# Surrogate Measures of Safety, 18 Years On

Hasselt University

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POLYTECHNIQUE MONTRÉAL
TECHNOLOGICAL UNIVERSITY

CIRRELT

# Outline

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# Context

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- Vision Zero was introduced in 2015 by the Canadian injury prevention charity Parachute, and has been adopted by Edmonton, Vancouver, Toronto, Ottawa and Montreal
- Yet safety has not improved as much for vulnerable road users (VRU) (pedestrians and cyclists) and has been worsening since 2016

# Odd Strain of Victim Blaming in North America

**Zero Fatalities**
@ZeroFatalities

Follow

Distracted walking is just as dangerous as distracted driving. Enjoy the weather safely and look before you cross.

9:01 AM - 9 May 2018

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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

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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 analysis
        - manual to automated

# Main Issues with Traditional Methods for Road Safety Analysis

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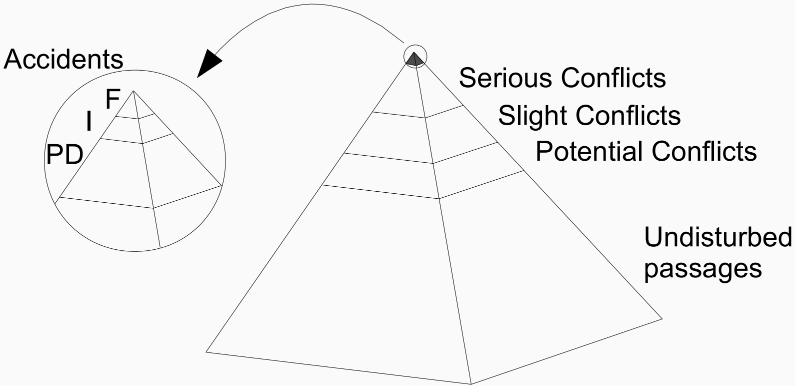
2. Small data quantity
3. Limited quality of the data reconstituted after the event, with a bias towards more damaging collisions
4. Traditional road safety analysis is reactive
    - the following paradox ensues: safety analysts need to wait for accidents to happen in order to prevent them

**Need for Proactive Methods for Road Safety Analysis**

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

# Foundation: The Safety/Severity Hierarchy



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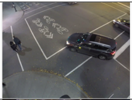
# Processing Steps

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

# Step 1: Video Data Collection

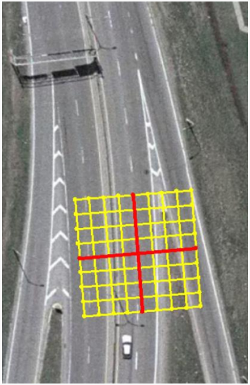

[Jackson et al., 2013]

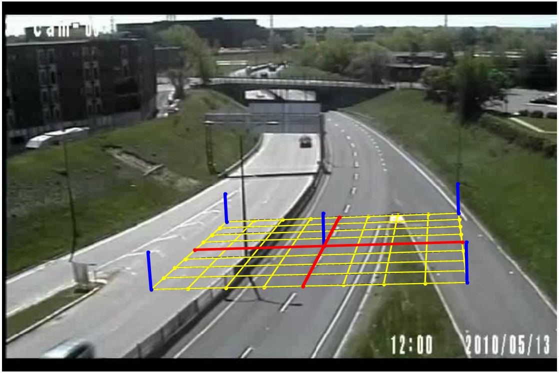
# Step 1: Video Data Collection

| 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.





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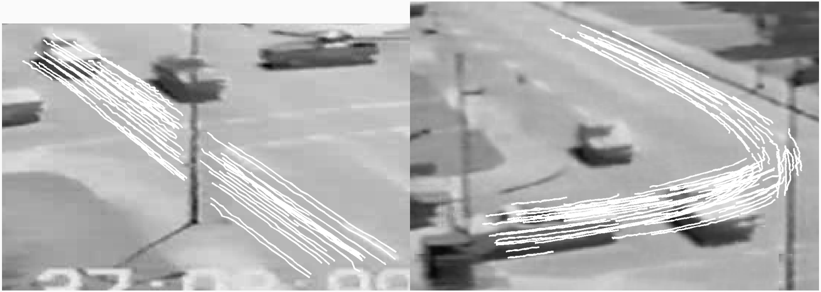
# Step 3: Road User Detection, Tracking and Classification



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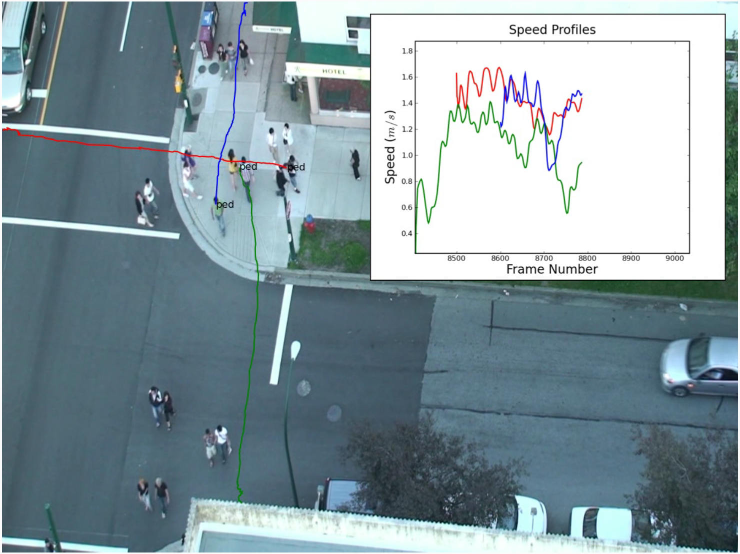
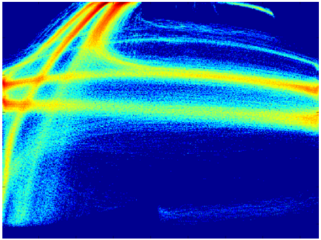


