time-to-collision (TTC)
  - Gap time (GT) (=predicted PET)
  - Deceleration-based indicators, e.g. deceleration to safety time (DST)
  - Speed-based indicators, (extended) Delta-V , etc.
- Unique measure per conflict
  - Post-encroachment time (PET)
  - Evasive action(s) (harshness), subjective judgment, etc.

Step 6: Safety Indicators

- Continuous measures (* based on motion prediction methods)
  - Time-to-collision (TTC) *
  - Gap time (GT) (=predicted PET) *
  - Deceleration-based indicators, e.g. deceleration to safety time (DST) *
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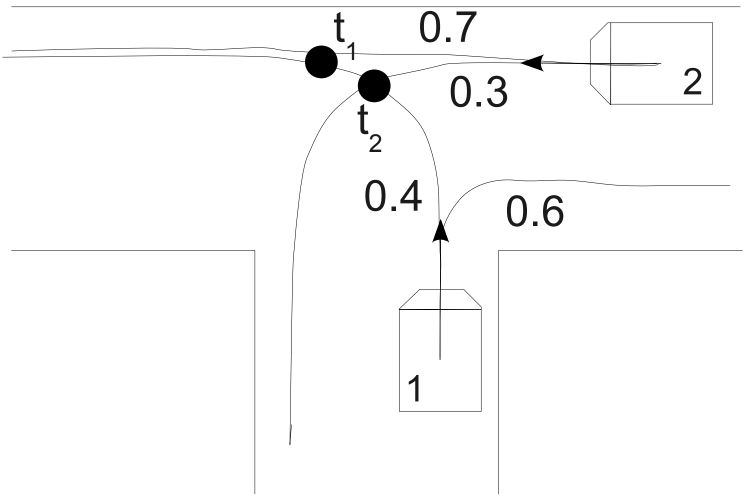
Step 6: Safety Indicators



Step 6: Safety Indicators

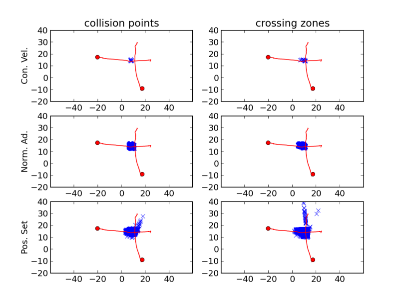
Using of a finite set of predicted trajectories, enumerate the collision points CP_n and the crossing zones CZ_m. Safety indicators can then be computed:

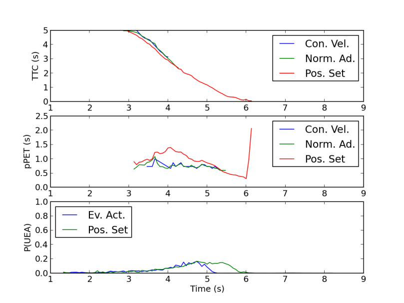
$$P(Collision(U_i, U_j)) = \sum_n P(Collision(CP_n))$$

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

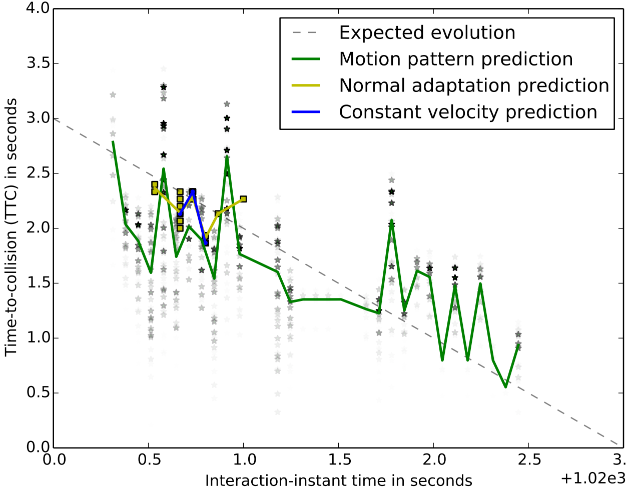
$$pPET(U_i, U_j, t_0) = \frac{\sum_m P(Reaching(CZ_m))\ |t_{i,m} - t_{j,m}|}{\sum_m P(Reaching(CZ_m))}$$

