Safety critical event detection- Applying and evaluating different SSMs in a roundabout traffic scenario

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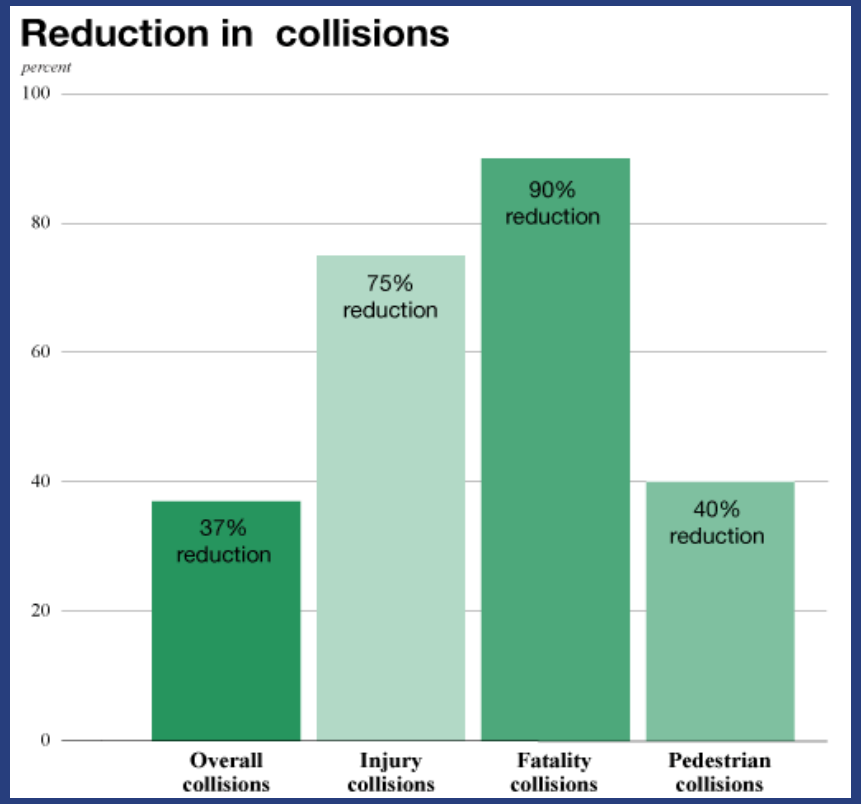
Background

Are roundabouts safe?

Compared to the signalized intersections, **yes**.

- Studies show roundabouts reduce crashes by 37%
- Reduced number of conflict points
- The potential injury collision degree is reduced



Roundabout safety benefits[1]

[1]Source: Washington State Department of Transportation: Roundabout safety benefits

Background

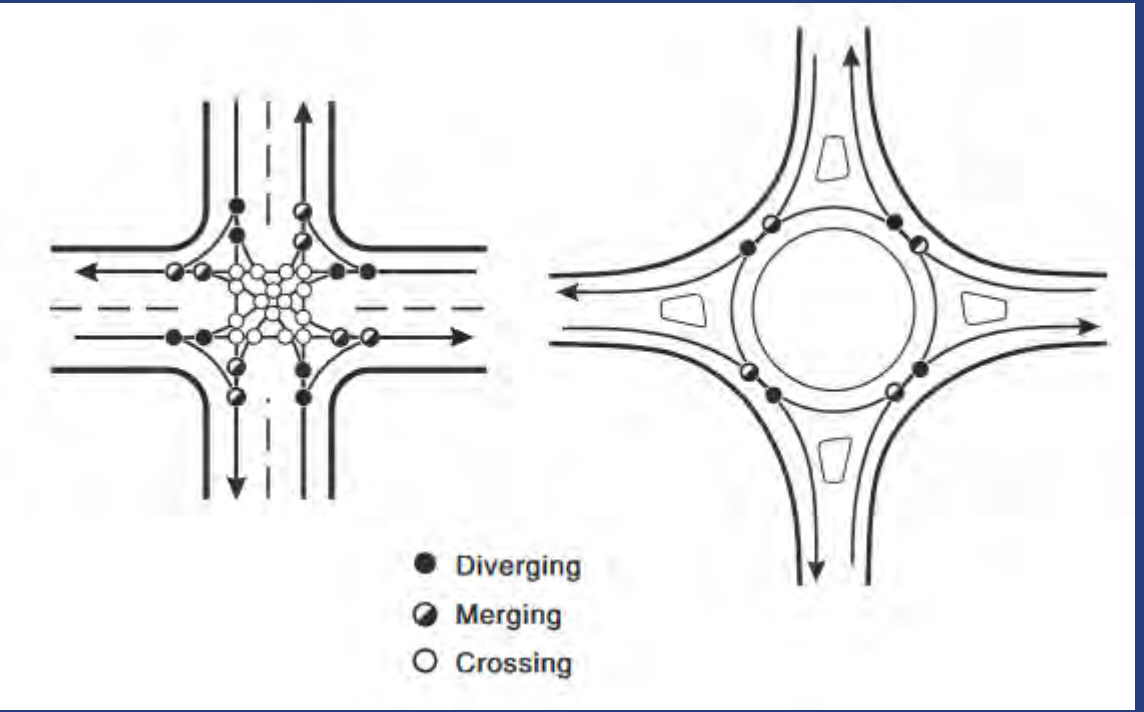
Are roundabouts safe?

