A Surrogate Safety Analysis at Protected Freeway Ramps Using Cross-Sectional and Before-After Video

Paul St-Aubin\textsuperscript{1,2}, Ph.D. Candidate

Luis Miranda-Moreno\textsuperscript{1}, Assistant Professor

Nicolas Saunier\textsuperscript{2}, Assistant Professor

\textsuperscript{1}Department of Civil Engineering, McGill University, Montreal
\textsuperscript{2}Département des Génies civil, géologique et des mines, École Polytechnique de Montréal

ITS Canada | ACGM 2012
June 12, 2012
Objective

- Road safety:
  - Conflict-based diagnostic tool for road design, particularly for road safety analysis, but adaptable for other purposes
  - Complement to the classical historical analysis approach, or where limited data is available (e.g. “design exceptions”)
  - Currently implementable for small before-after analyses

- Microscopic trajectory data:
  - Lane changes
  - Small-scale changes in speed/direction
  - Driver behaviour
  - Etc.

Tarko, A. (2012), Use of crash surrogates and exceedance statistics to estimate road safety, Accident Analysis and Prevention vol. 48
Why Surrogate Safety?

- Native use of interactions as a measure of exposure
- Return period of accident observations are often unpractical
- Prevention over treatment
- Accident reporting has consistency, accuracy issues
- Microscopic scale of analysis possible

Limitations

- Limited acceptance; technology still in its infancy
- Still some debate regarding transferability of results to other studies/environments
- No standard measurement
Basic Definition

- We can define the classical Time-To-Collision (TTC) measure as the travel time required for two vehicles on unchanged paths to enter a collision point (CP), if it exists:

\[ \text{TTC} = \frac{D_{CP}}{V} \]

Basic collision prediction used in straight highway segments, adapted from:

For every frame, every pair of two objects

- Interaction Type
  - Rear-End (Type a)
    - Interaction Subtype
      - $V_1 < V_2$
        - Converge (Subtype A)
          - TTC
        - Diverge (Subtype C)
          - CP(x,y)
      - $V_1 > V_2$
        - Diverge (Subtype C)
          - TTC
          - CP(x,y)
  - Lateral/ Diagonal (Type c)
    - Interaction Subtype
      - Crossing paths, TTA within range
        - Converge (Subtype A)
          - TTC
          - CP(x,y)
        - Post-Encroachment (Subtype B)
          - PET
      - Crossing paths, TTA out of range
        - Converge/Diverge (Subtype C)
          - Converge/Diverge Ratio
      - Paths do not cross

- CP(x,y)
  - Frequency Distributions
Automated Trajectory Tracking

- Allows for very large datasets to be efficiently collected
- Objective readings
  - Consistent and precise acceleration/speed tracking of multiple vehicles on a projected surface
  - Previous surrogate safety criticism included subjectivity and reliability in conflict measurements
- Cheap and versatile camera sensors; computer-vision-based detection technology improving rapidly

- Limited however by weather/visibility conditions
- Practical analysis zone of 50-200 metres, depending on visibility, resolution, camera height, obstacles, etc.
- Manual steps are still required for camera calibration and tracking parameter tuning
Conflict Heatmap

- Weighted density map of collision points (in this case weighted by $e^{-\text{TTC}}$)
- Identify microscopic conflict hotspots from CP’s and respective TTC measurements
- Weighing in terms of probability of collision to come with formal relationship between TTC and collision probability
TTC Distribution

- TTC is a solid general purpose indicator for unidirectional highway conflicts
- Many options for aggregation (subsegment, lane, vehicle pair, min, max, mean, moving average, etc.)
- Link between TTC distribution and collision probability is key, future research
Other Measures

- Speed distribution
- Following distance
- Lane changes
- Etc.
Case Study: Highway Horizontal Signalisation

- Highway design exception treatment evaluation (project for the Ministère des Transports du Québec)
  - “Ligne continue à gauche de la voie 1” (LCGV1)
  - Montreal
Highway Accidents

