Automated Methods for Surrogate Safety Analysis: Where We Are and Where to Go Next

ICTCT 2014 Workshop
University of Applied Science in Karlsruhe

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Outline

1. Motivation
2. Approach
3. Case Studies
4. Where to Go Next?
5. Conclusion
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Where We Are

- We should and can be proactive
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- “New” data collection technologies: automated video analysis (Videos)
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  - cheap hardware (computers and cameras), open source software for machine learning and computer vision (e.g. OpenCV), new analysis frameworks
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  - video analysis has thus become feasible with good enough results to extract microscopic road user data (trajectories)
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  - cheap hardware (computers and cameras), open source software for machine learning and computer vision (e.g. OpenCV), new analysis frameworks
  - video analysis has thus become feasible with good enough results to extract microscopic road user data (trajectories)
- A **fragmented** landscape of methods for “surrogate safety analysis”
Foundation: The Safety/Severity Hierarchy

Accidents

Serious Conflicts
Slight Conflicts
Potential Conflicts
Undisturbed passages

Motivation

[Diagram showing the hierarchy of undisturbed passages, potential conflicts, slight conflicts, serious conflicts, and accidents.]
Foundation: The Safety/Severity Hierarchy

Do the boundaries actually exist and do we need them?
A plethora of 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?
Some Issues with Current Methods

- 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)
How do we compare models/frameworks/theories?

Occam’s razor

There is trade-off between the complexity of a model and its explanatory power, i.e. given 2 models with similar explanatory power, the simpler one is the superior one.
Current Research Objectives

- Develop an **automated, robust and generic** probabilistic framework for surrogate safety analysis.
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  - applied to several case studies: urban intersections, vulnerable road users, highways, roundabouts
- Better understand **collision processes** and the similarities between interactions with and without a collision
Current Research Objectives

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

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

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

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

[Saunier et al., 2010, Mohamed and Saunier, 2013, Saunier and Mohamed, 2014]
Is this updated TTC sufficient?

- An extra dimension seems conceptually necessary to measure the ability of road users to avoid the collision, e.g. DST or a generic probability of unsuccessful evasive action [Mohamed and Saunier, 2013]
- Sample the space of possible evasive actions (e.g. using more extreme distribution of braking) and compute again the probability of collision
Interpret the Whole Traffic Continuum (Not Just Serious Conflicts)

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).

Interpret the Whole Traffic Continuum (Not Just Serious Conflicts)

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).

Interactions are characterized by time series of indicators (based on position and speed, and safety indicators)

Need for measures that naturally accomodate variable length vectors: Longest Common Sub-sequence (LCSS)

Cluster interactions to find similarities between interactions, with and without a collision
Automated Video Analysis

Image Sequence +

Road User Trajectories

Interactions

Applications

Camera Calibration

Labeled Images for Road User Type

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 Tracking (Kentucky Dataset)
Motion Prediction
Motion Prediction
Motion Prediction
Safety Indicators

![Graphs showing collision probability and TTC over time](image)

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Distribution of Indicators (Event Aggregation)

[Saunier et al., 2010]
Spatial Distribution of the Collision Points [Saunier et al., 2010]

Traffic Conflicts
Spatial Distribution of the Collision Points \cite{Saunieretal2010}
Before and After Study: Introduction of a Scramble Phase

Data collected in Oakland, CA [Ismail et al., 2010]
Distribution of Safety Indicators

Histogram of Before-and-After TTC

Histogram of Before-and-After DST

Histogram of Before-and-After PET

Histogram of Before-and-After GT
Before and After Distribution of the Collision Points

a) 
b) 
c) Before Scramble 
d) After Scramble
Lane-Change Bans at Urban Highway Ramps

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]
Case Studies

Lane-Change Bans at Urban Highway Ramps

Ramp: A20-E-E56-3  Region(s): UPreMZ
Treatment: No  Analysis length: 50 m

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

[St-Aubin et al., 2015b]

<table>
<thead>
<tr>
<th>#</th>
<th>Description</th>
<th>$N_{zones}$</th>
<th>$N_{obs}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Small single and double lane residential collectors</td>
<td>11</td>
<td>4,200</td>
</tr>
<tr>
<td>2</td>
<td>Single-lane regional highways and arterials with speed limits of 70-90 km/h and mostly polarised flow ratios</td>
<td>16</td>
<td>26,243</td>
</tr>
<tr>
<td>3</td>
<td>2-lane arterials with very high flow ratios</td>
<td>5</td>
<td>13,307</td>
</tr>
<tr>
<td>4</td>
<td>Hybrid lane $1 \rightarrow 2$, $2 \rightarrow 1$ arterials with very low flow ratios</td>
<td>3</td>
<td>4,809</td>
</tr>
<tr>
<td>5</td>
<td>Traffic circle converted to roundabout (2 lanes, extremely large diameters, tangential approach angle)</td>
<td>4</td>
<td>10,295</td>
</tr>
<tr>
<td>6</td>
<td>Single-lane regional highway with large-angle quadrants ($140^\circ$) and mixed flow ratios</td>
<td>2</td>
<td>2,235</td>
</tr>
</tbody>
</table>
The Aggregation Problem [St-Aubin et al., 2015a]
TTC Distribution Comparison by Cluster