But…

- Conflicts in roundabouts are mainly caused by merging and diverging scenarios

- Merging is more severe than diverging, due to lateral collisions

- Merging into roundabouts is highly uncertain[2]



Conflict points in an intersection and in a roundabout[3]

[2]Source: ITSC 2019 Merging into Single-Lane Roundabouts in the Presence of Uncertainty;
[3]Source: US Department of Transportation Roundabouts: An Informational Guide

Research goal and Motivation

- Safety critical event detection and analysis in a single-lane roundabout
- Is there a way of identifying degrees of criticality within merging scenarios?

Entering: C575
Circling: C576

Entering: C819
Circling: C821

Entering: C355
Circling: C353

Approach:

Usage of Surrogate Measures of Safety to represent the criticality parameter-space based on real trajectory data

Used Dataset

AIM mobile traffic unit

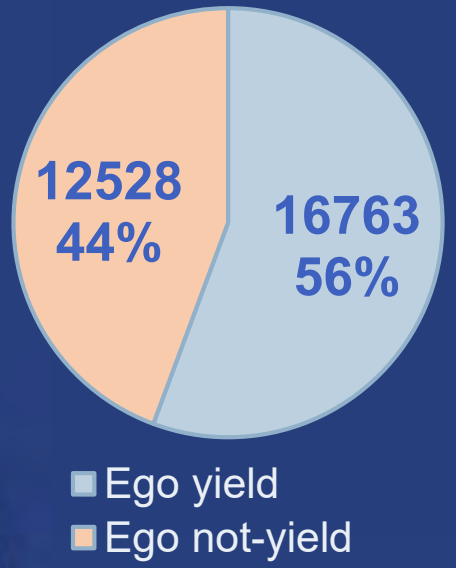
3 pole-units installed facing the center of the single-lane roundabout

- 24/7 real traffic data acquisition
- 30 days of recorded data (Oct-Nov 2019)
- EU Project L3Pilot

