Introduction to Surrogate Analysis in Non-Motorized Safety

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1 Introduction

A World Health Issue

> Over 1.2 million people die each year on the world's roads, and between 20 and 50 million suffer non-fatal injuries. In most regions of the world this epidemic of road traffic injuries is still *increasing*. (Global status report on road safety, World Health Organization, 2009)

TOTAL 2004

RANK	LEADING CAUSE	%
1	Ischaemic heart disease	12.2
2	Cerebrovascular disease	9.7
3	Lower respiratory infections	7.0
4	Chronic obstructive pulmonary disease	5.1
5	Diarrhoeal diseases	3.6
6	HIV/AIDS	3.5
7	Tuberculosis	2.5
8	Trachea, bronchus, lung cancers	2.3
9	Road traffic injuries	2.2
10	Prematurity and low birth weight	2.0
11	Neonatal infections and other	1.9
12	Diabetes mellitus	1.9
13	Malaria	1.7
14	Hypertensive heart disease	1.7
15	Birth asphyxia and birth trauma	1.5
16	Self-inflicted injuries	1.4
17	Stomach cancer	1.4
18	Cirrhosis of the liver	1.3
19	Nephritis and nephrosis	1.3
20	Colon and rectum cancers	1.1

TOTAL 2030

RANK	LEADING CAUSE	%
1	Ischaemic heart disease	12.2
2	Cerebrovascular disease	9.7
3	Chronic obstructive pulmonary disease	7.0
4	Lower respiratory infections	5.1
5	Road traffic injuries	3.6
6	Trachea, bronchus, lung cancers	3.5
7	Diabetes mellitus	2.5
8	Hypertensive heart disease	2.3
9	Stomach cancer	2.2
10	HIV/AIDS	2.0
11	Nephritis and nephrosis	1.9
12	Self-inflicted injuries	1.9
13	Liver cancer	1.7
14	Colon and rectum cancer	1.7
15	Oesophagus cancer	1.5
16	Violence	1.4
17	Alzheimer and other dementias	1.4
18	Cirrhosis of the liver	1.3
19	Breast cancer	1.3
20	Tuberculosis	1.1

Source: World health statistics 2008 (http://www.who.int/whosis/whostat/2008/en/index.html)

Safety

- Safety is characterized by the absence of accidents
- The term "accident" is usually avoided in order to highlight their predictable and preventable nature: *collision* or *crashes* are preferred
- Safety is defined as the number of collisions *expected* to occur at a given location per unit of time, where "expected" refers to "the average in the long run if it were possible to freeze all prevailing conditions that affect safety" [Hauer et al., 1988]

The Risk of Collision

Would you consider that the risk associated with *rolling a dice* and playing the *Russian roulette* are the same?

Would you consider that the risk associated with a collision involving *two cars*, or *a car and a pedestrian* are the same (other things being equal)?

The concept of risk associated with an event involves two dimensions:

- the *probability* of the event

- the *consequences* of the event

In mathematical terms, the risk corresponds to the expected value of a random variable measuring the consequence of the event

Methods for Road Safety Analysis
There are *two* main categories of methods, whether they are based on the observation of traffic events or not

1. Traditional road safety analysis relying on historical collision data
    - "Accident analysis is a desk tool, not a field tool" (C. Hydén)
2. Vehicular accident reconstruction providing in-depth collision data
3. Real-time collision-prone location identification
4. Naturalistic driving studies
5. Surrogate safety analysis

The Shortcomings of Traditional Road Safety Analysis
Historical collision data is collected after the occurrence of the collision. It suffers from the following issues [Ismail, 2010]

1. difficult *attribution* of collisions to a cause
    - reports are skewed towards the attribution of responsibility, not the search for the causes that led to a collision
2. *small* data quantity
3. limited quality of the data *reconstituted* after the event, with a bias towards more damaging collisions

Traditional Road Safety Analysis is <u>Reactive</u>

- The following *paradox* ensues: safety analysts need to wait for accidents to happen in order to prevent them
- There is a need for *proactive* methods for road safety analysis, i.e. that do not rely on the occurrence of collisions. The recent new keyword is *surrogate* safety analysis

Surrogate Safety Measures
Need for surrogate safety measures that

- bring complementary information
- are related to traffic events that are more frequent than collisions and can be observed in the field
- are correlated to collisions, logically and statistically

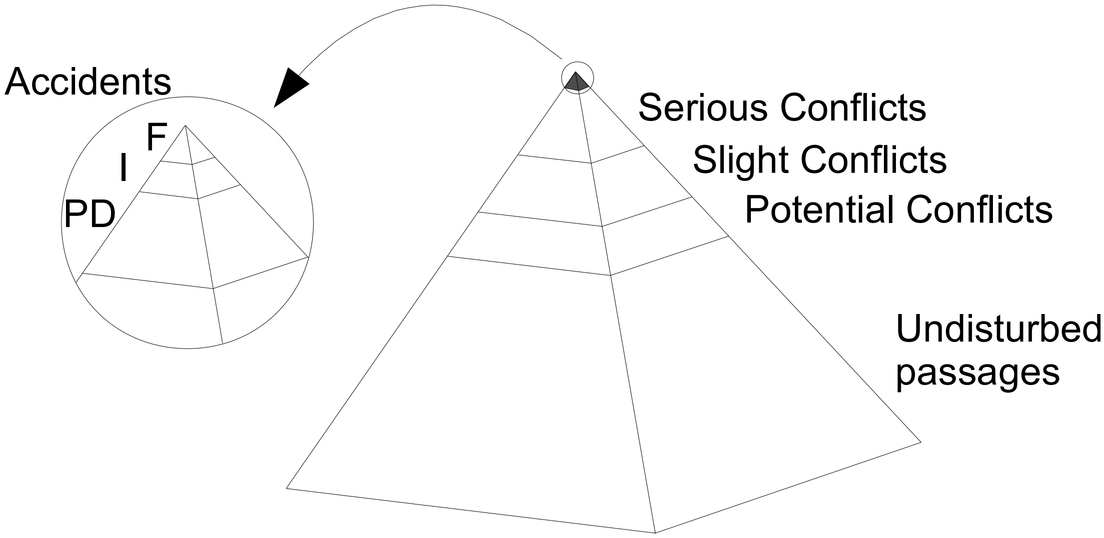
2 Traffic Conflict Techniques

Traffic Conflicts

- Traffic conflicts have received the most attention since their first conceptualization in 1968 in the General Motors Research Laboratories [Perkins and Harris, 1968]
- The accepted definition of 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]

A Traffic Conflict

The Safety Hierarchy



An *interaction* is a situation in which two road users are close enough (pre-condition or exposure to a collision involving two road users)

An encounter is defined as the simultaneous presence of two road users within some predefined area (similar to interaction) and a near miss as a situation when two road users unintentionally pass each other with a very small margin, so that the general feeling is that a collision was "near" in [Laureshyn, 2010].