Step 6: Safety Indicators



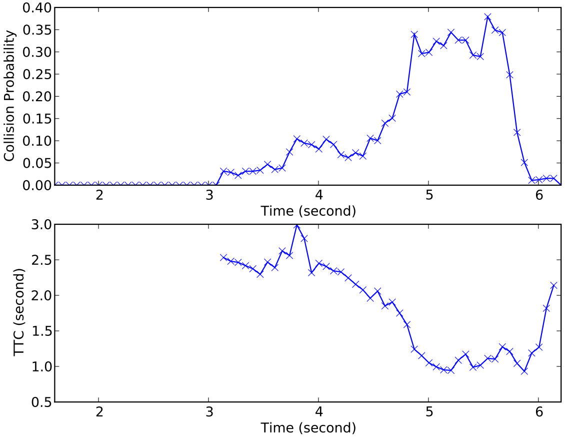


Step 6: Safety Indicators



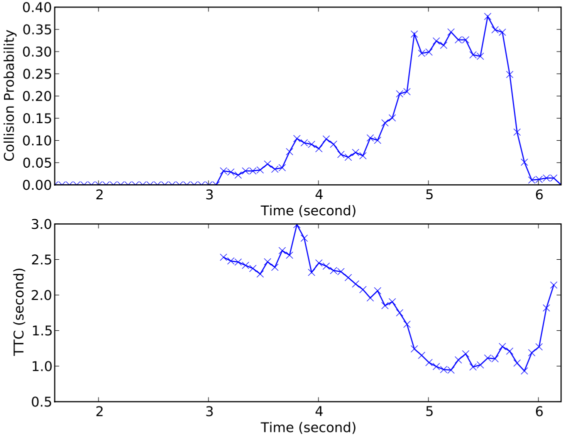
Step 7: Interpretation (SMoS)

For each interaction, we have



Step 7: Interpretation (SMoS)

How should data be aggregated?



Step 7: Interpretation (SMoS)

Should data be aggregated (to count severe events)?

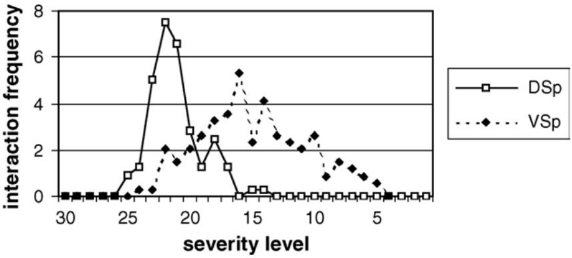
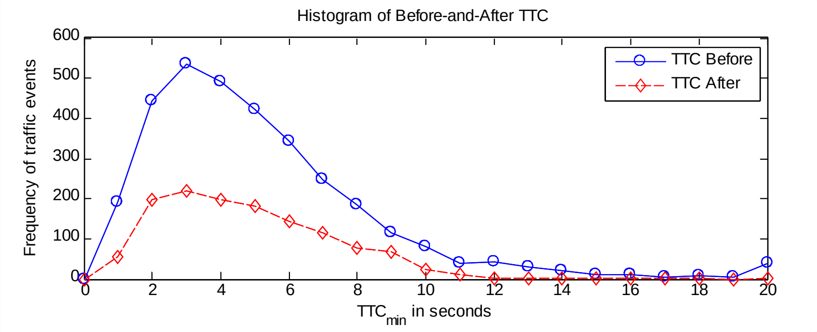


Fig. 6. Interaction frequency (interactions per observation hour) for different severity levels. Straight ahead driving vehicles versus pedestrians. The pedestrian is taking evasive action. A non-signalised intersection (DSp) and a signalised intersection (VSp).