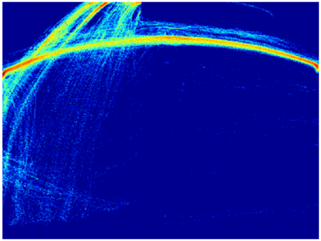

Video

# Step 3: Road User Detection, Tracking and Classification

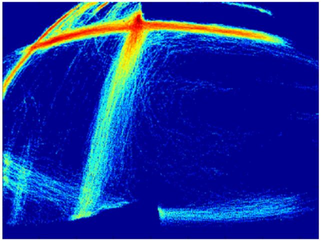
(a) Snapshot of video frame



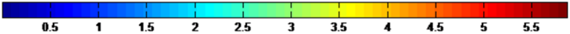
(b) Vehicle trajectory heat-map



(c) Cyclist trajectory heat-map

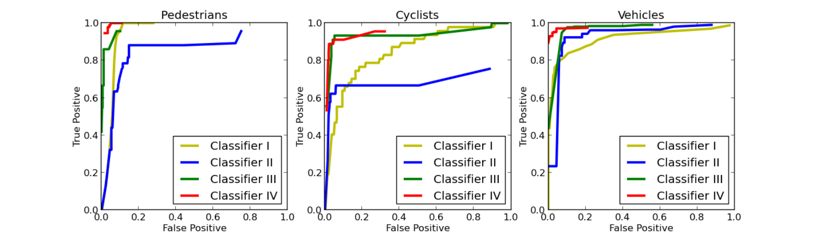


(d) Pedestrian trajectory heat-map



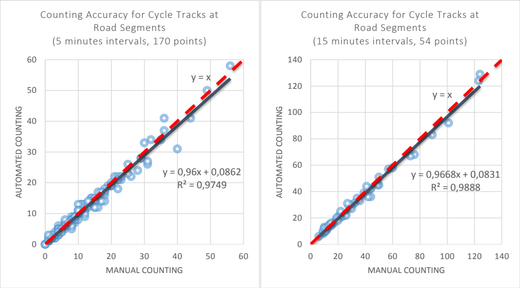

(e) Scale used for trajectorie heat-maps (log-scale)

# Step 3: Road User Detection, Tracking and Classification




ROC Curves

# Validating Cyclist Counts in Mixed Traffic




(a) (b)

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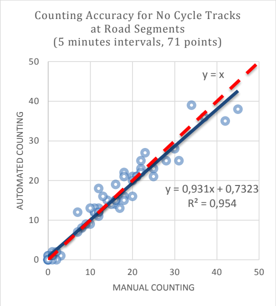
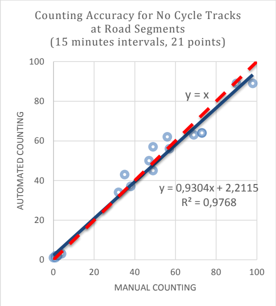
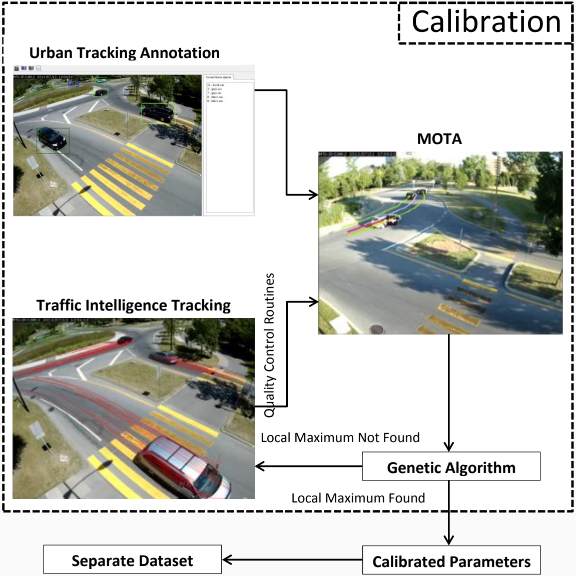



# Step 3’: Optimization of Tracking parameters



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| | | Parameters optimized for | | | | |
|---|---|---|---|---|---|---|
| Site | Default | S1S | S1W | S2 | S3V1 | S3V2 |
| S1S | 0.719046 | 0.904502 | 0.820976 | 0.817581 | 0.841254 | 0.823145 |
| S1W | 0.041073 | 0.114581 | 0.709927 | 0.077883 | 0.044429 | 0.050852 |
| S2 | 0.703178 | 0.74025 | 0.622532 | 0.766731 | 0.745787 | 0.718321 |
| S3V1 | 0.759758 | 0.797088 | 0.778268 | 0.793216 | 0.817457 | 0.799231 |
| S3V2 | 0.750416 | 0.704989 | 0.737339 | 0.776115 | 0.700151 | 0.788521 |


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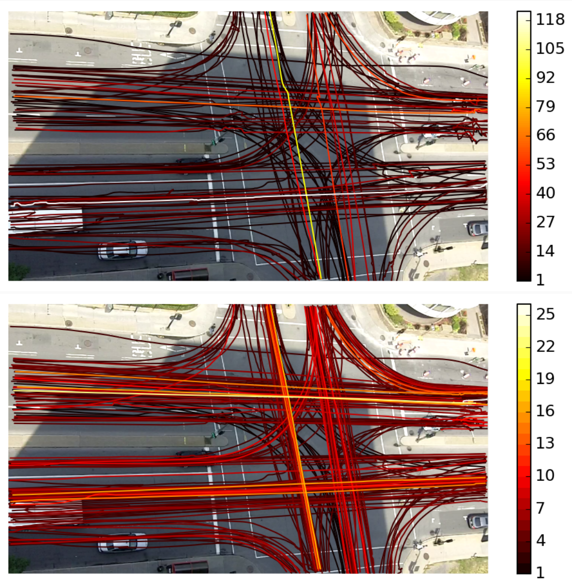
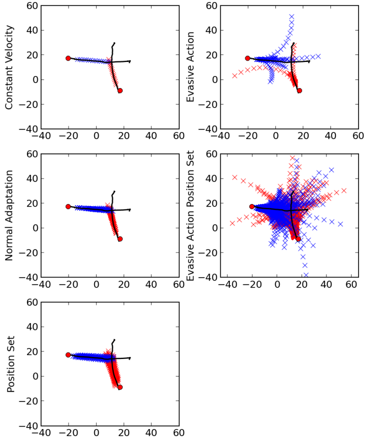
# Processing Steps

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

# Step 4: Motion Pattern Learning

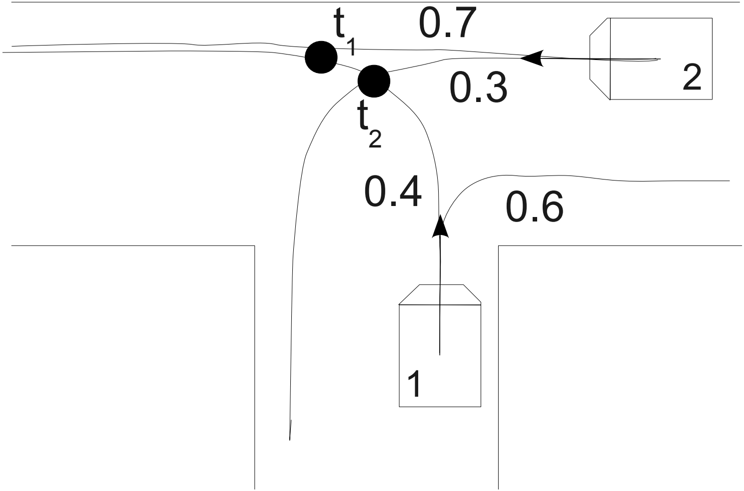


# Step 5: Motion Prediction




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



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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.
- Number of traffic events, e.g. (serious) traffic conflicts