Traffic as a Process of Constant Interactions

Table 1:1 The number of events an average driver faces in traffic, per unit of time or per km. The figures are based on an average speed of 60 km/h and an annual mileage of 20 000 km. The figures are gathered from US and Finnish data (Häkkinen & Luoma, 1991).

	number of events in a unit of time or per km	
Traffic information	5 in 1 sec	300 per km
Driver observations	2 in 1 sec	120 per km
Driver decisions	40 in 1 min	40 per km
Driver actions	30 in 1 min	30 per km
Driver errors	1 in 2 min	1 per 2 km
Risky situations	1 in 2 hours	1 per 120 km
Near-accidents	1 in 1 month	1 per 2 000 km
Accidents	1 in 7.5 years	1 per 150 000 km
Injury accidents	1 in 100 years	1 per 2 000 000 km
Fatal accidents	1 in 2 000 years	1 per 40 000 000 km

(Source [Svensson, 1998])

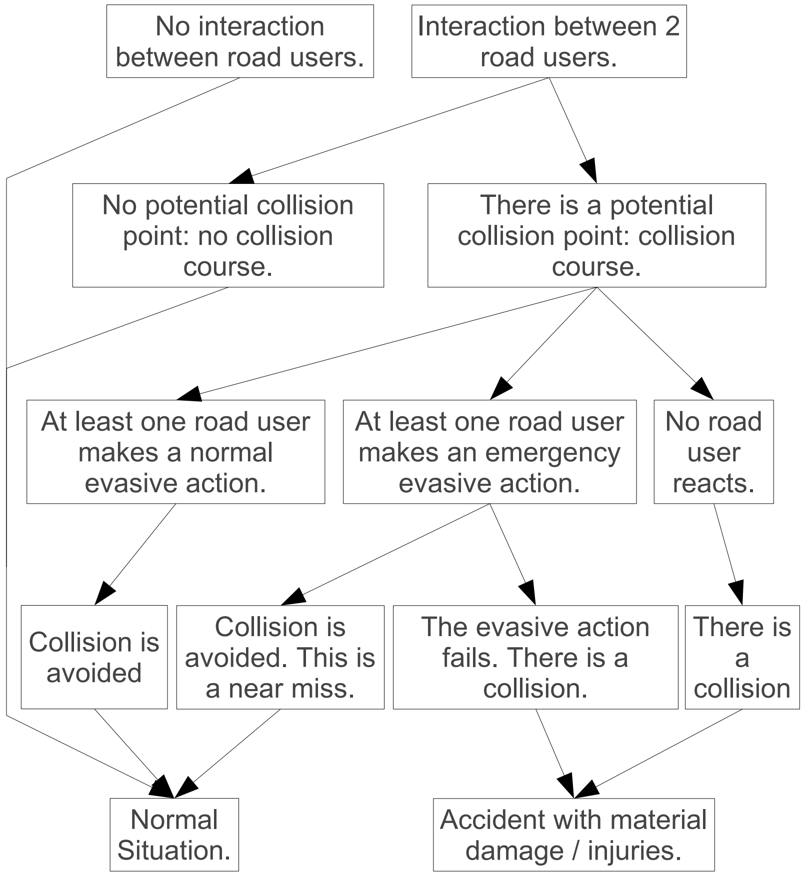
The Collision Course

- 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*"
- Road users are on a collision course if they would collide if they continue with unchanged speeds and paths

- ◦ Extrapolation hypothesis = *constant velocity*

- Extensions: crossing and diverging course [Laureshyn, 2010]
- If road users are on a collision course, an *evasive action* must be undertaken for the interaction to be a traffic conflict

The Traffic Conflict Process



The Severity of a Conflict

- "The severity is an operational parameter describing the "closeness" of an encounter (interaction) to a collision" [Laureshyn, 2010]
  - ◦ The definition continues with "ideally, encounter severity should reflect both the risk of a collision and the severity of possible consequences" (different vocabulary)
  - ◦ Different definitions: in this talk, severity is related to the probability dimension only
- Various severity *indicators*
- The *severity hierarchy* is the distribution of traffic events rated according to some operational severity measure [Laureshyn, 2010]

Traffic Conflict Techniques (TCTs)

- A TCT is a method for traffic safety estimation based on the observation of traffic conflicts [Laureshyn, 2010]
- The basic *hypothesis* of TCTs is that accidents and conflicts originate from the same type of processes in traffic and a relation between them can be found
- TCTs involve observing and evaluating the *frequency* and *severity* of traffic conflicts at a given road location by a team of *trained observers*. They include
  - operational definitions of traffic conflicts and their severity
  - methods to interpret the collected data as safety measures

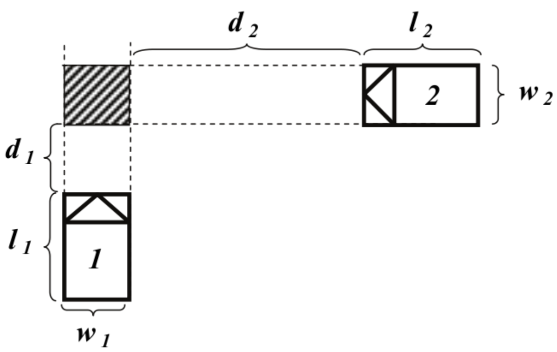
Severity Indicators

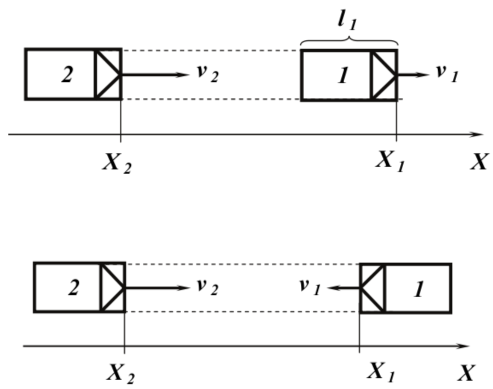
They can be objective or subjective, whether they are based on an objective measure or an observer's judgement: [Gettman and Head, 2003, Archer, 2004, Laureshyn, 2010]

- Continuous measures
  - Time-to-collision (TTC)
  - Gap time (GT) or predicted PET
  - Deceleration to safety time (DST)
  - Speed, etc
- Unique measures per conflict
  - Post-encroachment time (PET)
  - Evasive action(s) (harshness), subjective judgement, etc

Why are there no distance-based indicators?