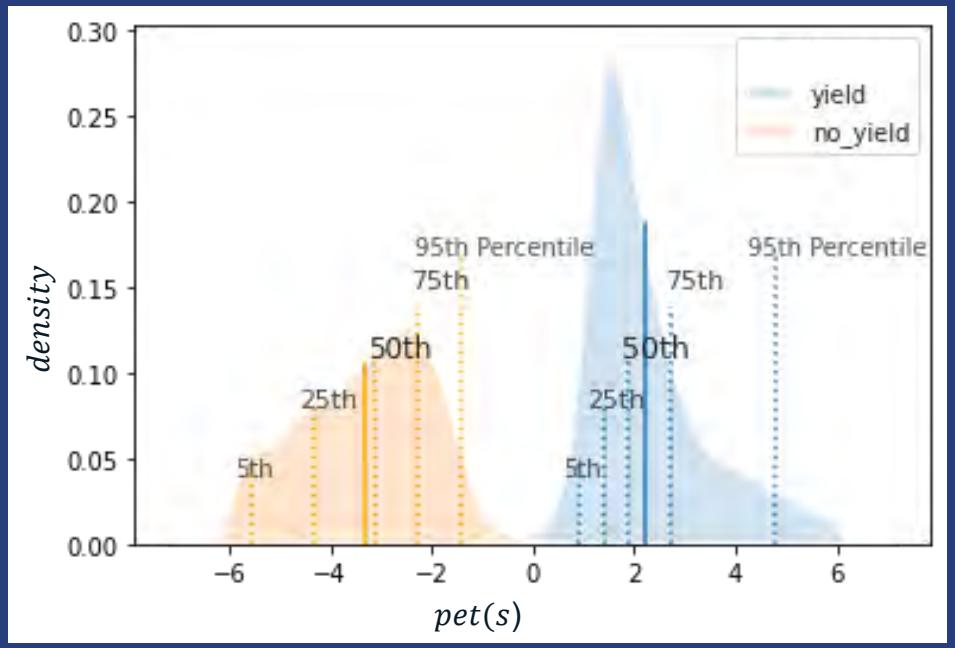
Descriptive Analysis

Yielding or not yielding?

- **Merging interaction**:
$|post\ encroachment\ time\ (pet)| \leq 6s$
- **Ego vehicle:** Entering stream
  - **pet > 0** : Ego yielded;
  - **pet < 0** : Ego did not yield



Pet Distribution (yield vs no yield)



In no yield sub-scenario bigger time gaps occur

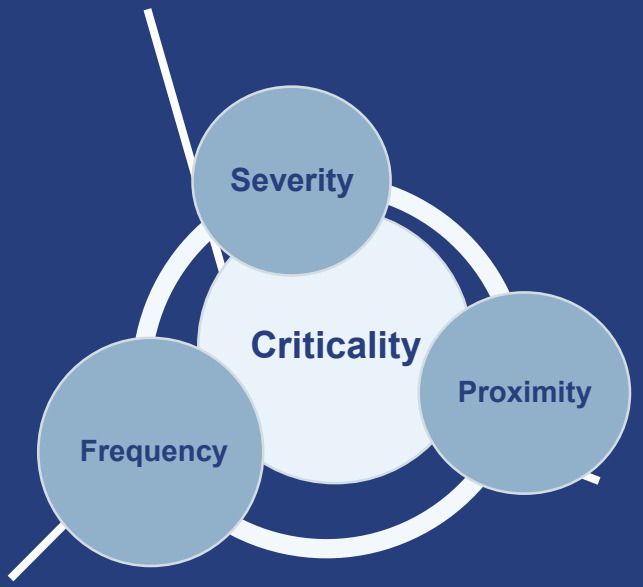
	Mean pet (s)	*STD (s)*	*Median pet (s)*
no yield	**3.31**	**1.3**	**3.15**
yield	**2.22**	**1.18**	**1.88**

Methodology

Given steps to detect critical events

- What is understood by criticality
- Scenario parameterization
- Practical example
- (Criticality) Parameter space selection
- Probabilistic based criticality degree

Methodology- Definition of criticality



What is criticality? [4]

- $\boldsymbol{Critical\ scenario} = f(Severity,\ P(collision))$
- $\boldsymbol{P(collision)} = f(Frequency,\ Proximity(t,s))$
- $\boldsymbol{Proximity \neq Risk}$
- $(e)pet \cong Proximity$

