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

1Source: 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

Source: ITSC 2019 Merging into Single-Lane Roundabouts in the Presence of Uncertainty;
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?

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

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

AIM mobile traffic unit

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

Yielding or not yielding?

- **Merging interaction:**
  \[ |\text{post encroachment time (pet)}| \leq 6s \]

- **Ego vehicle:** Entering stream
  - \( \text{pet} > 0 \): Ego yielded;
  - \( \text{pet} < 0 \): Ego did not yield

\[
\begin{array}{c|c|c}
\text{Mean pet (s)} & \text{STD (s)} & \text{Median pet (s)} \\
\hline
\text{no yield} & 3.31 & 1.3 \\
\text{yield} & 2.22 & 1.18
\end{array}
\]

\text{In no yield sub-scenario bigger time gaps occur}
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?\(^4\)

- **Critical scenario** = \(f(\text{Severity}, \ P(\text{collision}))\)
- \(P(\text{collision}) = f(\text{Frequency}, \ \text{Proximity}(t,s))\)
- **Proximity ≠ Risk**
- \((e)pet \equiv \text{Proximity}\)

**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 \( i \)
- \( i \) is the moment the 1st vehicle of the merging scenario exposes to a certain collision probability
- Set of SSMs:
  - \( d_{2i} \) (Distance of 2nd entity to exposed point)
  - \( DRAC_i = f(v_{2i}, d_{2i}) \) (Distance to Approach Coordinate)
  - \( SD_i = f(v_{2i}, MDRAC) \) (Stopping Distance)
  - \( PSD_i = f(SD, d_{2i}) \) (Proportion of SD)
  - \( T_{2i} = f(v_{2i}, d_{2i}) \) (Expected arrival time)
  - \( IAAP_{i} = f(v_{2i}, d_{2i}) \) (Initially Attempted PET)
  - \( \Delta v_i = f(v_{2i}, v_{1i}) \) (Difference in velocity)
Methodology - Practical example

Are these parameters sensitive to criticality?

Risk ($\text{pet} = 0.6s$)  Close encounter ($\text{pet} = 0.5s$)

- 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

<table>
<thead>
<tr>
<th>Correlation matrix (pearson)</th>
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</thead>
<tbody>
<tr>
<td><strong>pet</strong></td>
</tr>
<tr>
<td><strong>pet</strong></td>
</tr>
<tr>
<td><strong>DRAC</strong></td>
</tr>
<tr>
<td><strong>IAPT</strong></td>
</tr>
<tr>
<td><strong>$T_2$</strong></td>
</tr>
<tr>
<td><strong>$d_2$</strong></td>
</tr>
<tr>
<td><strong>delta $v$</strong></td>
</tr>
<tr>
<td><strong>PSD</strong></td>
</tr>
</tbody>
</table>

- Find 2 metrics representative of **severity** and **proximity**: $\text{delta } v$,$^5$ $d_2$
- 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’ \((d_2, \text{deltav})\) probabilities combined are used to measure criticality in a single value between 0 and 1.

\[
\text{Criticality Degree (Cd)} = (1 - P(X \geq x_{\text{deltav}})) \times P(X \geq x_{d_2})
\]

\[0 \leq \text{Cd} \leq 1\]

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

- The \textit{iapt/pet} ratio gives a hint of the 2nd entity’s reaction to the merging scenario.
- The higher the Cd, the more likely the 2\textsuperscript{nd} entity is about to brake.

\[
\text{iapt/pet} \begin{cases} 
  = 1 & \rightarrow \text{No reaction} \\
  < 1 & \rightarrow \text{braking} \\
  > 1 & \rightarrow \text{acceleration}
\end{cases}
\]
Conclusions & Next steps

Conclusions

• A probabilistic based method is proposed to give criticality degree to scenarios
• The higher the $C_d$, the more criticality is empirically perceived in the scenario
• The higher the $C_d$, 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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