- Unidirectional
  - Rear-end converging (45%; MTQ)
  - Lateral/side-swipe converging (25%; MTQ)
- High-speed
  - Highly dependent on reaction-time, safety distances (following and merging)

Focus: collision probability (as opposed to severity)
- Conflicts during congestion are, so far, too noisy to be significant
- Observation of high-speed conflicts at off-peak periods
Measured TTC (s)

Frequency (% per 0.5 increment)

- All conflicts
- Type A conflicts
- Type C conflicts
- All unique pair conflicts
- Type A unique pair conflicts
- Type C unique pair conflicts
- All unique individual conflicts
- Type A unique individual conflicts
- Type C unique individual conflicts
Measured TTC (s)

Frequency (% per 0.5 increment)

- All conflicts
- Type A conflicts
- Type C conflicts
- All unique pair conflicts
- Type A unique pair conflicts
- Type C unique pair conflicts
- All unique individual conflicts
- Type A unique individual conflicts
- Type C unique individual conflicts
Without treatment

With treatment

---

**Measured TTC (s)**

- **Without treatment**
  - All conflicts
  - Type A conflicts
  - Type C conflicts
  - All unique pair conflicts
  - Type A unique pair conflicts
  - Type C unique pair conflicts
  - All unique individual conflicts
  - Type A unique individual conflicts
  - Type C unique individual conflicts

- **With treatment**
  - All conflicts
  - Type A conflicts
  - Type C conflicts
  - All unique pair conflicts
  - Type A unique pair conflicts
  - Type C unique pair conflicts
  - All unique individual conflicts
  - Type A unique individual conflicts
  - Type C unique individual conflicts

---

**Frequency (% per 0.5 increment)**

- **Without treatment**
  - All conflicts
  - Type A conflicts
  - Type C conflicts
  - All unique pair conflicts
  - Type A unique pair conflicts
  - Type C unique pair conflicts
  - All unique individual conflicts
  - Type A unique individual conflicts
  - Type C unique individual conflicts

- **With treatment**
  - All conflicts
  - Type A conflicts
  - Type C conflicts
  - All unique pair conflicts
  - Type A unique pair conflicts
  - Type C unique pair conflicts
  - All unique individual conflicts
  - Type A unique individual conflicts
  - Type C unique individual conflicts
**Rear-end Conflicts**

Cumulative TTC (s) distributions

**Side-swipe Conflicts**

Cumulative TTC (s) distributions

<table>
<thead>
<tr>
<th>Site</th>
<th>Treatment</th>
<th>q%</th>
<th>Mean % flow by lane</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Lane 1</td>
</tr>
<tr>
<td>A20-E-E56-3</td>
<td>No</td>
<td>-</td>
<td>27.5%</td>
</tr>
<tr>
<td>A20-W-E62</td>
<td>No</td>
<td>24.9%</td>
<td>21.3%</td>
</tr>
<tr>
<td>A20-E-E58</td>
<td>No</td>
<td>10.9%</td>
<td>12.3%</td>
</tr>
<tr>
<td>A720-E-E3</td>
<td>Yes</td>
<td>3.0%</td>
<td>31.4%</td>
</tr>
<tr>
<td>A20-E-E56-3</td>
<td>Yes</td>
<td>-</td>
<td>32.5%</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>-</td>
<td>12.6%</td>
</tr>
<tr>
<td>A13-N-S3-1</td>
<td>No</td>
<td>5.9%</td>
<td>17.0%</td>
</tr>
<tr>
<td>A25-S-S3</td>
<td>No</td>
<td>18.2%</td>
<td>38.3%</td>
</tr>
<tr>
<td>A20-E-S58</td>
<td>Yes</td>
<td>-</td>
<td>27.2%</td>
</tr>
<tr>
<td>A25-N-S5</td>
<td>Yes</td>
<td>9.7%</td>
<td>23.4%</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>-</td>
<td>11.3%</td>
</tr>
</tbody>
</table>

