Validating criticality metrics for cyclist-vehicle interactions

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Acknowledgement

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- Data utilized from two research projects

Gimm, Kay und Junghans, Marek und Saul, Hagen und Dotzauer, Mandy (2018) *Infrastructure Based Approach to Increase Cycling Safety in case of Turning Motorists Interacting with Crossing Cyclists at an Urban Intersection.* 11th International Conference on Risk Analysis and Hazard Mitigation, 6-8. Jun. 2018, Sevilla, Spanien.

Goos, K. (2021, January). *Risiko im Verkehr: Wie wird es wahrgenommen und welche Kritikalitätsphänomene werden berücksichtigt?* (Master’ s Thesis).

Why do we need criticality metrics?

- 25% of people involved in accidents are cyclists
- Dangerous: conflicts between turning motorists and cyclists going straight
- This type of crash is mainly caused by motorists and leads to (severe) injuries in 80% of all cases
- Problems:
  - Infrastructure: e.g. cycle paths with less than 2m or more than 4m distance to the street
  - Visibility conditions: Cyclist perception due to missing line-of-sight, ignoring and missing actions (e.g. look over the shoulder)
- Solutions:
  - Improved (and understandable) infrastructure
  - Advanced Driver Assistance Systems (ADAS) with cyclist detection and **increased driver's situation awareness → XCYCLE**

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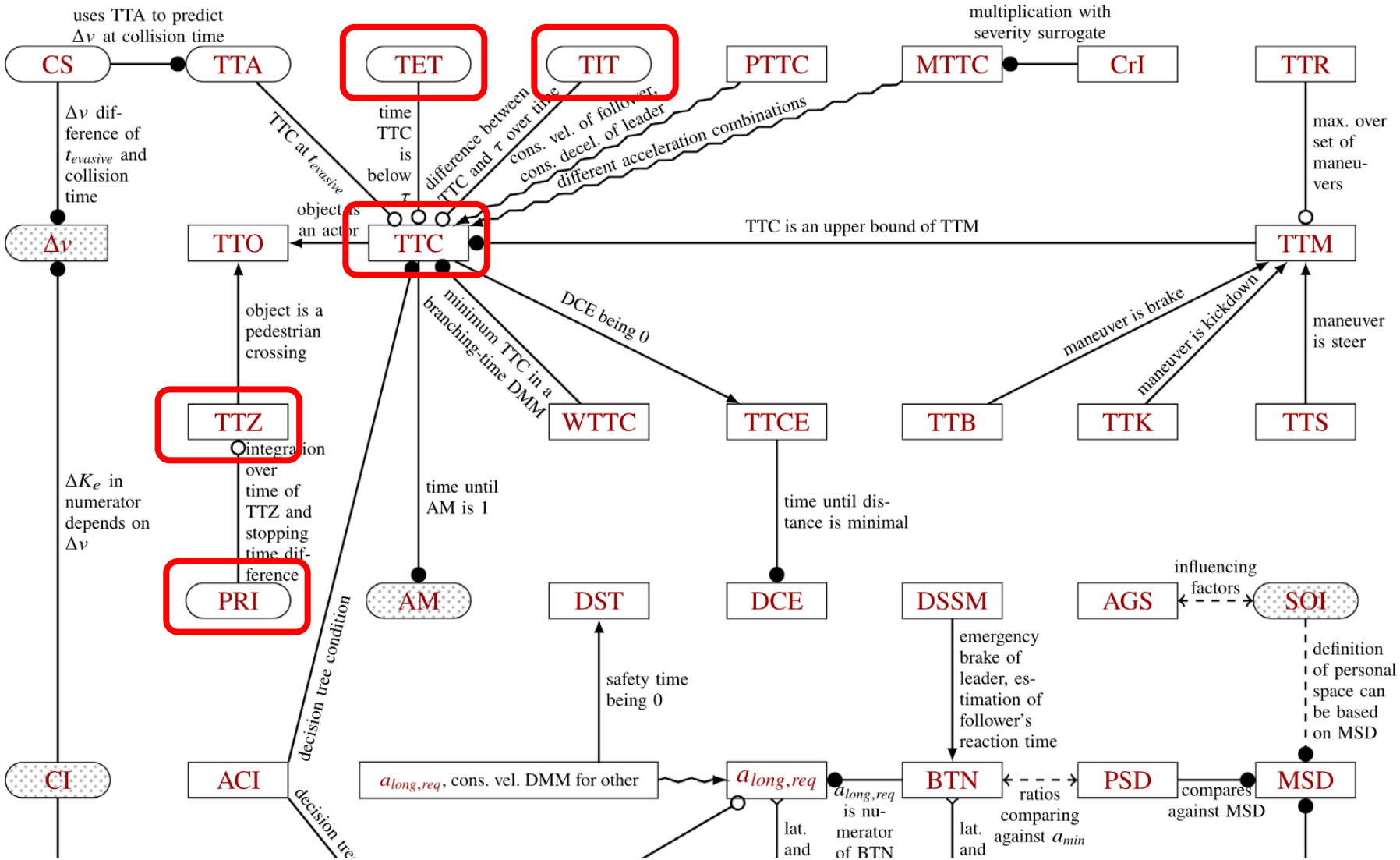