Step 7: Interpretation (SMoS)



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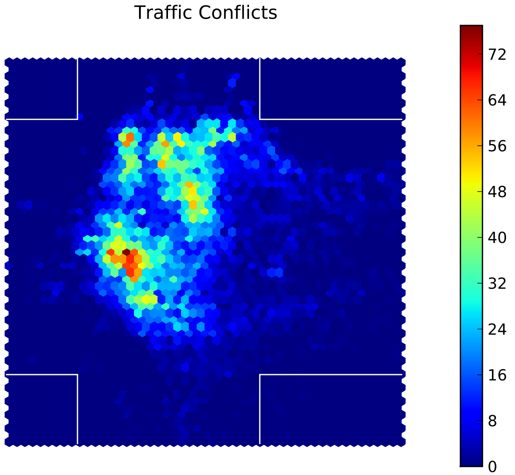

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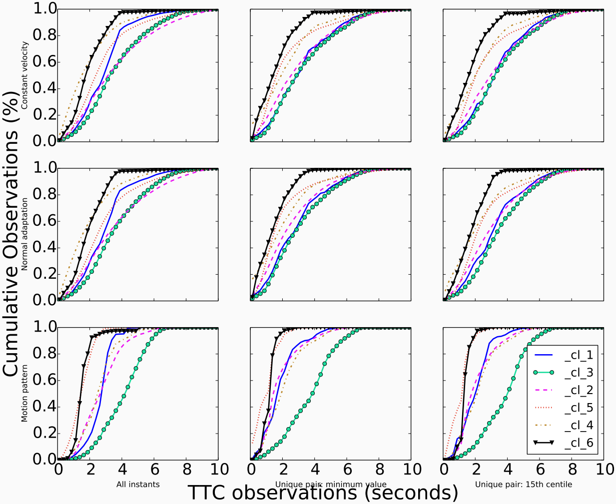
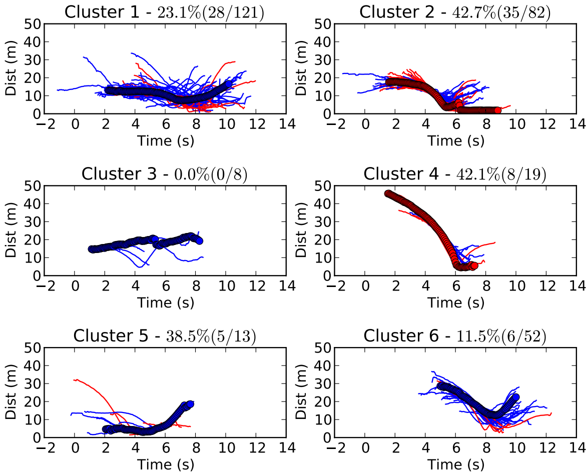


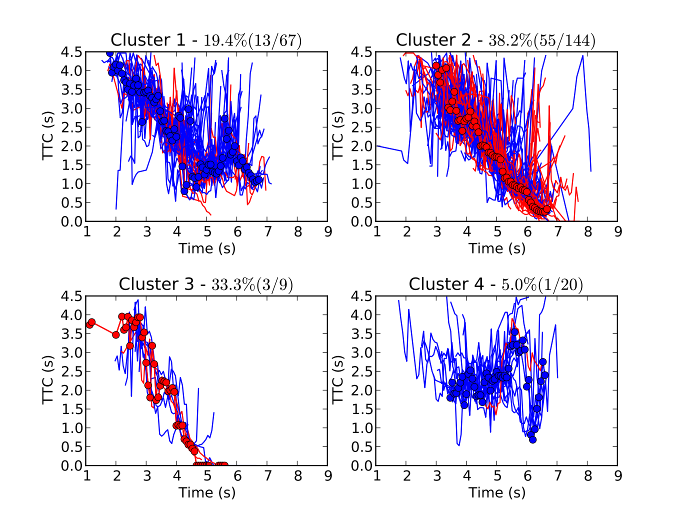
Step 7: Interpretation (SMoS)