Safety Critical event $(pet = 0.6s)$

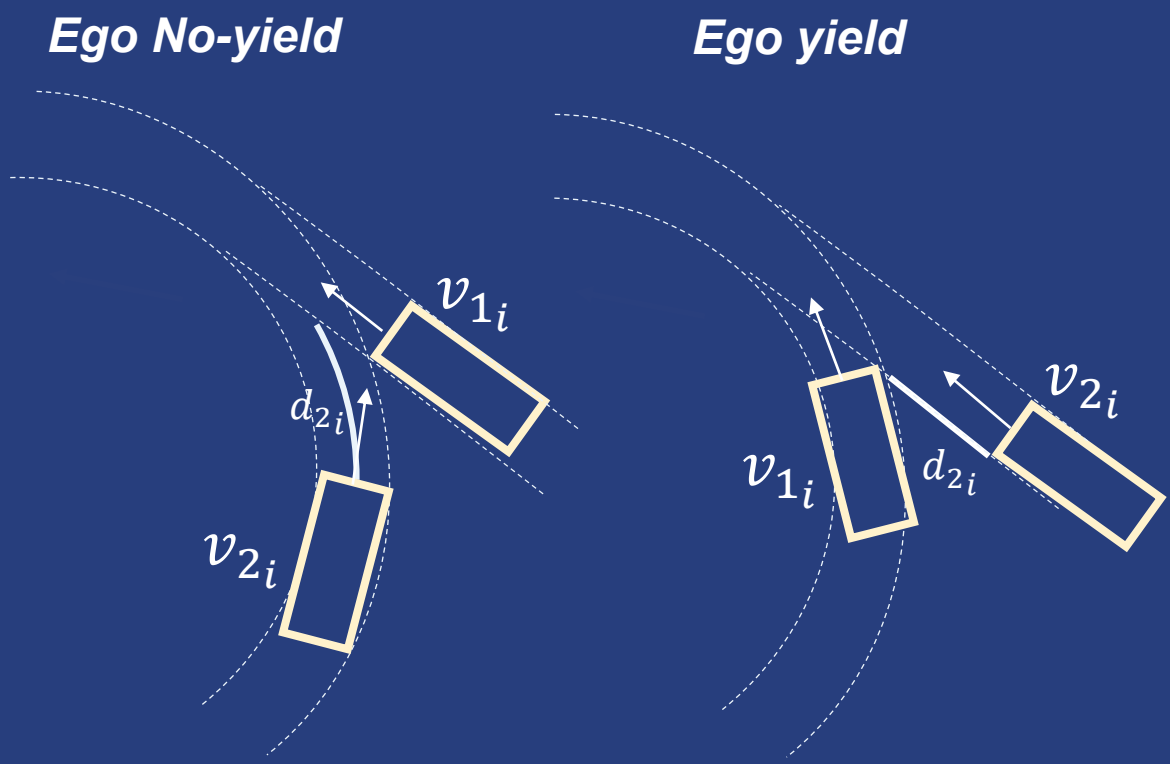
Close encounter $(no\ critical)\ (pet = 0.5s)$