# Step 6: Safety Indicators

- Continuous measures (* based on motion prediction methods)
  - Time-to-collision (TTC) *
  - Gap time (GT) (=predicted PET) *
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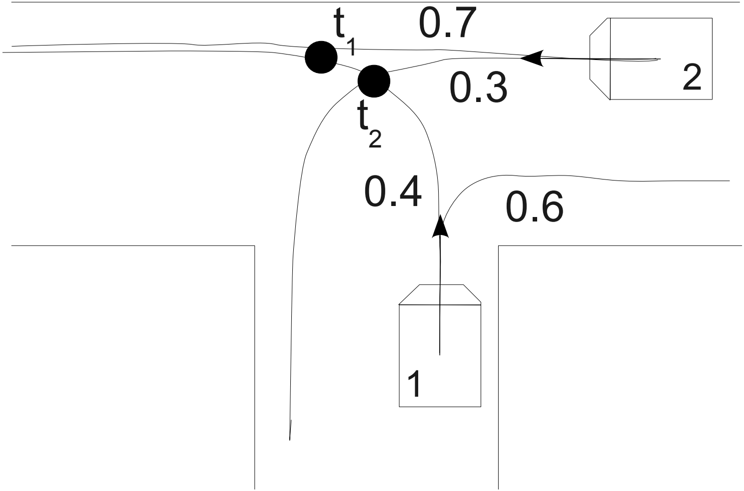

# Step 6: Safety Indicators

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:

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

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

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

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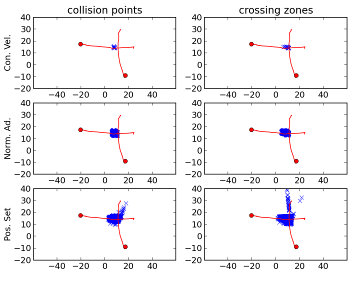


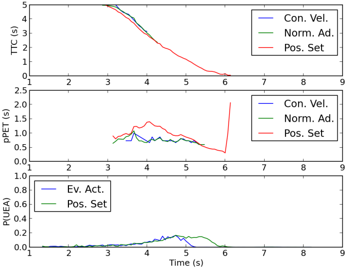

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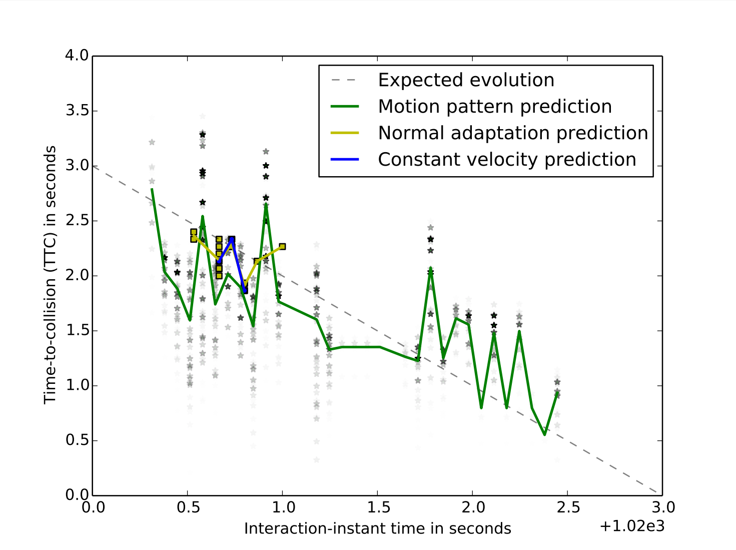
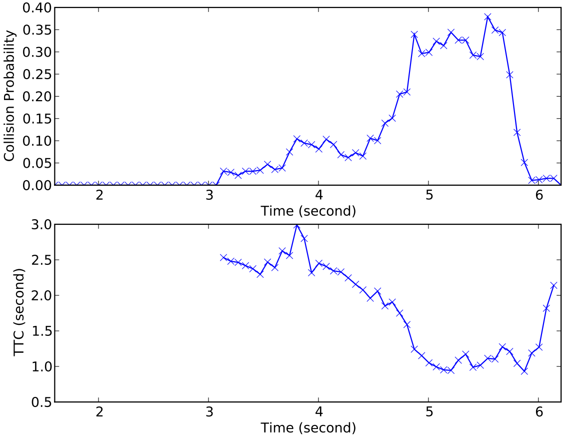


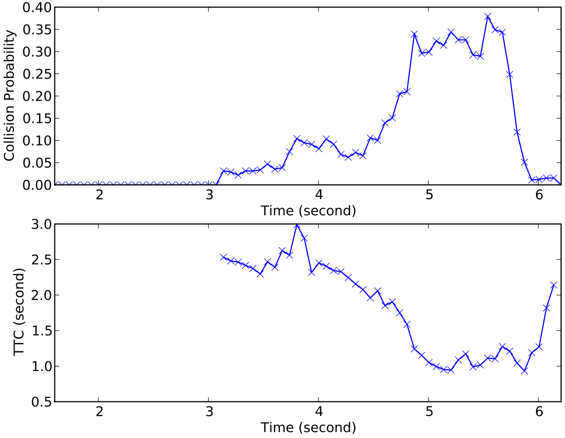
# Step 7: Interpretation

For each interaction, we have



# Step 7: Interpretation

How should data be aggregated?



Should data be aggregated (to count severe events)?

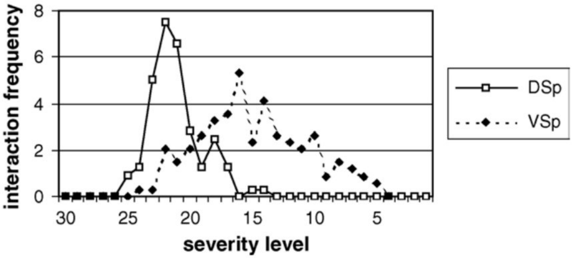
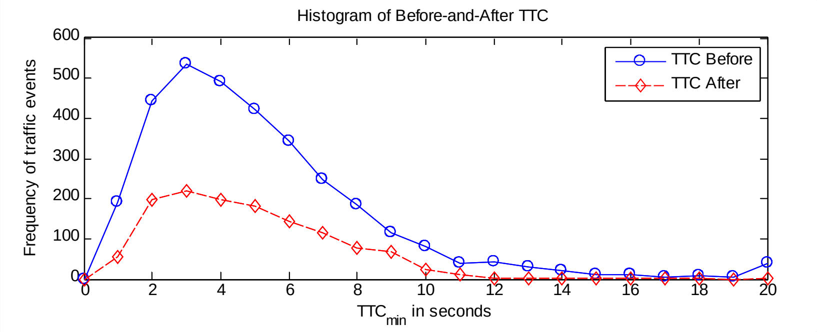



Fig. 6. Interaction frequency (interactions per observation hour) for different severity levels. Straight ahead driving vehicles versus pedestrians. The pedestrian is taking evasive action. A non-signalised intersection (DSp) and a signalised intersection (VSp).