	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		

Step 7: Interpretation (SMoS)



Step 7: Interpretation (SMoS)

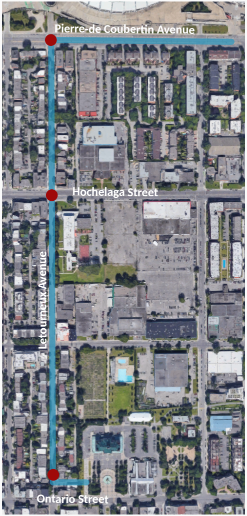


Outline

Safety Studies Using SMoS

- Highway on-ramps and roundabouts
- Cycling infrastructure and the lack thereof
- Pedestrian crosswalks
- Stop-controlled intersections: 2-way vs all-way
- Pedestrian workers (traffic police) vs their stress
- Connected and Automated Vehicles (CAVs)
- Pedestrian countdowns and driver behaviour

Study of Low-Speed Automated Shuttles in Montreal and Candiac



Work with Étienne Beauchamp and Marie-Soleil Cloutier, INRS

Sites in Montreal

Pierre-de-Coubertin

Hochelaga

Ontario

Sites in Candiac

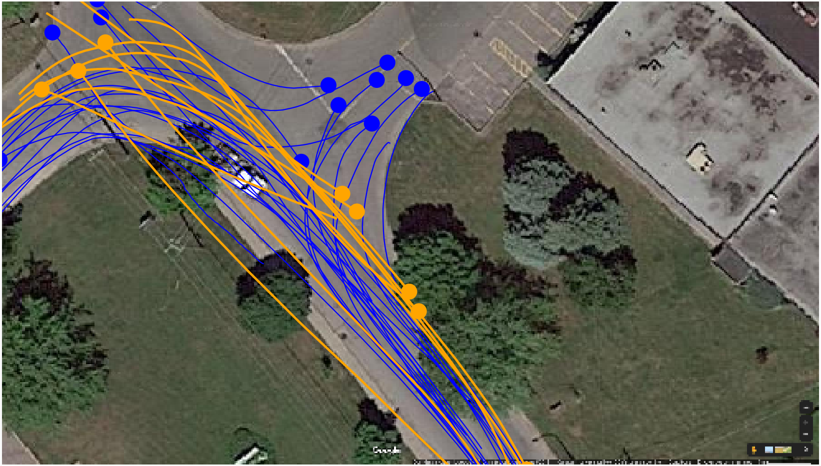
Residence

Inverness

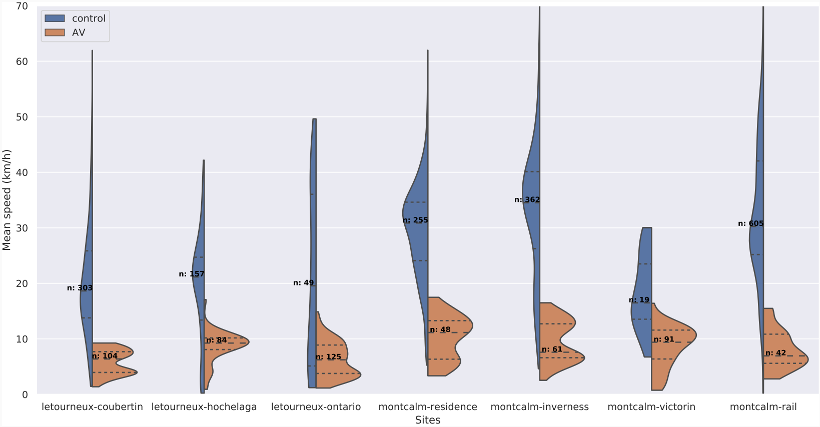
Marie-Victorin

Rail

Motion Patterns at Inverness Site

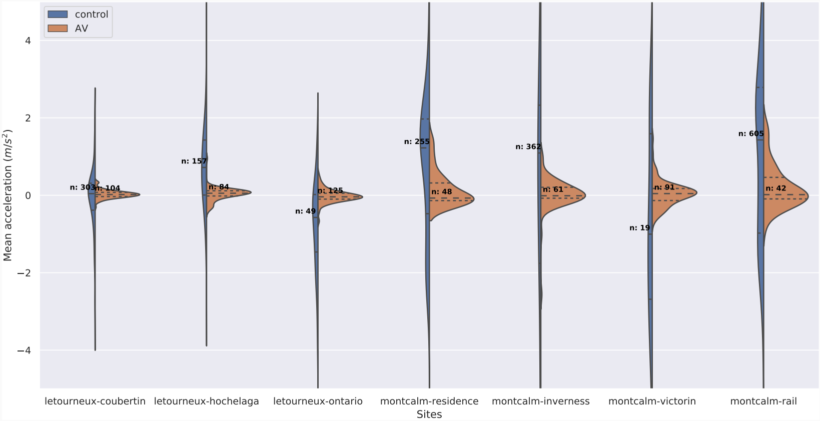


Results

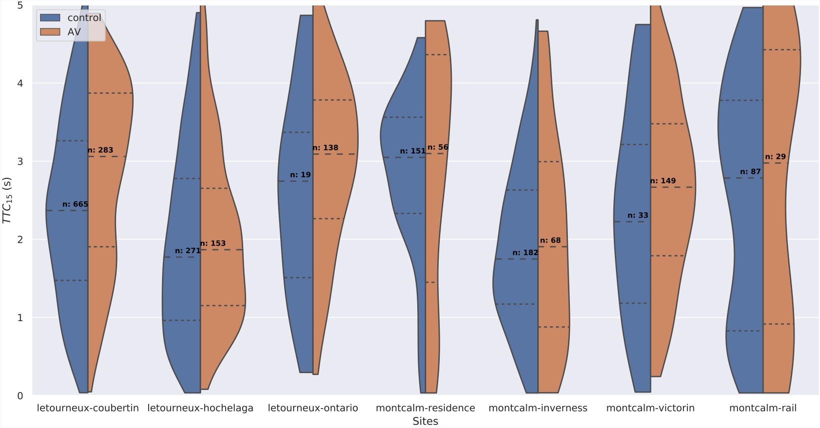


control
AV
Mean speed (km/h)
70
60
50
40
30
20
10
0
n: 303
n: 104
n: 157
n: 84
n: 49
n: 125
n: 255
n: 48
n: 362
n: 61
n: 19
n: 91
n: 605
n: 42
letourneux-coubertin
letourneux-hochelaga
letourneux-ontario
montcalm-residence
montcalm-inverness
montcalm-victorin
montcalm-rail
Sites