[4]Source: ISO 26262: Management of Functional Safety, Hazardous Event

Methodology - Scenario parameterization

Scenario parameters sensitive to criticality…

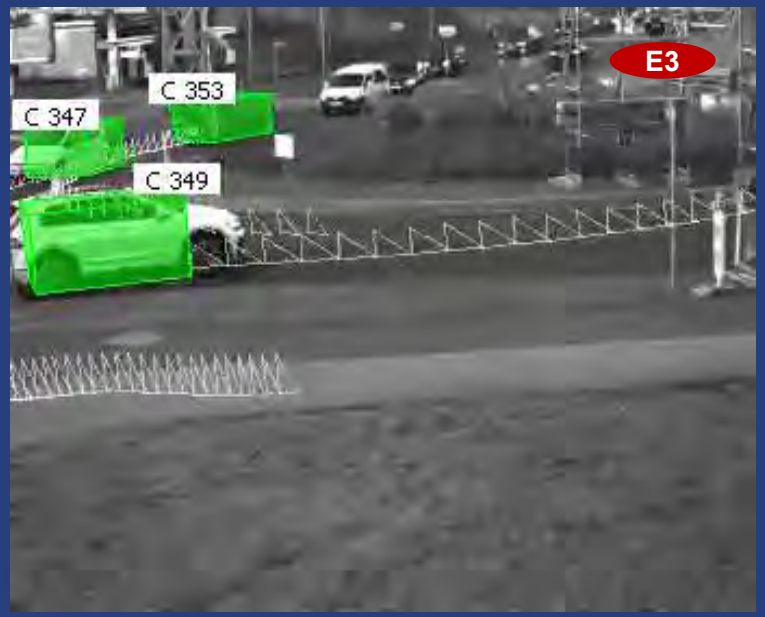
- Use trajectories' path to select moment of interest ($\boldsymbol{i}$)
- $\boldsymbol{i}$ is the moment the 1st vehicle of the merging scenario exposes to a certain collision probability
- **Set of SSMs:**
  - d_{2_i} *(Distance of 2nd entity to exposed point)*
  - $DRAC_i = f(v_{2_i}, d_{2_i})$
  - $SD_i = f(v_{2_i}, MDRAC)$ *(Stopping Distance)*
  - $PSD_i = f(SD, d_{2_i})$ *(Proportion of SD)*
  - $T_{2_i} = f(v_{2_i}, d_{2_i})$ *(Expected arrival time)*
  - $IAPT_i = f(v_{2_i}, d_{2_i})$ *(Initially Attempted PET)*
  - $Delta\ v_i = f(v_{2_i}, v_{1_i})$ *(Difference in velocity)*



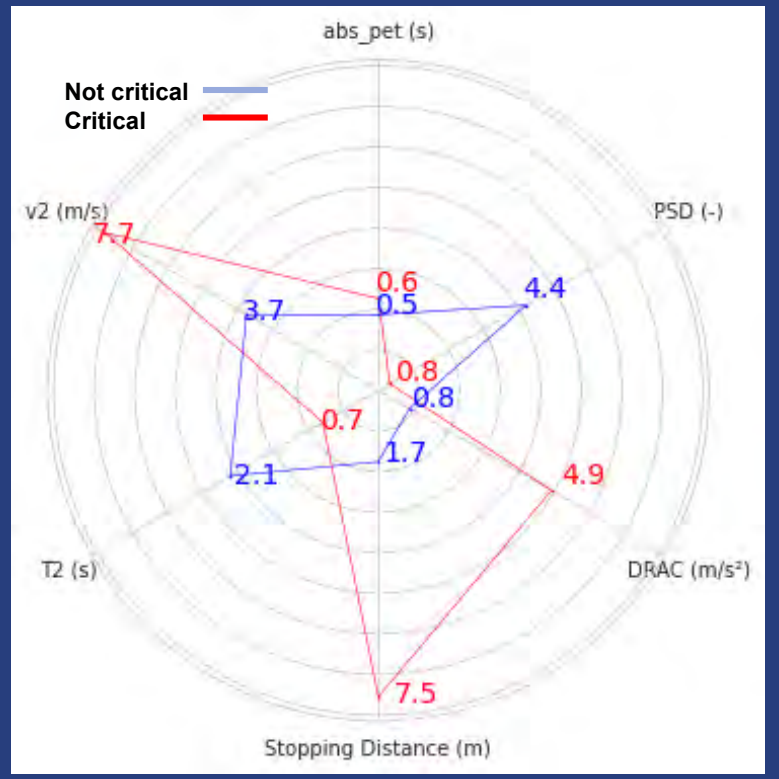
Methodology- Practical example

Are these parameters sensitive to criticality ?