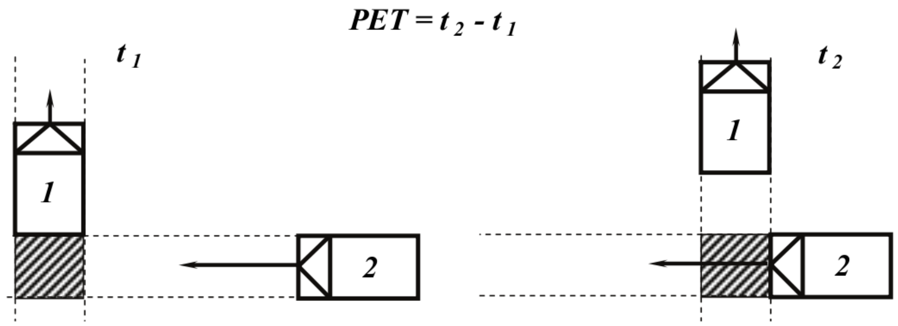
Time-to-Collision





$$TTC = \frac{d_2}{v_2} \; if \; \frac{d_1}{v_1} < \frac{d_2}{v_2} < \frac{d_1 + l_1 + w_2}{v_1}$$
$$TTC = \frac{d_1}{v_1} \; if \; \frac{d_2}{v_2} < \frac{d_1}{v_1} < \frac{d_2 + l_2 + w_1}{v_2} \; (side)$$
$$TTC = \frac{X_1 - X_2 - l_1}{v_1 - v_2} \; if \; v_2 > v_1 \; (rear\ end)$$
$$TTC = \frac{X_1 - X_2}{v_1 + v_2} \; (head\ on)$$

Post-Encroachment Time and Gap Time



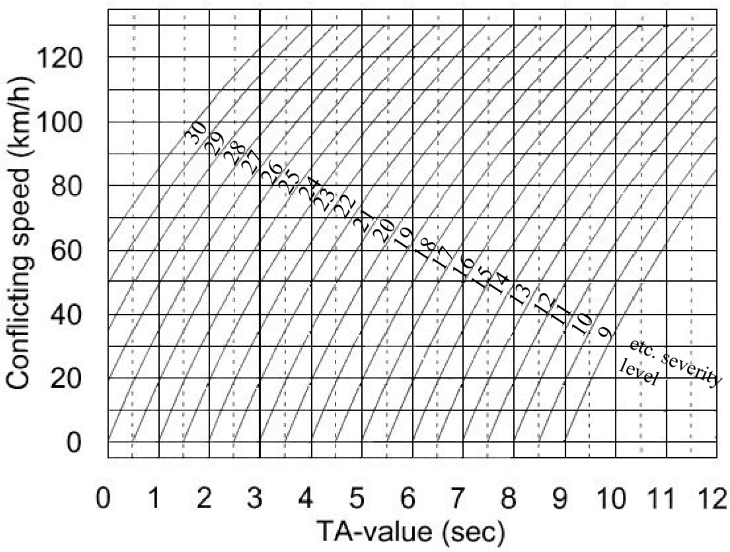
- PET is the time difference between the moment an offending road user leaves an area of potential collision and the moment of arrival of a conflicted road user possessing the right of way
- GT is calculated at each instant by extrapolating the movements of the interacting road users in space and time

Gap time is called Time Advantage in [Laureshyn, 2010].

Deceleration to Safety Time and Speed

- Based on a momentary measure of speed and distance to a conflict point, DST is the average (linear) braking required to avoid a collision from the point the measure is taken
- Speed is especially important if the severity is meant to measure the potential collision outcome
    - speed differential

The Swedish TCT



- Based on TTC and conflicting speed measured at the beginning of the evasive action
- Serious conflict *threshold* between severity level 25 and 26
- Conversion factors from serious conflicts to accidents

The TTC measured at the beginning of the evasive action is called Time to Accident in the Swedish TCT. The relevant road user for the indicator measures is

- the road user who takes evasive action if only one does,
- if both take evasive action, the one of the two primarily involved road users whose combination of TA and CS produce the value with lowest risk.

The Canadian TCT

Two indicators [Brown, 1994, Sayed and Zein, 1999]

TTC and ROC scores	*Time to collision (TTC) (s)*	*Risk of collision (ROC)*
1	1.6–2.0	Low risk
2	1.0–1.5	Moderate risk
3	0.0–0.9	High risk

- Time-to-Collision score
- ROC (risk of collision) score: "it is a *subjective measure* of the seriousness of the observed conflict and is dependent on the perceived control that the driver has over the conflict situation, the severity of the evasive manoeuvre and the presence of other road users or constricting factors which limit the driver's response options"

Indicators

"An *indicator* is an objective and measurable parameter that has a relation to a studied quality of the traffic system (e.g. efficiency, safety, comfort, etc)" [Laureshyn, 2010]. Indicators have two important characteristics

Validity the property of an indicator to describe the quality that it is intended to represent

Reliability the property of an indicator to be measured with the same accuracy and objectivity regardless to where, in what conditions and by whom the measurements are performed

Various TCTs

- 12 TCTs in 1988: Swedish [Hydén, 1987, Svensson, 1998, Laureshyn, 2010], French [Muhlrad, 1988], Dutch [van der Horst, 1990], US [Parker and Zegeer, 1989], Canada [Brown, 1994, Sayed and Zein, 1999], etc
- Calibration conferences: Malmö (1983, 10 teams) and Trautenfels (1985, 6 teams)
    - Differences: the detection threshold of serious traffic conflicts and the definition of severity indicator(s) (related to national definitions of safety)

    - *Broad agreement* of severity dimension once a conflict is detected
    - "Best" indicator: minimum TTC (TTC_{min})
    - Severe conflict threshold: $TTC_{min} = 1.5$ s, $PET = 1$ s

The work done in calibration conferences continues in the International Co-operation on Theories and Concepts in Traffic Safety which holds annual workshops.

Reliability of TCTs

- Observers in the Swedish TCT under-estimated TTC by 0.05 s and speed by 3 km/h, and failed to score about 26 % of the conflicts [Svensson, 1998]
- "Reliability tests of the observation method gave 77 % accuracy with a 95 % level of confidence, with an 85 % accuracy for assessing the correct TTC" [Brown, 1994, Sayed and Zein, 1999]

Validity of TCTs
How good is the TCT in *estimating safety* (the expected number of accidents)?