**Flow by lane**

**Lane changes in lane changes per veh-km**

<table>
<thead>
<tr>
<th>Site</th>
<th>Treatment</th>
<th>1 → 2</th>
<th>2 → 3</th>
<th>3 → 4</th>
<th>4 → 3</th>
<th>3 → 2</th>
<th>2 → 1**</th>
</tr>
</thead>
<tbody>
<tr>
<td>A20-E-E56-3</td>
<td>No</td>
<td>0.148</td>
<td>0.192</td>
<td>-</td>
<td>-</td>
<td>0.097</td>
<td>0.136</td>
</tr>
<tr>
<td>A20-W-E62</td>
<td>No</td>
<td>0.126</td>
<td>0.327</td>
<td>-</td>
<td>-</td>
<td>0.120</td>
<td>0.103</td>
</tr>
<tr>
<td>A20-E-E58</td>
<td>No</td>
<td>0.024</td>
<td>0.068</td>
<td>-</td>
<td>-</td>
<td>0.096</td>
<td>0.140</td>
</tr>
<tr>
<td>A720-E-E3</td>
<td>Yes</td>
<td>0.151</td>
<td>0.091</td>
<td>0.046</td>
<td>0.025</td>
<td>0.065</td>
<td>0.093</td>
</tr>
<tr>
<td>A20-E-E56-3</td>
<td>Yes</td>
<td>0.118</td>
<td>0.068</td>
<td>-</td>
<td>-</td>
<td>0.053</td>
<td>0.139</td>
</tr>
<tr>
<td>A13-N-S3-1</td>
<td>No</td>
<td>0.175</td>
<td>0.345</td>
<td>-</td>
<td>-</td>
<td>0.344</td>
<td>0.126</td>
</tr>
<tr>
<td>A25-S-S5</td>
<td>No</td>
<td>0.184</td>
<td>0.162</td>
<td>-</td>
<td>-</td>
<td>0.042</td>
<td>0.279</td>
</tr>
<tr>
<td>A20-E-S58</td>
<td>Yes</td>
<td>0.126</td>
<td>0.097</td>
<td>-</td>
<td>-</td>
<td>0.099</td>
<td>0.176</td>
</tr>
<tr>
<td>A25-N-S5</td>
<td>Yes</td>
<td>0.184</td>
<td>0.510</td>
<td>-</td>
<td>-</td>
<td>0.225</td>
<td>0.145</td>
</tr>
</tbody>
</table>
Direction for Future Work

- Robot navigation
  - Overlap with smart vehicle driving systems (e.g. collision warning, Google car, etc.)
  - Changes in road design according to changes in vehicle safety performance (e.g. reduction in reaction times through automation)

- Probabilistic trajectory prediction
  - Trajectory prototypes and path prediction (Saunier et al. 2010)
  - HMMs, K-Means, FCM, Similarity Threshold, I-kMeans, Agglomerative, Divisive, SOM, Fuzzy SOM and SOFM (Morris & Trivedi, 2008)
Conclusion

- Safety benefit not significant
- LCGV1 treatment has its flaws
  - For some sites, its use may be justified, but for many sites, it creates or, at the very least, only **displaces problems** instead of correcting them.

- Conflict analysis methodology is in place, currently adequate for basic **comparative analysis**
- Computer vision tracking algorithms constantly improving
- Next steps:
  - Improvements in path and collision prediction
  - Continued use of methodology in a wider variety of environments
  - Comparison with historical accident data
We want to acknowledge the support of the Ministère des Transports du Québec which funded this project.

Questions?
- Laugier et al. (2011) *Probabilistic Analysis of Dynamic Scenes and Collision Risks Assessment to Improve Driving Safety*, IEEE Intelligent Transportation Systems