[St-Aubin et al., 2015b]
Cycle Track Safety [Zangenehpour et al., 2015]
## Case Studies

### Cycle Track Safety [Zangenehpour et al., 2015]

#### Model I. Cycle track on the right vs. no cycle track

|                     | 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 | -6.684 | 0.2836 | -25.56 | 0.000 | -7.2443 | -6.1326 |
| Cut-off 2 | -3.8927 | 0.1968 | -19.92 | 0.000 | -4.2785 | -3.5070 |
| Cut-off 3 | -2.5246 | 0.1812 | -23.01 | 0.000 | -2.8148 | -2.1695 |

#### Model II. Cycle track on the left vs. no cycle track

|                     | 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 | 0.0035 | 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 | -36.70 | 0.000 | -7.956 | -7.0285 |
| Cut-off 2 | -3.5944 | 0.1243 | -29.52 | 0.000 | -3.8380 | -3.3509 |
| Cut-off 3 | -2.0168 | 0.1132 | -17.95 | 0.000 | -2.2387 | -1.7950 |

#### Model III. Cycle track on the right vs. cycle track on the left

|                     | 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 | -25.12 | 0.000 | -8.3532 | -7.1471 |
| Cut-off 2 | -3.7916 | 0.2684 | -14.32 | 0.000 | -4.3177 | -3.2655 |
| Cut-off 3 | -2.2953 | 0.2650 | -8.65 | 0.000 | -2.8148 | -1.7758 |
Indicator/Interaction Clustering [Saunier and Mohamed, 2014]

Cluster 1 - 23.1% (28/121)

Cluster 2 - 42.7% (35/82)

Cluster 3 - 0.0% (0/8)

Cluster 4 - 42.1% (8/19)

Cluster 5 - 38.5% (5/13)

Cluster 6 - 11.5% (6/52)
Case Studies

Indicator/Interaction Clustering [Saunier and Mohamed, 2014]

Cluster 1 - 27.6%(42/152)
Cluster 2 - 30.0%(18/60)
Cluster 3 - 37.5%(21/56)
Cluster 4 - 3.8%(1/26)
Cluster 1 - 35.6% (36/101)
Cluster 2 - 23.0% (20/87)
Cluster 3 - 17.5% (10/57)
Cluster 4 - 33.3% (16/48)
Indicator/Interaction Clustering [Saunier and Mohamed, 2014]

Cluster 1 - 19.4% (13/67)
Cluster 2 - 38.2% (55/144)
Cluster 3 - 33.3% (3/9)
Cluster 4 - 5.0% (1/20)
## Indicator/Interaction Clustering

[Saunier and Mohamed, 2014]

**Cluster 1** - 18.6% (24/129)

**Cluster 2** - 45.3% (34/75)

**Cluster 3** - 18.2% (2/11)

**Cluster 4** - 0.0% (0/5)

**Cluster 5** - 18.2% (2/11)

**Cluster 6** - 20.0% (1/5)

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Open Questions

- How can we aggregate indicators over time and space (and severity), without hiding information?
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- 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]
The Groundhog Day Syndrome

We must stop reinventing the wheel
Steps Forward: Some Challenges to the Research Community

We need to

- Stop fragmenting: first read the literature (all of it!), try the existing most promising methods, then identify gaps, if any, and address them

Share our methods, at least freely with the research community, ideally as open source software

Collaborate with other researchers to improve their (open source) methods

Collect and share data, use benchmarks to compare to other methods [Saunier et al., 2014]

Maybe we need new calibration conferences (Malmö and Trautenfels)?
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- Please free past research
Steps Forward: Some Challenges to the Research Community

Please free past research

- scan old dusty technical reports, theses and conference proceedings etc., and put them on the ICTCT website
Steps Forward: Some Challenges to the Research Community

- Please **free past research**
  - scan old dusty technical reports, theses and conference proceedings etc., and put them on the ICTCT website
- Beware of **boundaries**: study the whole continuum of interactions and similarities between interactions with and without a collision
The challenge is to propose a simple and generic framework for surrogate safety analysis with good explanatory and predictive power.
Conclusion

- The challenge is to propose a *simple* and *generic* framework for surrogate safety analysis with good *explanatory* and *predictive* power
- Please *share* and *collaborate* to improve road safety
The challenge is to propose a simple and generic framework for surrogate safety analysis with good explanatory and predictive power.

Please share and collaborate to improve road safety.

Traffic Intelligence open source project

https://bitbucket.org/Nicolas/trafficintelligence
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)

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)

Questions?


In *The 10th International IEEE Conference on Intelligent Transportation Systems*, pages 872–878, Seattle. IEEE.


Conclusion

Comparison of various objectively defined surrogate safety analysis methods.

In *Transportation Research Board Annual Meeting Compendium of Papers.*
15-4629.

In *Transportation Research Board Annual Meeting Compendium of Papers.*
15-5317.

Detailed driver behaviour analysis and trajectory interpretation at roundabouts using computer vision data.
In *Transportation Research Board Annual Meeting Compendium of Papers.*