# Step 7: Interpretation



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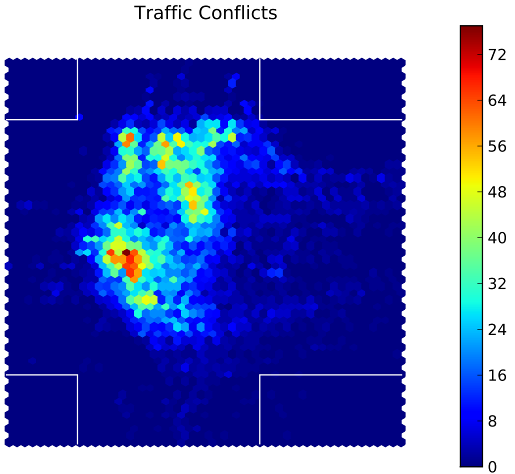

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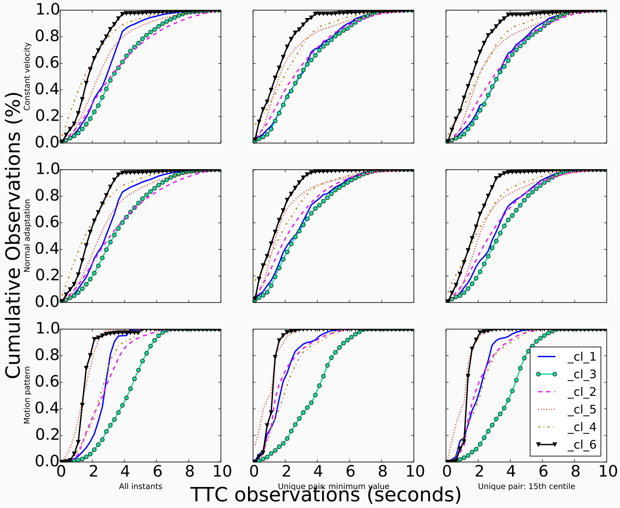

# Step 7: Interpretation

| | 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 | | |

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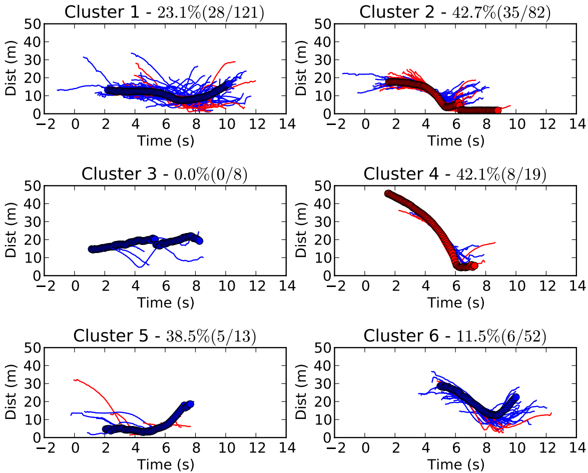

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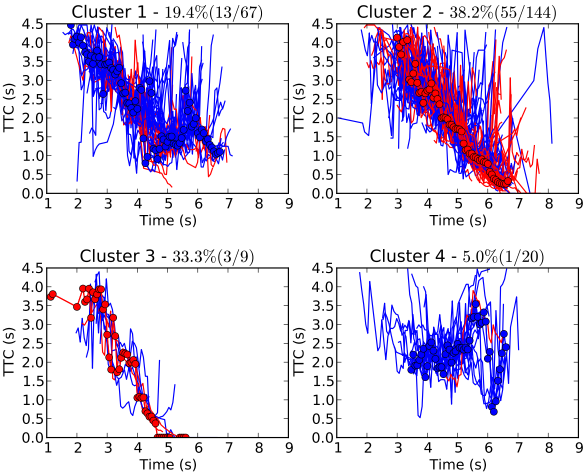

# Outline

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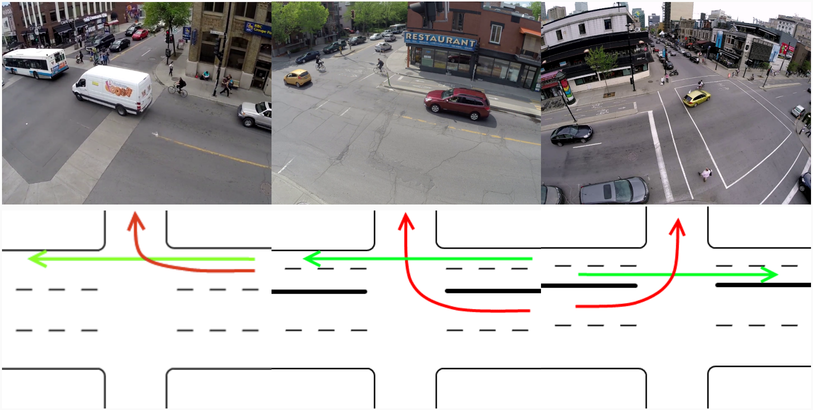
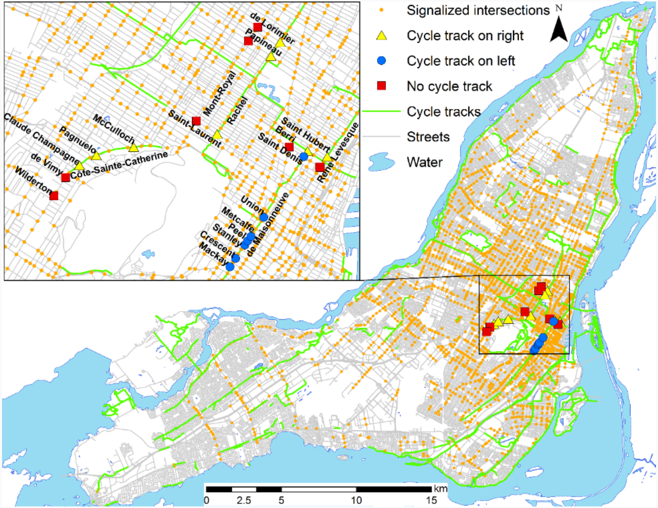
# Turning Vehicle Interactions with Cycle Tracks