$Risk\ (pet = 0.6s)$



$Close\ encounter\ (pet = 0.5s)$

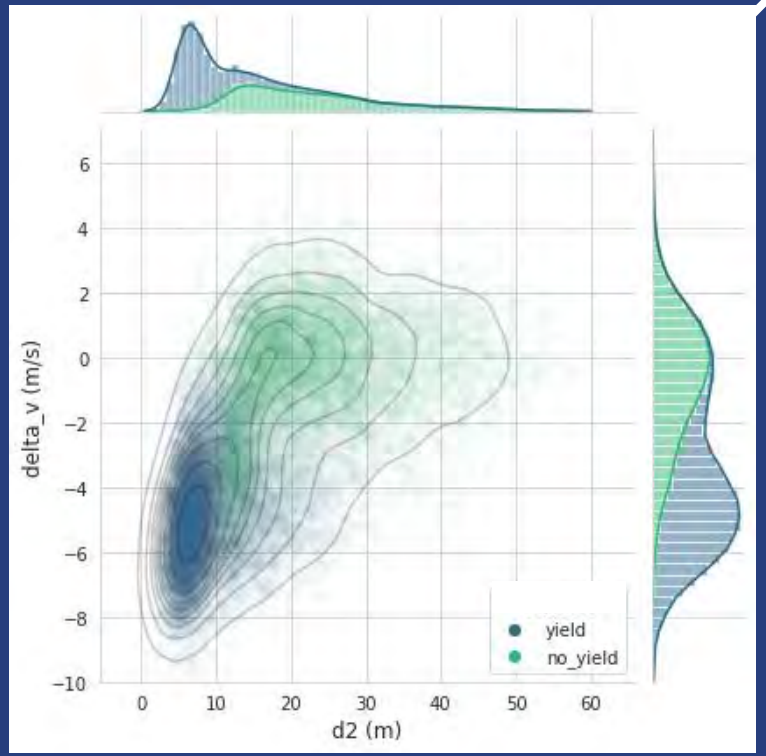


- The proposed **metrics** show a **significant difference** for both scenarios, while pet is relatively similar
- **pet** itself is **not enough to detect criticality**

Methodology- Definition of risk parameter space

Selection and evaluation of most relevant parameters

Correlation matrix (pearson)							
	pet	*DRAC*	*IAPT*	T_2	d_2	*delta v*	*PSD*
pet	1	-0.08	0.27	0.27	0.66	0.42	-0.01
DRAC	-0.08	1	-0.47	-0.49	0	0.38	-0.41
IAPT	0.27	-0.47	1	0.96	0.31	-0.21	0.79
T_2	0.27	-0.49	0.96	1	0.37	-0.18	0.78
d_2	0.66	0	0.31	0.37	1	**0.57**	-0.14
delta v	0.42	0.38	-0.21	-0.18	0.57	1	-0.41
PSD	-0.01	-0.41	0.79	0.78	-0.14	-0.41	1



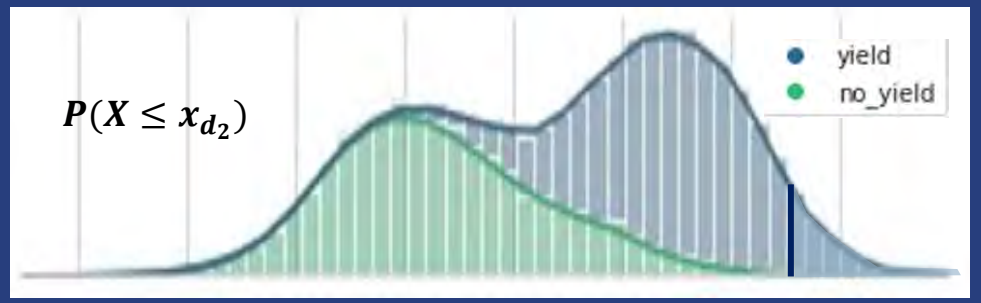
- Find 2 metrics representative of **severity** and **proximity:** $deltav$[5], d_2
- Select different combination of metrics that are not strongly correlated

[5]Source: A.Laureshyn et al. (January, 2017) In search of the severity dimension of traffic events: Extended Delta-V as a traffic conflict indicator