- "Traffic conflicts of certain types are good surrogates of accidents in that they produce estimates of average accident frequencies nearly as accurate, and just as precise, as those produced from historical accident data" [Svensson, 1998]
    - "in the validation of the US TCT, the expected accident frequencies estimated by conflicts and accidents proved to be very close to the actual observed accident frequencies"
- Canadian TCT: in a study of 13 intersections, at eight of 11 intersections, conflicts are significantly correlated with accidents at the 95 % level of confidence with $R^2 > 0.64$, with three intersections having $R^2 > 0.81$ [Brown, 1994, Sayed and Zein, 1999]
    - correlation improves if events are disaggregated by movement types

Traffic Conflicts and Exposure

- Traffic conflicts are defined operationally to have a known relationship to safety
- The concept of exposure to the risk of collision has been introduced to "take account of the amount of opportunity for collisions which the driver of the traffic system experiences" [Chapman, 1973]
    - exposure is defined as a "measure of spatial or temporal duration in the traffic system in relation to the number of dynamic system objects, road users, vehicles, etc" [Archer, 2004]
- The two concepts serve *different purposes* [Hauer, 1982]
- In the general sense, a traffic conflict is a necessary condition for a collision to occur, i.e. exposure to the risk of collision

Limitations of TCTs

- *Costly* manual/semi-automated collection
- Reliability and subjectivity of human observers
- Mixed validation results in the literature: difficulty to apply the techniques?

Decreasing interest in the late 1980s, 1990s, trained teams of observers dissolved

The Whole Hierarchy

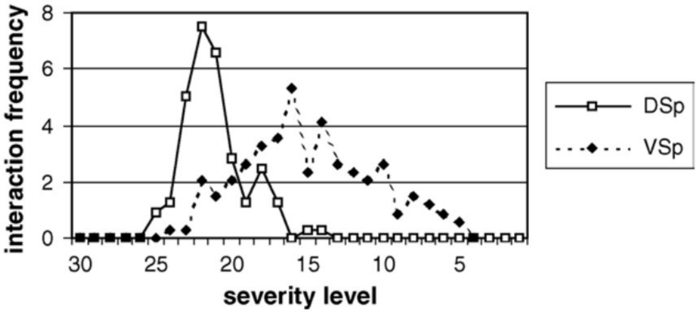


Fig. 6. Interaction frequency (interactions per observation hour) for different severity levels. Straight ahead driving vehicles versus pedestrians. The pedestrian is taking evasive action. A non-signalised intersection (DSp) and a signalised intersection (VSp).

Feedback and *learning* process: collisions with injuries occurred at the signalized intersection [Svensson, 1998, Svensson and Hydén, 2006]

Safety in Roundabouts

Suggest a hypothesis that explains the safety of roundabouts

3 Recent Developments

3.1 Safety Analysis using Traffic Micro-Simulation

Recent Interest

- Theses: [Archer, 2004, Cunto, 2008]
- FHWA project: Surrogate Safety Assessment Methodology (SSAM) [Gettman and Head, 2003, Gettman et al., 2008]
  - 83 four-leg, urban, signalized intersections (US and Canada) were modelled in VISSIM and simulated and assessed with SSAM
  - $\frac{Crashes}{Year} = 0.119(\frac{Conflicts}{Hour})^{1.419}$ ($R^2 = 0.41$)
  - intersection rankings based on total conflict frequency correlated with intersection rankings based on total crash frequency with a Spearman rank coefficient of 0.463
  - lack of simulated conflicts during path-crossing manoeuvres (e.g. left turns colliding with opposing through-traffic)
- Need for a "less-than-perfect" driver model [Xin et al., 2008]

3.2 Probability Framework for Automated Road Safety Analysis

Rethinking the Collision Course

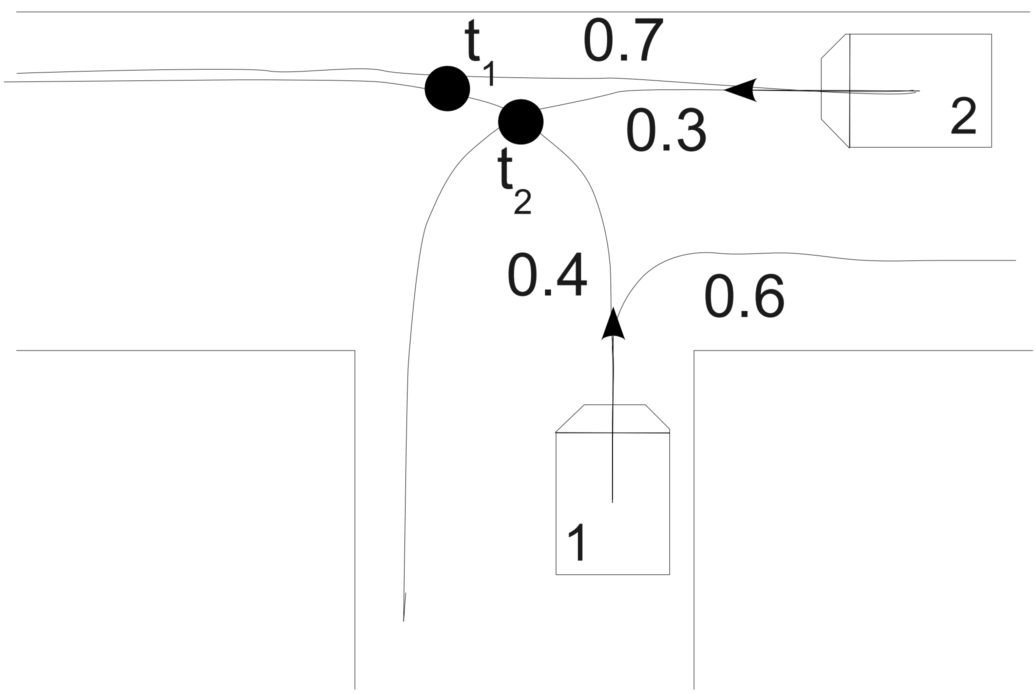
- A traffic conflict is "an observational situation in which two or more road users approach each other in space and time to such an extent that a collision is imminent *if their movements remain unchanged*"
- For two interacting road users, *many* chains of events may lead to a collision
- It is possible to estimate the probability of collision if one can *predict* the road users' future positions

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 severity 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]

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. Severity indicators can then be computed:

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

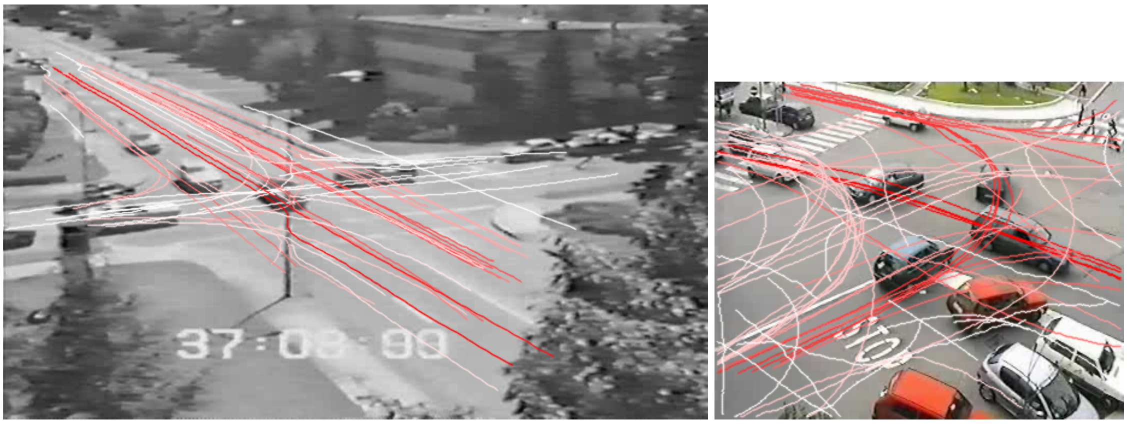
$$TTC(U_i, U_j, t_0) = \frac{\sum_n P(Collision(CP_n))\, t_n}{P(Collision(U_i, U_j))}$$

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

[Saunier et al., 2010, Mohamed and Saunier, 2013]

3.3 Experimental Results using Video Data

Motion Pattern Learning



Traffic Conflict Dataset, Vancouver	Reggio Calabria, Italy
58 prototype trajectories (2941 trajectories)	58 prototype trajectories (138009 trajectories)

[Saunier et al., 2007]

The Kentucky Dataset

- Video recordings kept for a few seconds before and after the sound-based automatic detection of an interaction of interest
  - 229 traffic conflicts
  - 101 collisions
  - The existence of an interaction or its severity is not always obvious
  - The interactions recorded in this dataset involve only motorized vehicles
  - Limited quality of the video data: resolution, compression, weather and lighting conditions
- Calibration done using the tool developed by Karim Ismail at UBC [Ismail et al., 2010b]

[Saunier et al., 2010]