Video

# Site Selection

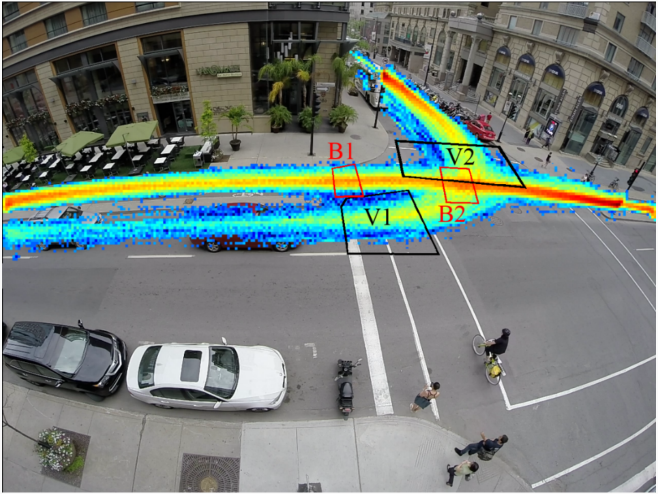


# Site Selection

| | # 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



# Interaction Attributes

- Each cyclist arriving to the intersection is an observation
- PET is the dependent variable and is discretized into 4 categories
  - $PET \leq 1.5\ s$: dangerous interaction
  - $1.5\ s < PET \leq 3\ s$: mild interaction
  - $3\ s < PET \leq 5\ s$: interaction
  - $PET > 5\ s$: no interaction
- Tested independent variables
  - Cycle track on the right side
  - Cycle track on the left side
  - Number of lanes on the road
  - Presence of bus stops at the intersection
  - One way street
  - Turning-vehicle and cyclist flows per hour
  - Bicycle and vehicle flow 5, 15 and 30 s before and after the arrival of each cyclist

# Three PET Ordered Logit Models

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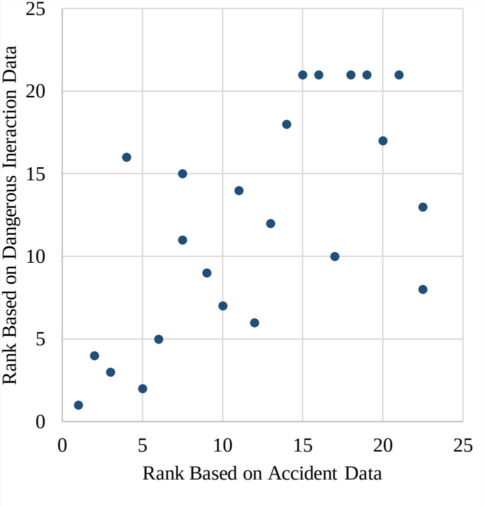
# Correlation with Accidents




Spearman Rank Correlation of 0.64

# Association of Gender with Interaction Safety

| | $\beta_1$ | | | $\beta_2$ | | |
|---|---|---|---|---|---|---|
| | | | $y^* = \beta_1 X + \beta_2 wX + \beta_3 w + \varepsilon$ | | | |
| **Explanatory variables** | **Parameter** | **z stat** | **p value** | **Parameter** | **z stat** | **p value** |
| Bike Speed | - | - | - | **0.0272** | **2.31** | **0.021** |
| Helmet | - | - | - | - | - | - |
| Vehicle Speed | - | - | - | **0.0250** | **2.38** | **0.017** |
| Truck/Van | - | - | - | - | - | - |
| Platoon Leader | - | - | - | 0.2395 | 1.63 | 0.104 |
| Red | **-0.7713** | **-4.99** | **0.000** | - | - | - |
| Bike First | - | - | - | - | - | - |
| Pedestrian | - | - | - | - | - | - |
| Stanley | **-0.3774** | **-2.56** | **0.010** | - | - | - |
| Peel | - | - | - | - | - | - |
| Mackay | - | - | - | **-0.4946** | **-2.41** | **0.016** |
| Metcalfe | *-0.2384* | *-1.75* | *0.080* | - | - | - |
| Denis | - | - | - | - | - | - |
| Union | **-0.8953** | **-2.21** | **0.027** | 0.6657 | 1.35 | 0.178 |
| | $\beta_3$ | | | $\beta_3$ | | |
| Male | **-1.1703** | **-3.79** | **0.000** | **-1.1703** | **-3.79** | **0.000** |
| Tau 1 | | | -0.2007 | | | |
| Tau 2 | | | 1.0455 | | | |
| Number of cases | | | 1514 | | | |
| Log likelihood at convergence | | | -1488.69 | | | |
| Log likelihood for constants- only model | | | -1522.09 | | | |
| Pseudo $R^2$ | | | 0.0219 | | | |

# Association of Gender with Interaction Safety

| Explanatory variables | Female<br>$\beta_1$ | Male<br>$\beta_1 + \beta_2$ |
|---|---|---|
| Bike Speed | - | 0.0272 |
| Helmet | - | - |
| Vehicle Speed | - | 0.0250 |
| Truck/Van | - | - |
| Platoon Leader | - | 0.2395 |
| Red | -0.7713 | -0.7713 |
| Bike First | - | - |
| Pedestrian | - | - |
| Stanley | -0.3774 | -0.3774 |
| Peel | - | - |
| Mackay | - | -0.4946 |
| Metcalfe | -0.2384 | -0.2384 |
| St Denis | - | - |
| Union | -0.8953 | -0.2296 |
| Male | -1.1703 | -1.1703 |

# Cycling Network Discontinuities

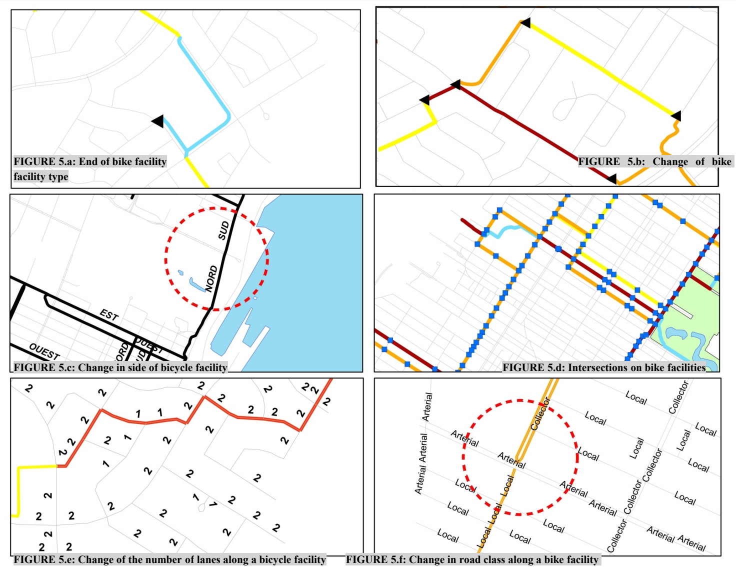
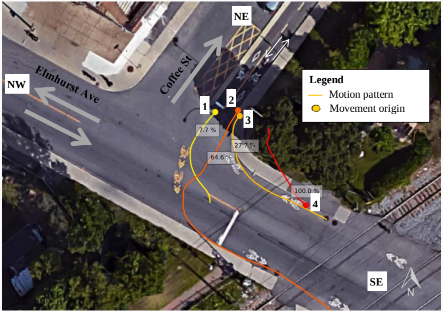
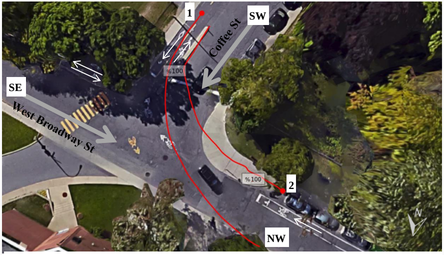