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https://link.springer.com/article/10.1007/s11831-022-09788-7

Event based analysis

Time Integrated TTC (TIT)
Area between threshold and TTC below threshold

Time to collision (TTC_min)
Seconds until collision

DLR

Amberlight Risk Maximum (ARMA)
Amberlight Risk Modal (ARMO)

Time to Zebra (TTZ_min)
TTC to zebra crossing

Pedestrian Risk Index (PRI)
Collision risk multiplied by severity summed

Post Encroachment Time (PET)
Time between road users crossing paths

Time Exposed TTC (TET)
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Predicted Encroachment Time (PrET_min)
Estimated PET based on speed and trajectory

Good Overview in

Johnsson, Laureshyn & Ceunynck (2018) DOI: 10.1080/01441647.2018.1442888

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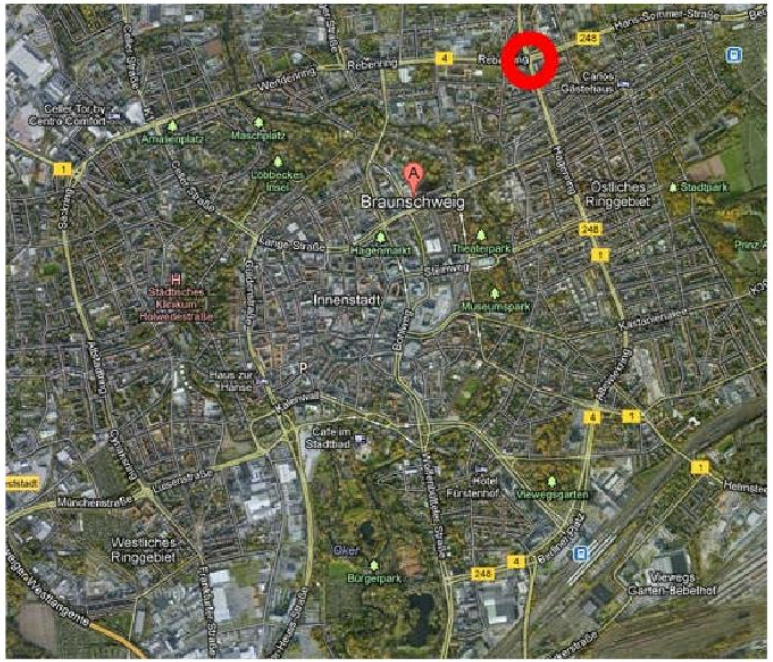
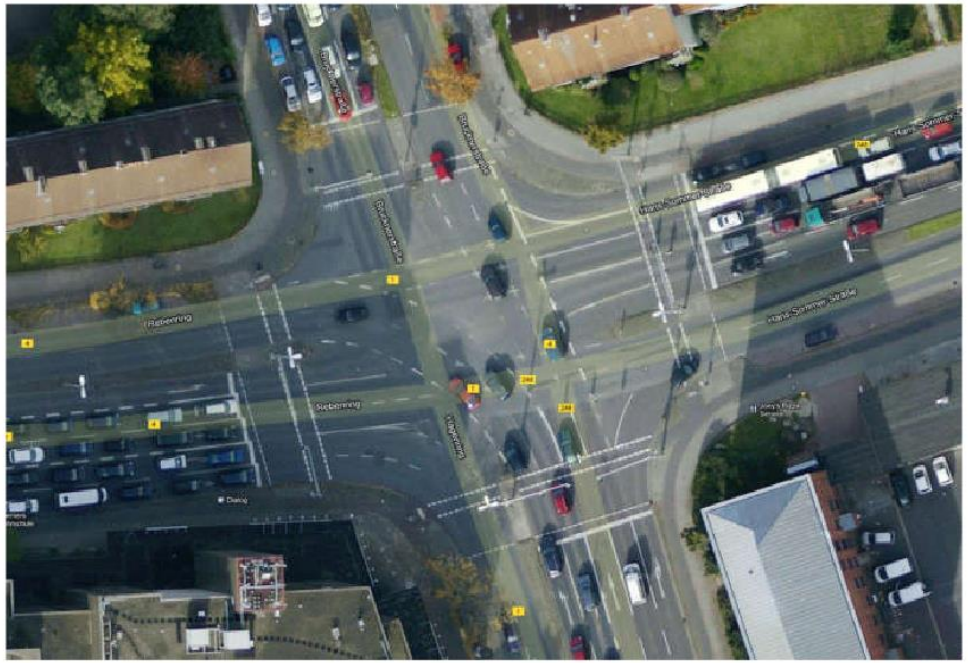
Object detection, classification and tracking