Results

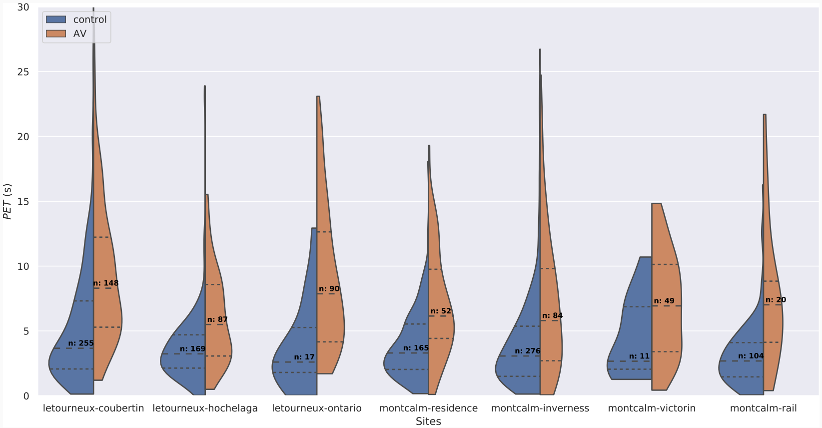

control
AV
4
2
0
−2
−4
Mean acceleration (m/s^2)
n: 303
n: 104
n: 157
n: 84
n: 49
n: 125
n: 255
n: 48
n: 362
n: 61
n: 19
n: 91
n: 605
n: 42
letourneux-coubertin
letourneux-hochelaga
letourneux-ontario
montcalm-residence
montcalm-inverness
montcalm-victorin
montcalm-rail
Sites

Results

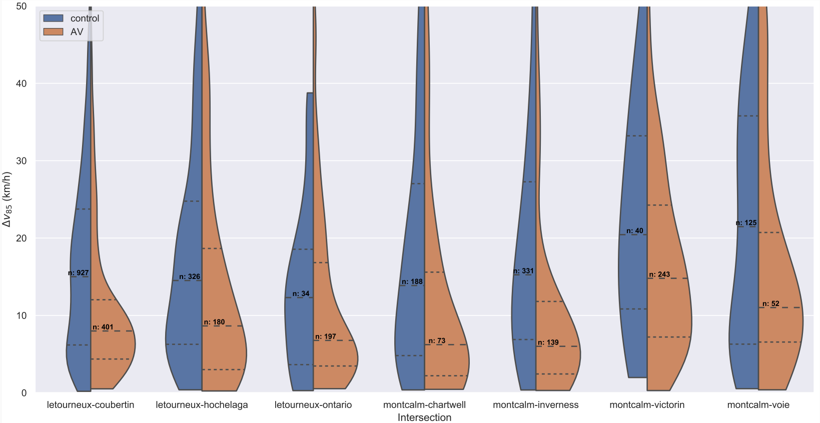


control
AV
n: 665
n: 283
n: 271
n: 153
n: 19
n: 138
n: 151
n: 56
n: 182
n: 68
n: 33
n: 149
n: 87
n: 29
TTC_{15} (s)
0
1
2
3
4
5
letourneux-coubertin
letourneux-hochelaga
letourneux-ontario
montcalm-residence
montcalm-inverness
montcalm-victorin
montcalm-rail
Sites

Results

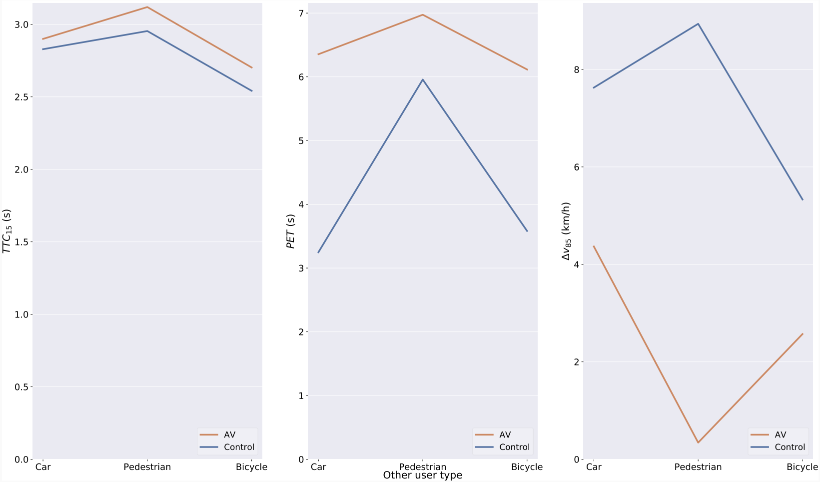

control
AV
PET (s)
30
25
20
15
10
5
0
n: 255
n: 148
n: 169
n: 87
n: 17
n: 90
n: 165
n: 52
n: 276
n: 84
n: 11
n: 49
n: 104
n: 20
letourneux-coubertin
letourneux-hochelaga
letourneux-ontario
montcalm-residence
montcalm-inverness
montcalm-victorin
montcalm-rail
Sites