FIGURE 5.a: End of bike facility
FIGURE 5.b: Change of bike facility type
FIGURE 5.c: Change in side of bicycle facility
FIGURE 5.d: Intersections on bike facilities
FIGURE 5.e: Change of the number of lanes along a bicycle facility
FIGURE 5.f: Change in road class along a bike facility

# Cycling Behaviour at Discontinuities



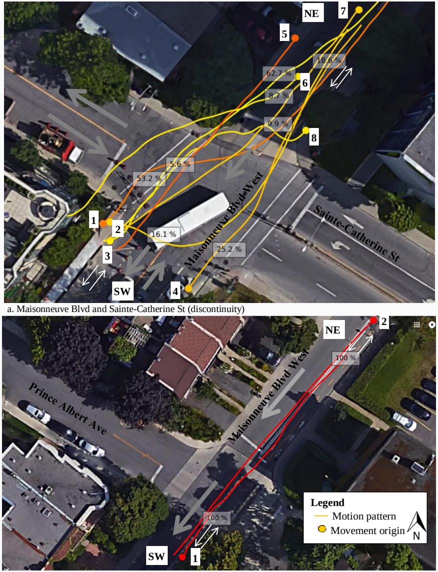

a. Coffee St and Elmhurst Ave (discontinuity)




b. Coffee St and West Broadway St (control)

**Figure 2 Cyclist motion patterns (represented by their prototype trajectories) for the change in cycling facility type discontinuity**

# Cycling Behaviour at Discontinuities

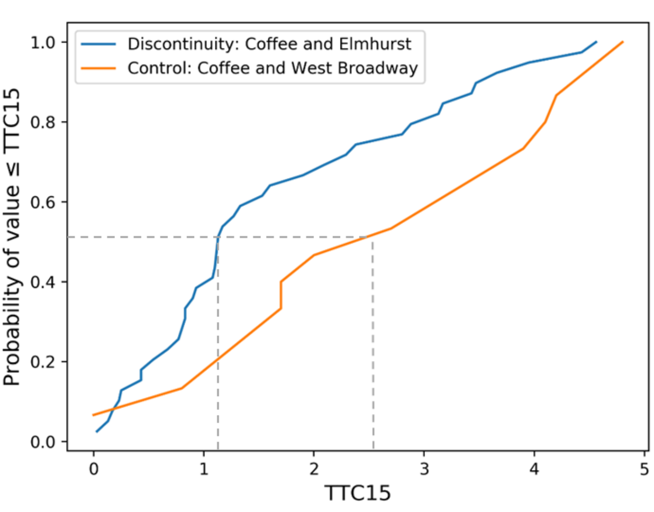



a. Maisonneuve Blvd and Sainte-Catherine St (discontinuity)

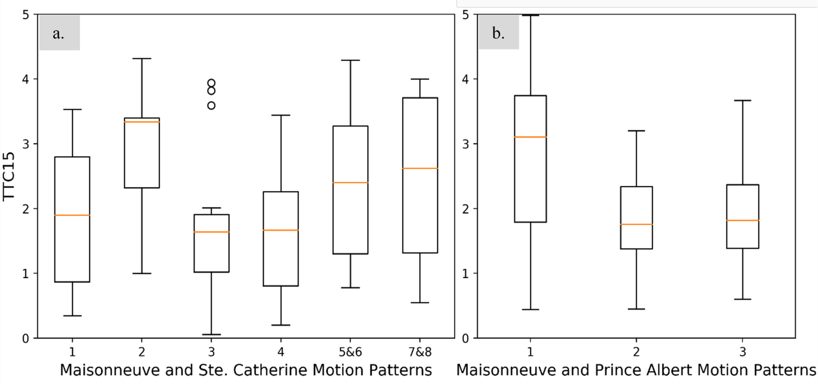
b. Maisonneuve Blvd west and Prince Albert Ave (control)

**Figure 3 Cyclist motion patterns (represented by their prototype trajectories) for the change in cycling facility side discontinuity**

# Cycling Safety at Discontinuities



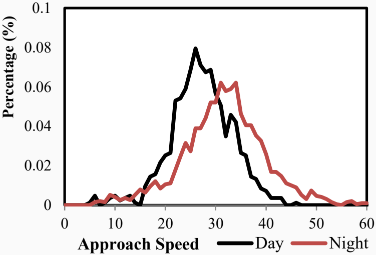
# Cycling Safety per Motion Pattern



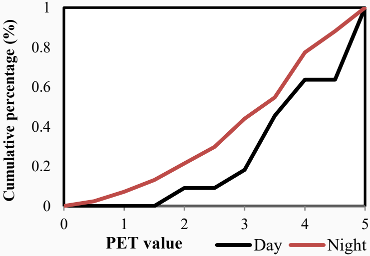
# Outline

# Safety of Pedestrian Crossings at Night

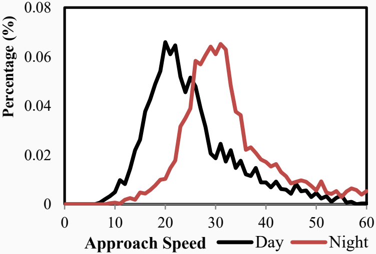
# Safety of Pedestrian Crossings at Night



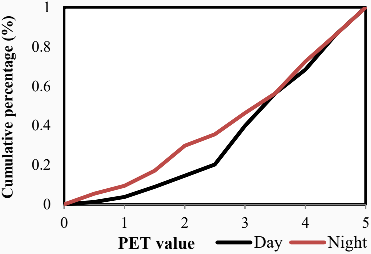

a) Speed distribution – du Fort




b) Accumulative conflict distribution – du Fort

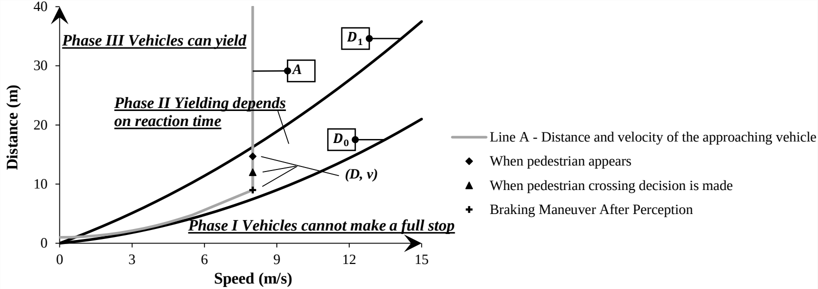



c) Speed distribution – st-Laurent

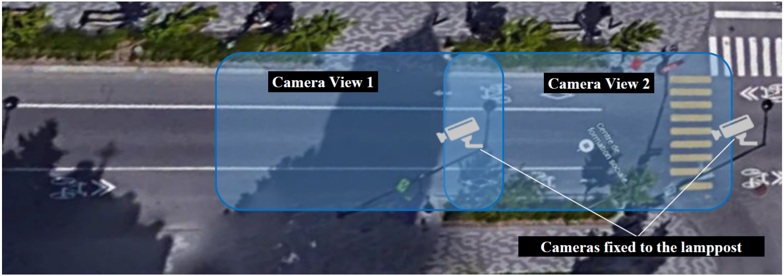



d) Accumulative conflict distribution – st-Laurent

# Behavioural Indicators: Distance-Velocity Framework



# Behavioural Indicators: Distance-Velocity Framework




*a) Camera locations and installations on the aerial map*


*b) Trajectories of the same vehicle through multiple cameras (displayed on the video frames after the correction for lens*