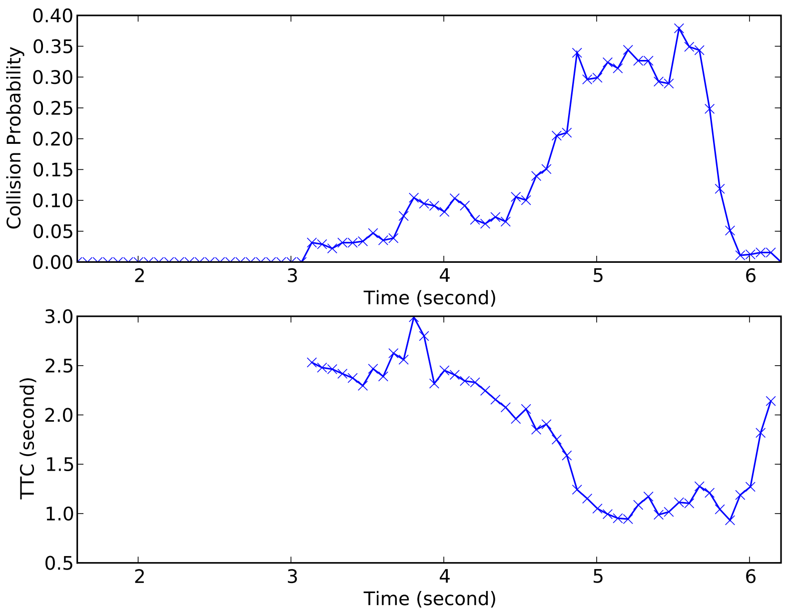
Road User Tracking

Motion Prediction

Motion Prediction

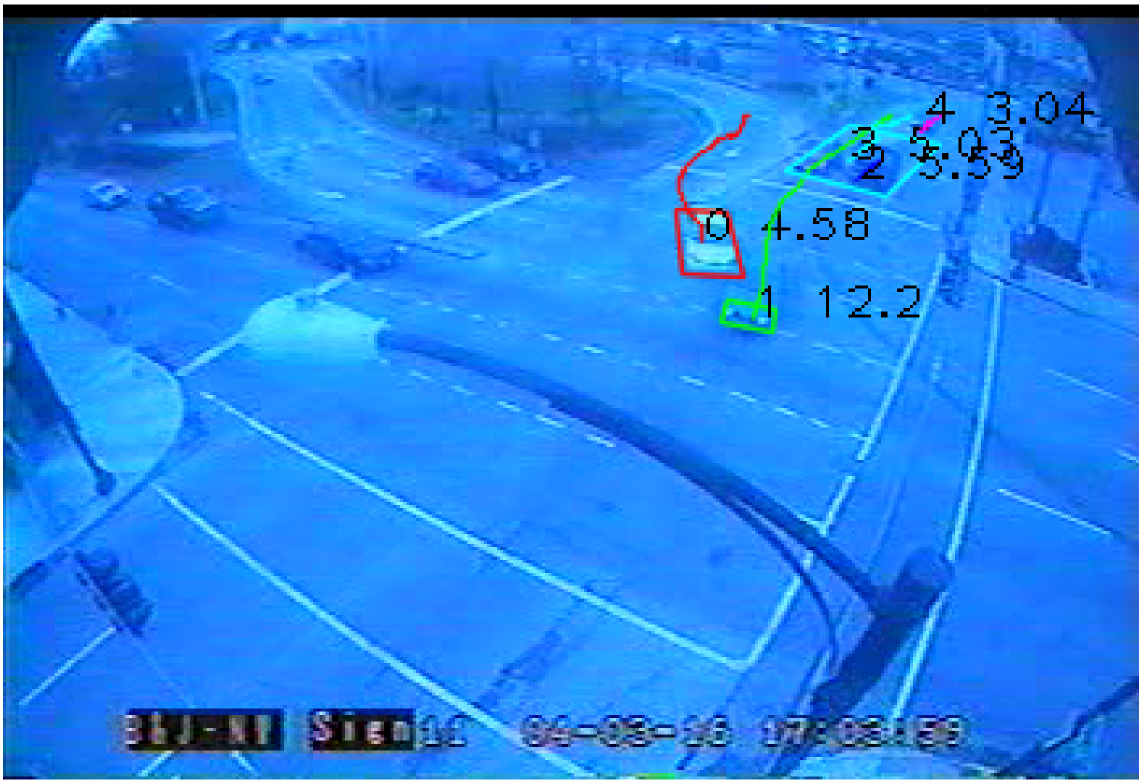
Motion Prediction

The Severity Indicators



Parallel conflict, Kentucky dataset

Road User Tracking

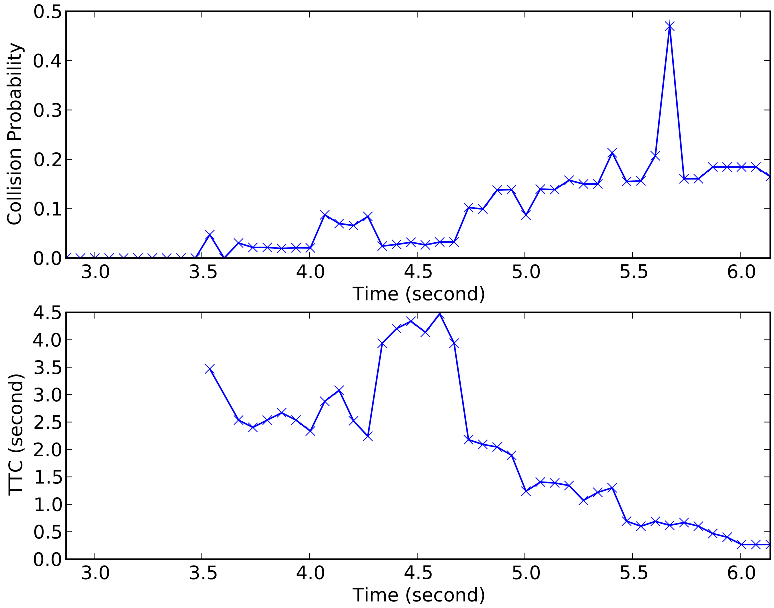


Motion Prediction

Motion Prediction

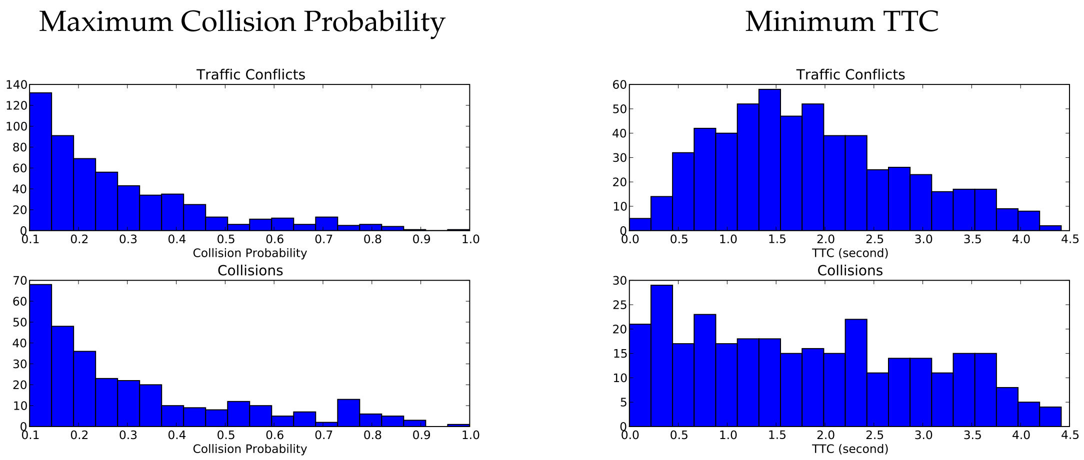
Motion Prediction

The Severity Indicators

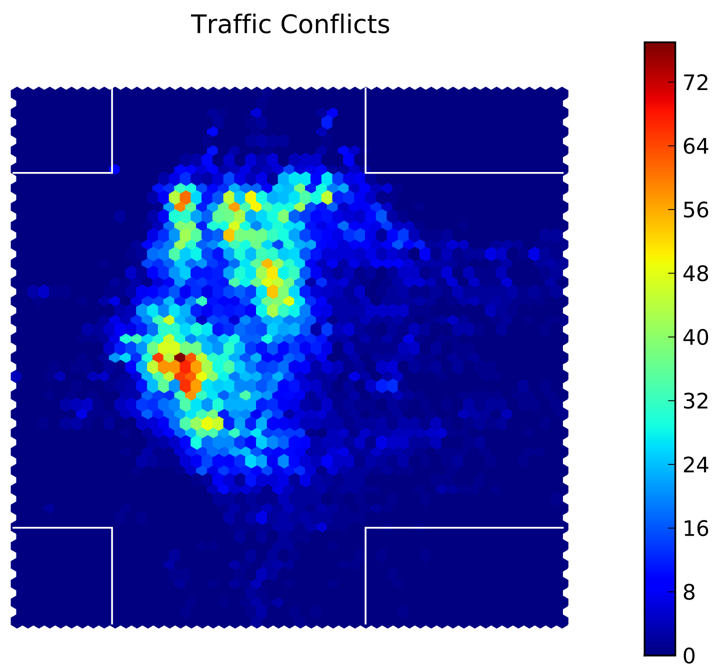