Results



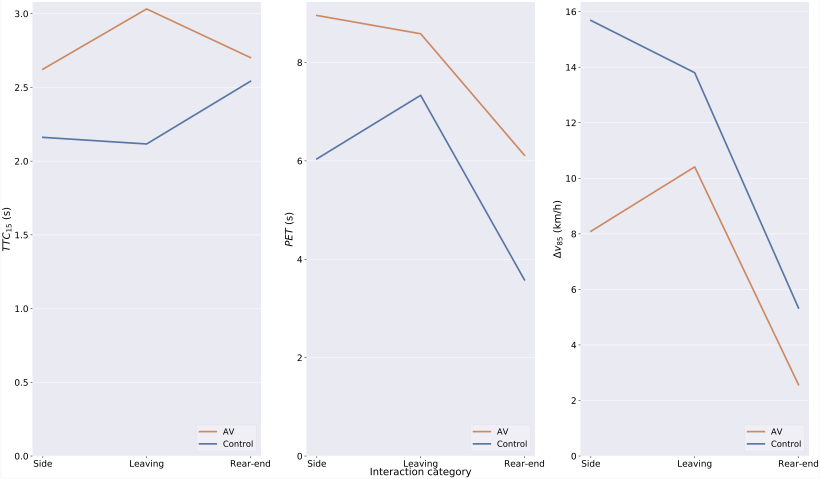
control
AV
50
40
30
20
10
0
Δv_{85} (km/h)
n: 927
n: 401
n: 326
n: 180
n: 34
n: 197
n: 188
n: 73
n: 331
n: 139
n: 40
n: 243
n: 125
n: 52
letourneux-coubertin
letourneux-hochelaga
letourneux-ontario
montcalm-chartwell
montcalm-inverness
montcalm-victorin
montcalm-voie
Intersection

Results



3.0
2.5
2.0
1.5
1.0
0.5
0.0
TTC_{15} (s)
AV
Control
Car
Pedestrian
Bicycle
7
6
5
4
3
2
1
0
PET (s)
AV
Control
Car
Pedestrian
Bicycle
Other user type
8
6
4
2
0
Δv_{85} (km/h)
AV
Control
Car
Pedestrian
Bicycle

Results



TTC_{15} (s)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Side
Leaving
Rear-end
AV
Control
PET (s)
8
6
4
2
0
Interaction category
Δv_{85} (km/h)
16
14
12
10

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Conclusion

We have access to increasing amounts of trajectory data, from various sensors (various types of cameras, LIDAR, radar, etc.), which enables

- naturalistic studies: large scale analysis of road user behaviour and safety

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- naturalistic studies: large scale analysis of road user behaviour and safety
- calibration of road user models
- which in turn enable proactive safety analysis, i.e. to predict road safety through the simulation of potential scenarios at the microscopic level

Predicting road safety through the simulation of potential scenarios at the microscopic level to compute safety indicators (e.g. TTC) is not the same as current traffic simulations that generate SMoS, since, in one way or the other, they must reproduce the mechanisms that lead to crashes

Predicting road safety through the simulation of potential scenarios at the microscopic level to compute safety indicators (e.g. TTC) is not the same as current traffic simulations that generate SMoS, since, in one way or the other, they must reproduce the mechanisms that lead to crashes

or you end up simulating AVs

It therefore remains an open question

how one should measure safety in a traffic simulation: e.g. should one simulate conflicts or crashes?

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Questions?