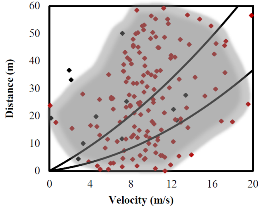
# Behavioural Indicators: Distance-Velocity Framework

## Application to 15 sites

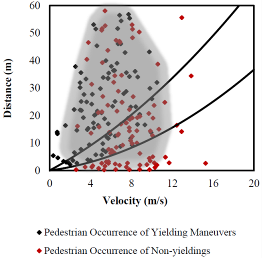
| Type of Crosswalk | Type A<br>Uncontrolled | Type B<br>Marked | Type C<br>Stop sign controlled | All Sites |
|---|---|---|---|---|
| ***Results for Yielding Behavior*** | | | | |
| **No. of Total Interactions** | 292 | 222 | 168 | 682 |
| **No. of Non-infraction Non-yieldings** | 32 | 33 | 4 | 69 |
| **No. of Uncertain Non-yieldings** | 38 | 31 | 10 | 79 |
| **No. of Non-Yielding Violations** | 207 | 50 | 21 | 278 |
| **No. of Yielding Maneuvers** | 15 | 108 | 133 | 256 |
| **Yielding Rate** | 5.1 % | 48.7 % | 79.2 % | 37.5 % |
| **Yielding Compliance** | 5.8 % | 57.1 % | 81.6 % | 41.8 % |

# Behavioural Indicators: Distance-Velocity Framework

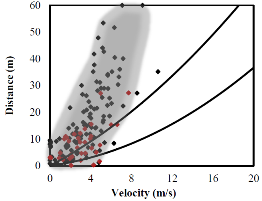
## Application to 15 sites



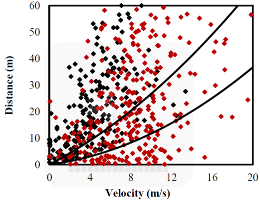

*a) Uncontrolled crosswalks*




*b) Marked crosswalk*



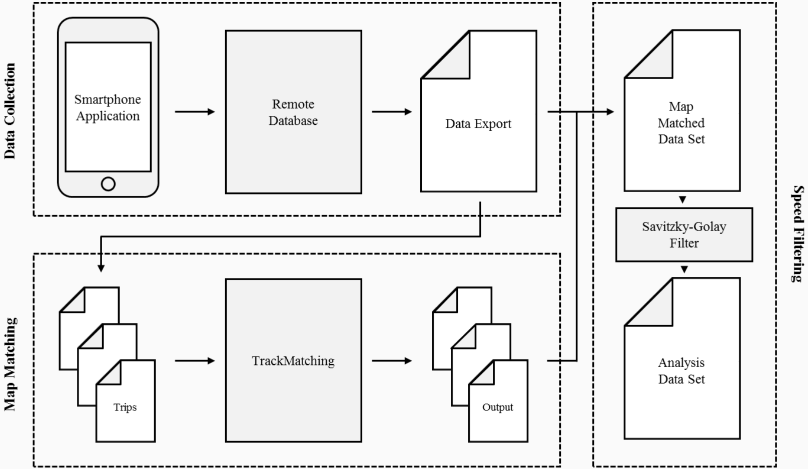

*c) Stop sign controlled crosswalk*




*d) Pedestrian occurrence – all sites*

# Outline

# Extracting Indicators from Vehicle GNSS Data



# Extracting Indicators from Vehicle GNSS Data

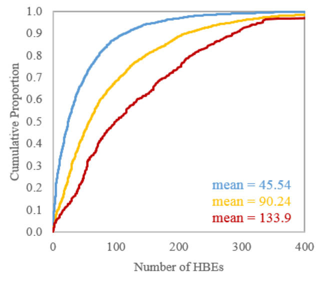
- Event-based measures: hard braking/acceleration events (threshold $\pm 3\ m.s^{-2}$
- Congestion index $CI = \frac{v_f - v}{v_f}$ if free flow speed $v_f \leq$ vehicle speed $v$, 0 otherwise, averaged per link
- Average speed ($v_f$ in the study)
- Coefficient of variation of speed among vehicles

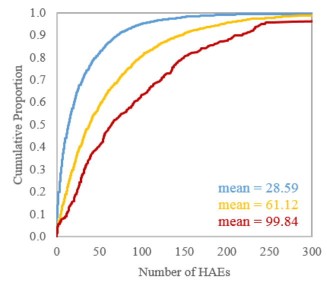
# Validation of Event-based Measures

*Spearman's rho for HBEs and HAEs*

| Link Level | | | Intersection Level | | |
|---|---|---|---|---|---|
| **Classification** | **HBE** | **HAE** | **Classification** | **HBE** | **HAE** |
| Motorway | 0.118 | 0.155 | Motorway | 0.603 | 0.641 |
| Primary | 0.260 | 0.297 | Primary | 0.540 | 0.554 |
| Secondary | 0.261 | 0.333 | Secondary | 0.532 | 0.536 |
| Tertiary | 0.213 | 0.244 | Tertiary | 0.573 | 0.584 |
| Residential | 0.270 | 0.256 | Residential | 0.615 | 0.625 |

# Validation of Event-based Measures



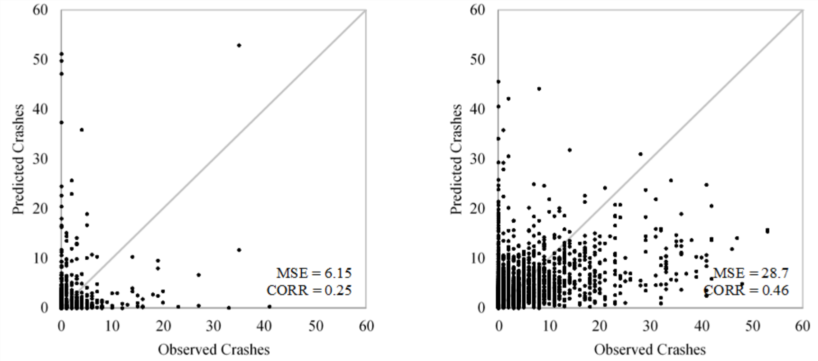




Sites were divided into groups with: 1) at least one fatal collision, 2) at least one major injury collision but no fatal, and 3) only minor injury collisions