Parallel collision, Kentucky dataset

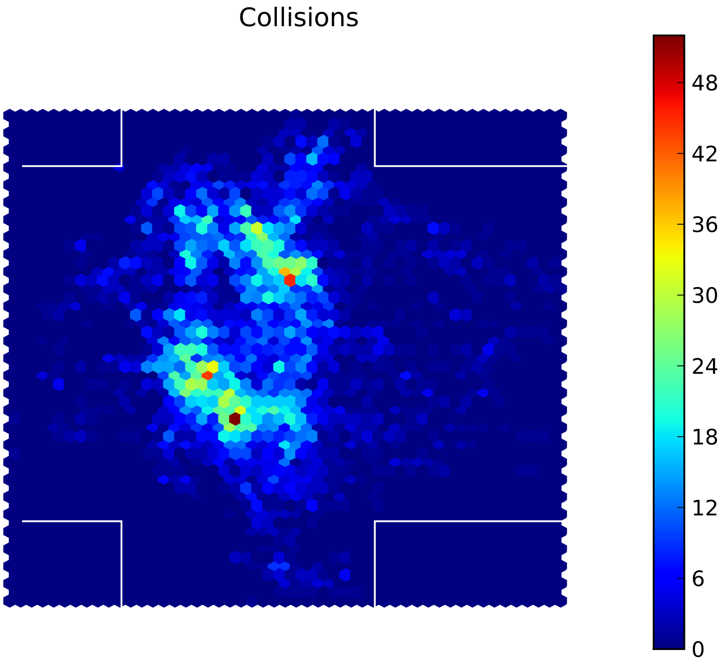
Distribution of Indicators



Spatial Distribution of the Collision Points



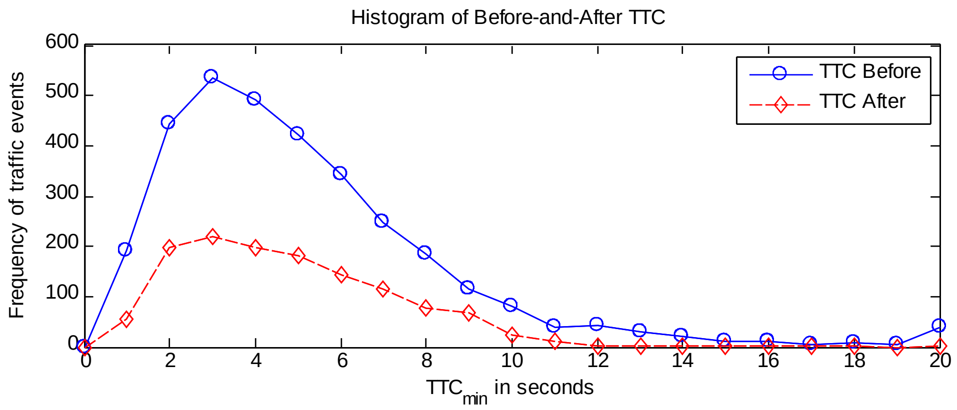
Spatial Distribution of the Collision Points

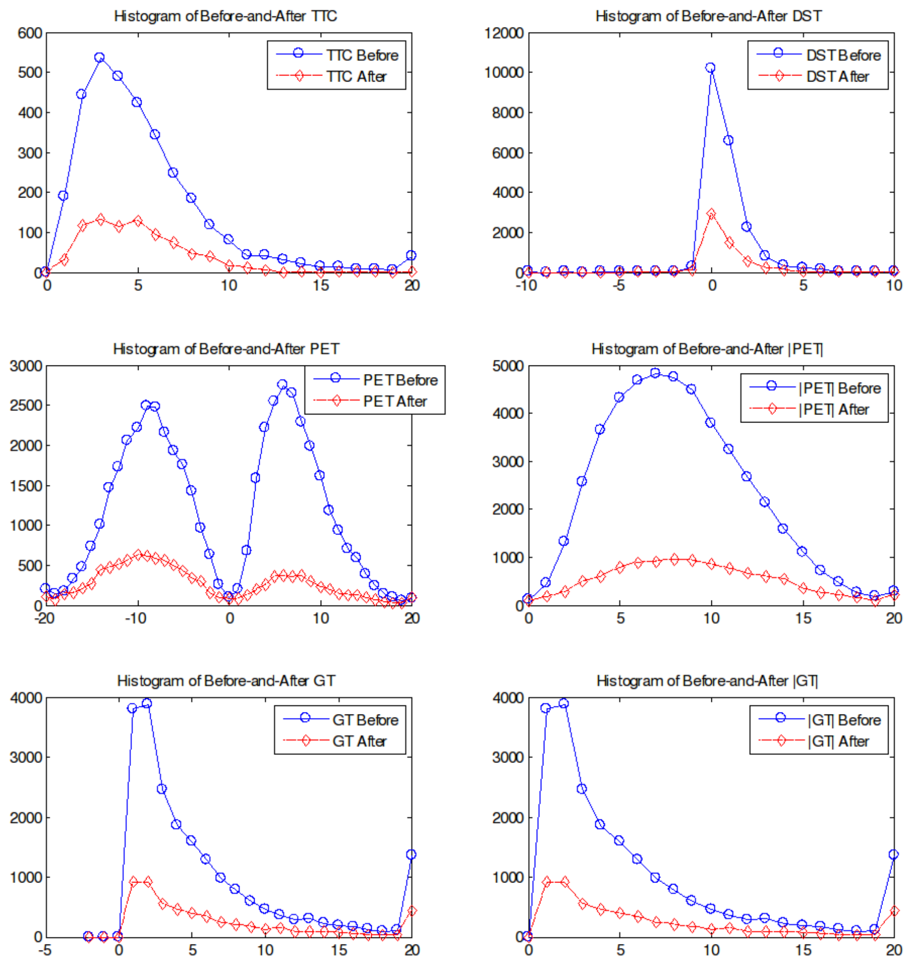


Study Before and After the Introduction of a Scramble Phase

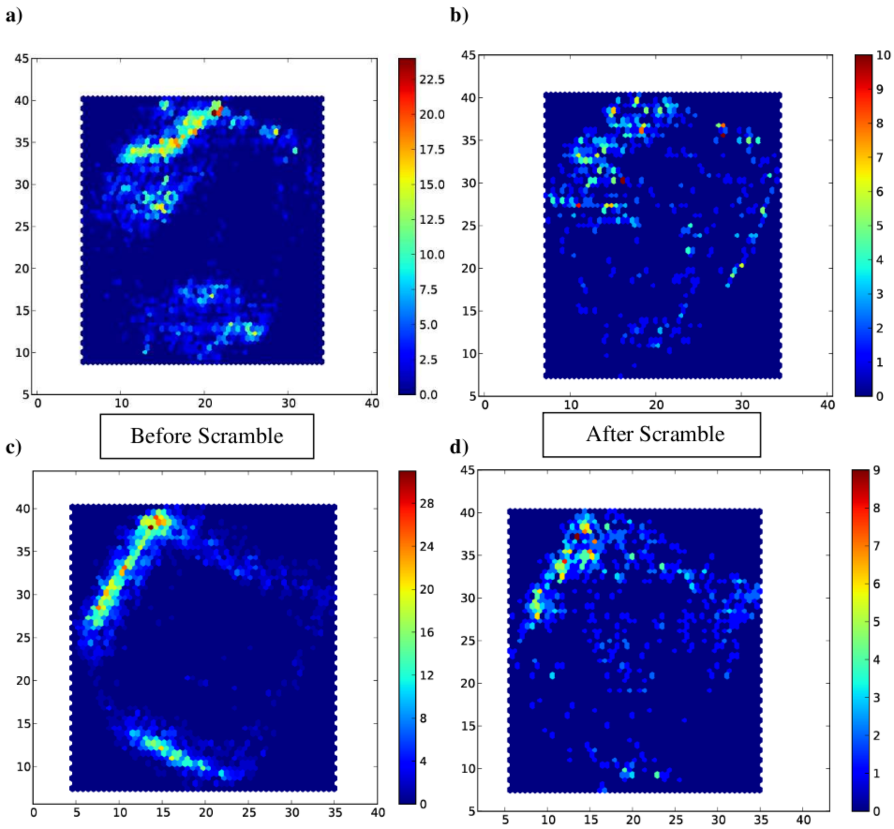
Data collected in Oakland, CA [Ismail et al., 2010a]