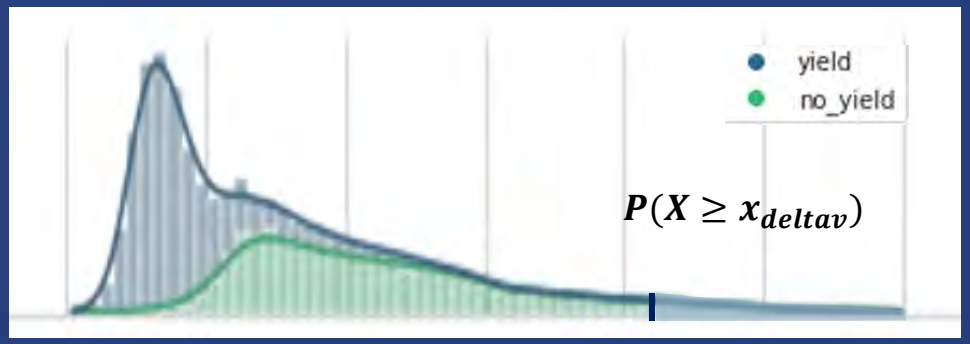
Methodology- Criticality measure definition

Probability-based criticality metric

Both dimensions' $(\boldsymbol{d_2}, \boldsymbol{deltav})$ probabilities combined are used to measure criticality in a single value between 0 and 1



***deltav* probability density function** x_{deltav}



d_2 ***probability density function*** x_{d_2}

$$\begin{cases} \textbf{Critiality Degree(Cd)} = \left(1 - P(X \geq x_{deltav})\right) * P(X \geq x_{d_2}) \\ 0 \leq \textbf{Cd} \leq 1 \end{cases}$$

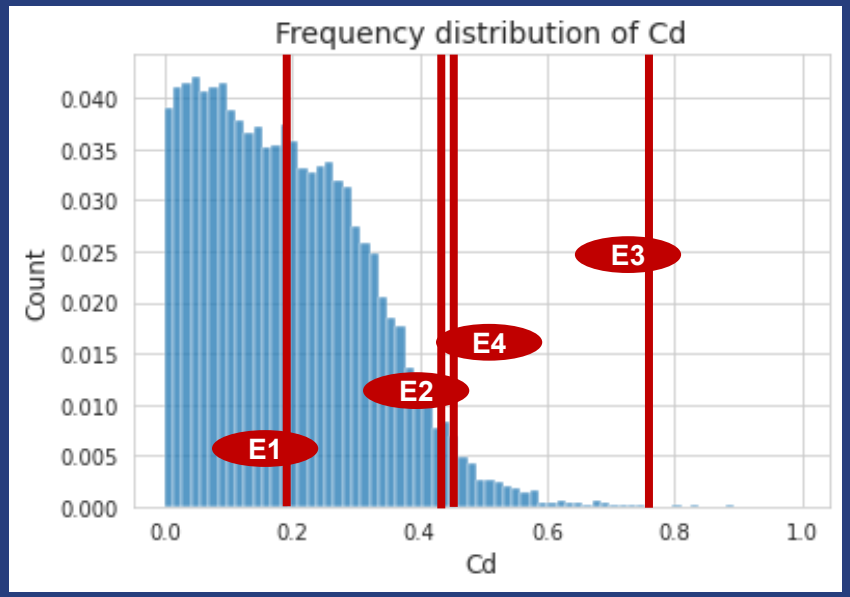
The closer the Cd to 1, the higher the probability of an event being critical…

Results

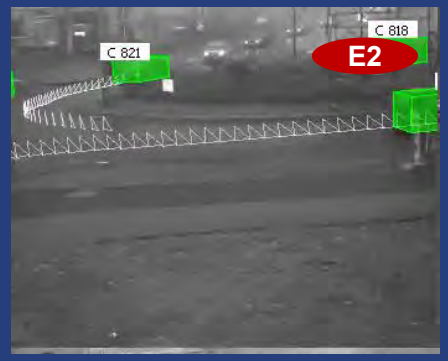
Back to the motivation…

Is there a way to measure different event's degree of criticality?