# Modelling Crash Frequency and Severity

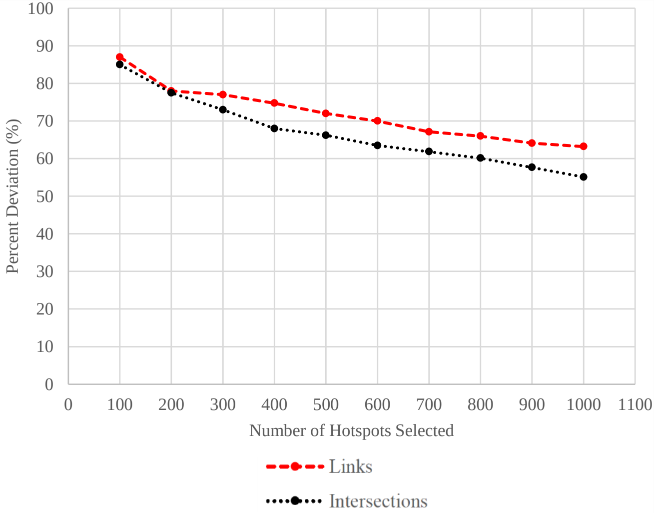
- Full Bayesian Spatial Latent Gaussian Model (LGM) accounting for spatial correlations for crash frequency
- Fractional Multinomial Logit (FMNL) model for crash severity
- Site ranking using different costs per severity level (and link length) and comparison to a traditional crash-based approach
- Validation using cross-validation

# Results



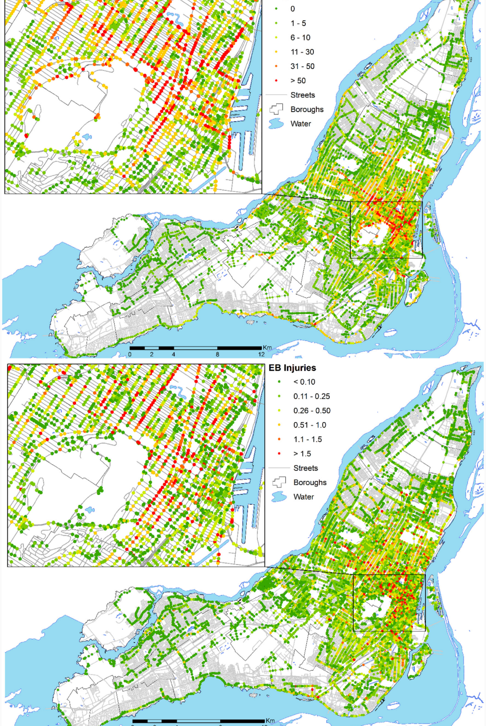
60
50
40
30
20
10
0
Predicted Crashes
0
10
20
30
40
50
60
Observed Crashes
MSE = 6.15
CORR = 0.25
60
50
40
30
20
10
0
Predicted Crashes
0
10
20
30
40
50
60
Observed Crashes
MSE = 28.7
CORR = 0.46

# Results


Percent Deviation (%)
100
90
80
70
60
50
40
30
20
10
0
0
100
200
300
400
500
600
700
800
900
1000
1100
Number of Hotspots Selected
Links
Intersections

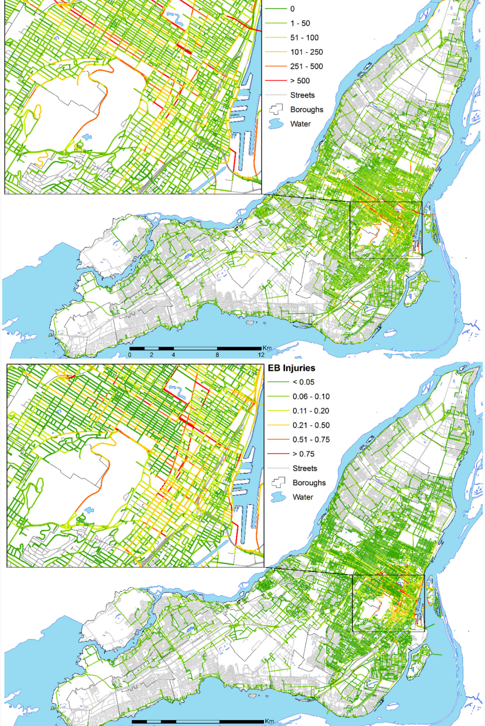
# Results

- Calibrated models achieved a correlation of 0.60 with the observed data, while prediction resulted in correlations of 0.46 for intersections and 0.25 for links
- Site rankings were between 20 % and 45 % similar measured on the validation data set, depending on the number of hotspots considered




## Cyclist Probe Data

Correlation of the number of hard cyclist decelerations with the Empirical Bayes estimator of the number of cyclist injuries at intersections: 0.6 and 0.53 for signalized and unsignalized intersections resp.

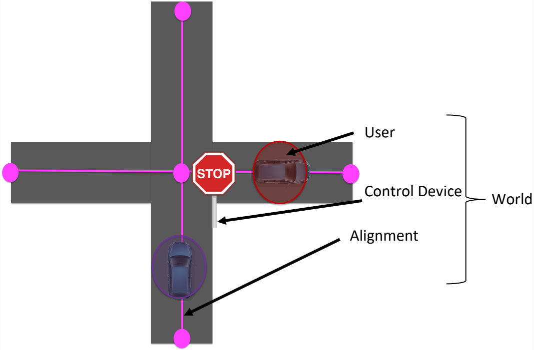



## Cyclist Probe Data

Correlation of 0.57 for the number of hard cyclist decelerations with the Empirical Bayes estimator of the number of cyclist injuries on links

# Outline

# Minimal Simulation Model




Explore the shape of the safety hierarchy

# Conclusion

- More studies are done

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- But we have not validated most surrogate measures of safety: lack of ground truth

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- More studies are done
- But we have not validated most surrogate measures of safety: lack of ground truth
- Video analysis is useful and more and more used, more or less automatically
    - possible manual annotation for quality improvement and additions (e.g. gender, age and helmet use)

# Perspectives

- Promising new sources of data for continous safety diagnosis, often available from user-based (telematics) insurance programs

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- Promising new sources of data for continous safety diagnosis, often available from user-based (telematics) insurance programs
  - how to combine multiple sources of data?
- New challenges of vehicle automation
  - surrogate measures of safety provide the only way to measure safety as the relationships between safety and exogenous variables shift continuously and quickly

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Questions?

Jackson, S., Miranda-Moreno, L. F., St-Aubin, P., and Saunier, N. (2013).
**A flexible, mobile video camera system and open source video analysis software for road safety and behavioural analysis.**
*Transportation Research Record: Journal of the Transportation Research Board*, 2365:90–98.
Presented at the 2013 Transportation Research Board Annual Meeting.