Distribution of Severity Indicators





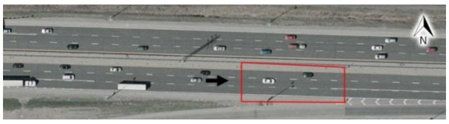
Before and After Distribution of the Collision Points

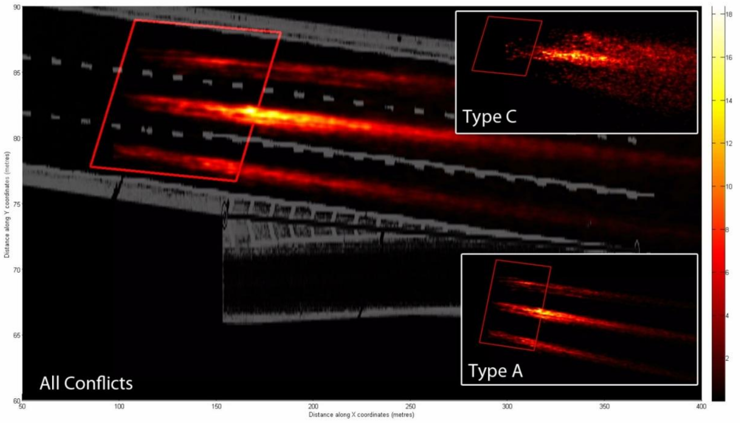


Lane-Change Bans at Urban Highway Ramps

Ramp: A20-E-E56-3 **Region(s):** UPreMZ, PPreMZ

Treatment: Yes **Analysis length:** 50 m





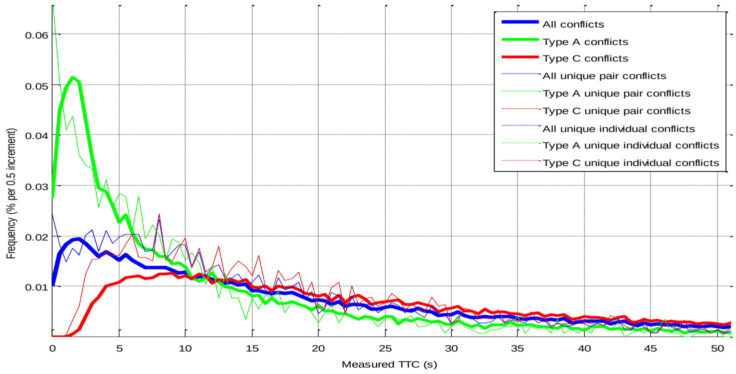


Figure 37 – Conflict analysis Cam20-16-Dorval (Treated).

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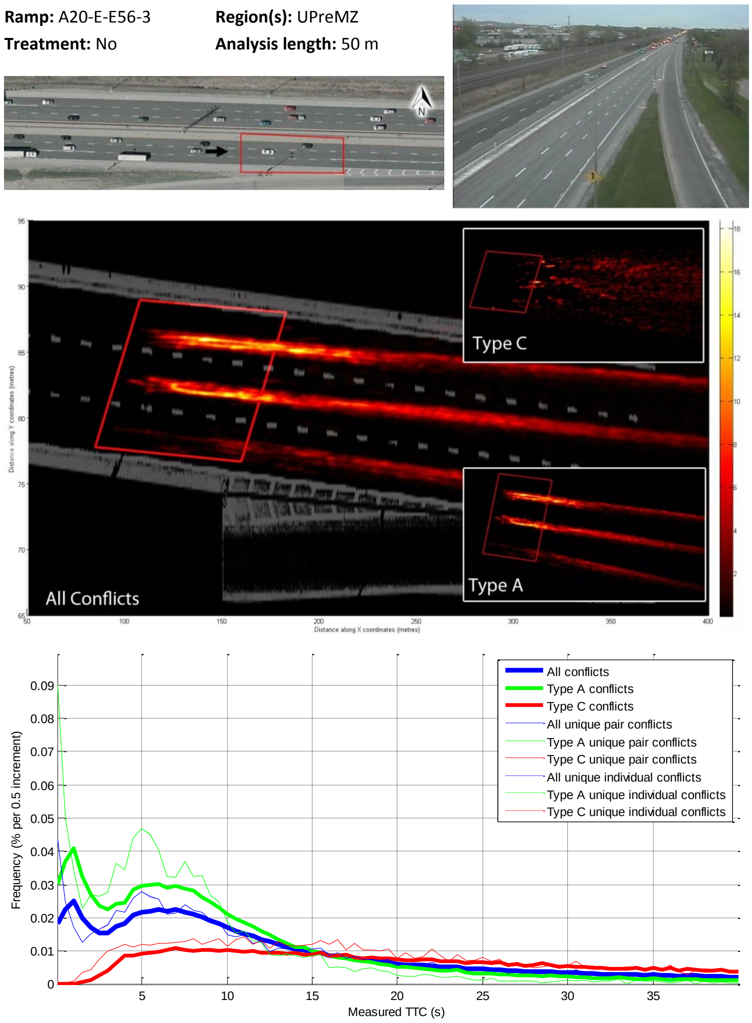

Figure 27 – Conflict analysis Cam20-16-Dorval (Untreated).

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

4 Conclusion

Conclusion

- 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, instead of pretending more special cases and indicators are needed
  - is TTC sufficient to measure interaction severity, or probability of collision?
  - an extra dimension is conceptually necessary to measure the ability of road users to avoid the collision: the “probability of unsuccessful evasive action”

Perspectives

- Improve the tools for *automated* data collection (computer vision)
- Need for *large* amounts of data for the understanding and modelling of collision processes
  - video-based trajectory data collection, naturalistic driving studies (SHRP2)
  - need for data mining and visualization techniques for safety analysis
- Validation of proactive methods for road safety analysis
- *Open Science*: data sharing and open source code
  - benchmarks
  - http://nicolas.saunier.confins.net

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