Application of proposed methodology to the traffic dataset

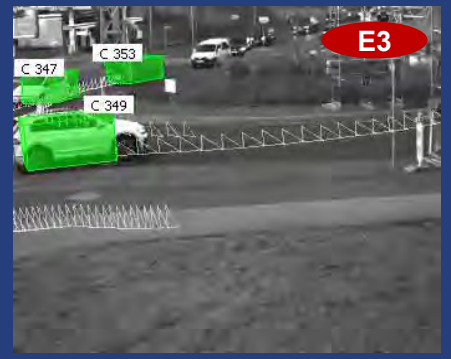


Entering: C575
Circling: C576
Cd = 0.18
$pet = 3.71s$



Entering: C819
Circling: C821
Cd = 0.43
$pet = 2.2s$

Entering: C376
Circling: C375
Cd = 0.44
$pet = 0.5s$



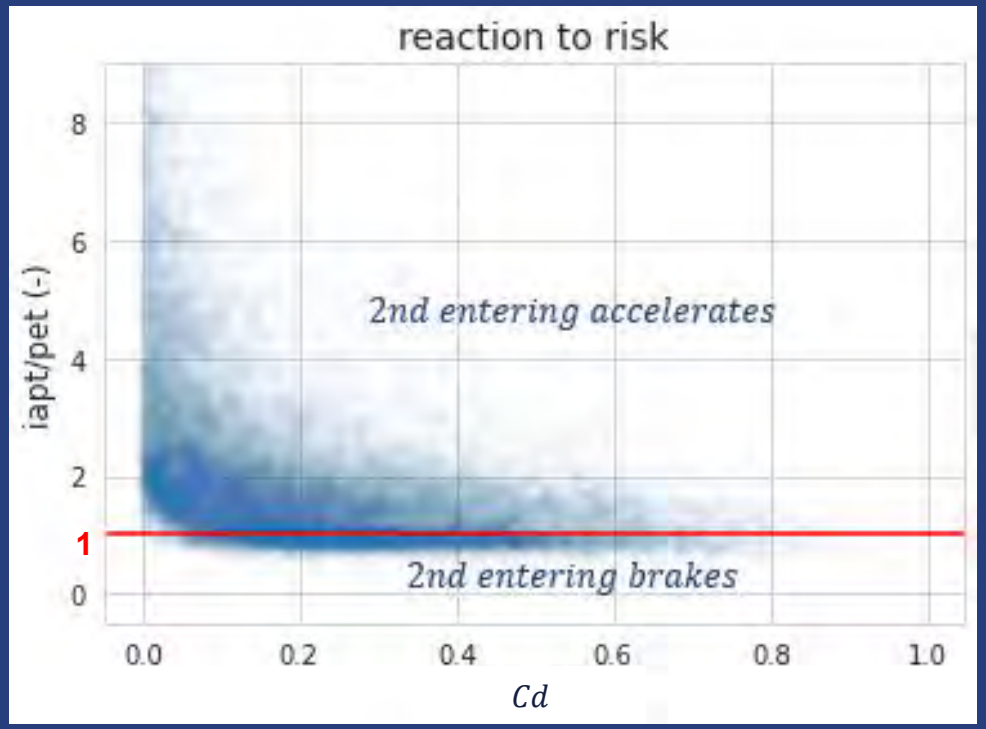
Entering: C355
Circling: C353
Cd = 0.75
$pet = 0.6$

Results – Further interesting findings…

How does the vehicle being 2nd in the merging scenario react to an already merged vehicle?

- The **iapt/pet** ratio gives a hint of the 2nd entity's reaction to the merging scenario
- **The higher the Cd, the more likely the 2nd entity is about to brake**

$$\boldsymbol{iapt/pet}\ldots\begin{cases} = \mathbf{1} & \rightarrow No\ reaction \\ < \mathbf{1} & \rightarrow braking \\ > \mathbf{1} & \rightarrow acceleration \end{cases}$$



P(scenario being critical)

Acceleration of 2nd merging

Conclusions & Next steps

Conclusions

- A probabilistic based method is proposed to give criticality degree to scenarios
- The higher the Cd, the more criticality is empirically perceived in the scenario
- The higher the Cd, the more likely is the 2nd merging entity to brake

Next steps

- Empirical testing by investigating more scenario-videos
- Add further combination of metrics as risk parameter spaces and evaluate their performance
- Use lane mark information instead of each trajectories' a posteriori detected path as the reference timestamp from which to derive the parameters.
- Is this methodology applicable to other scenarios?

Many thanks for your attention!!

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