- Application platform Intelligent Mobility
- large-scale research infrastructure in Braunschweig, Germany: the entire city as a platform for application-focused science, research, and development
- AIM Research Intersection



Google



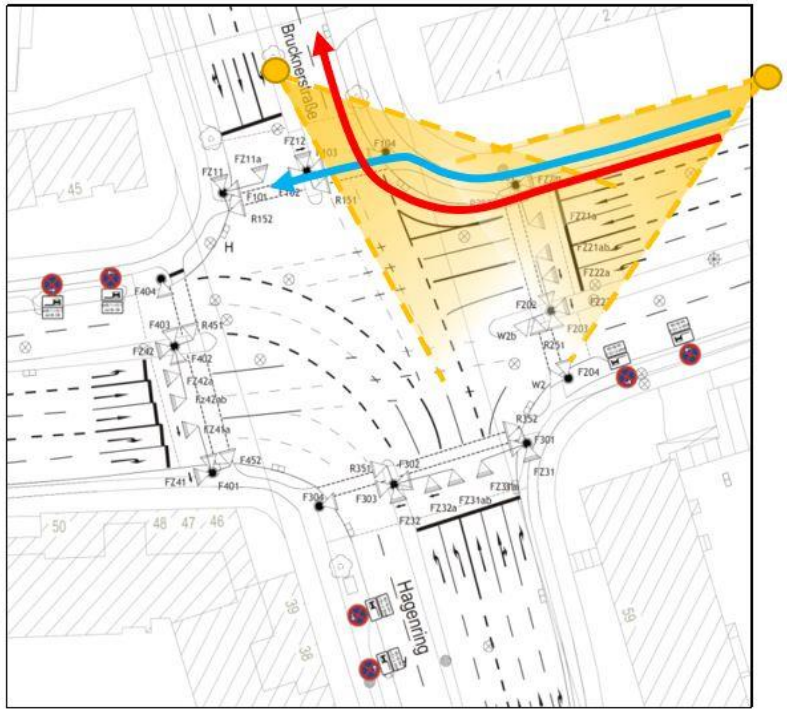
Google

XCYCLE - Advanced measures to reduce cyclists' fatalities and increase comfort in the interaction with motorised vehicles H2020 - 635975

Infrastructure at AIM Research Intersection

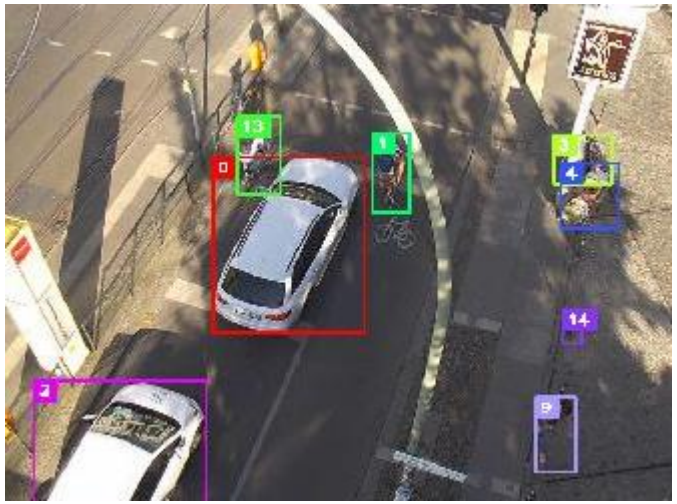
Resulting data:

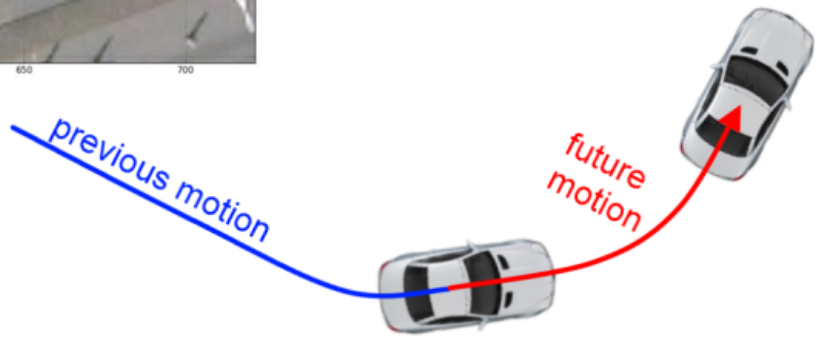
- 25 Hz trajectories (space-time curves) of all traffic participants (time, position, speed, acceleration, object size and classification)
- Communication: V2X (Vehicle-to-X) and I2V (Infrastructure-to-Vehicle)



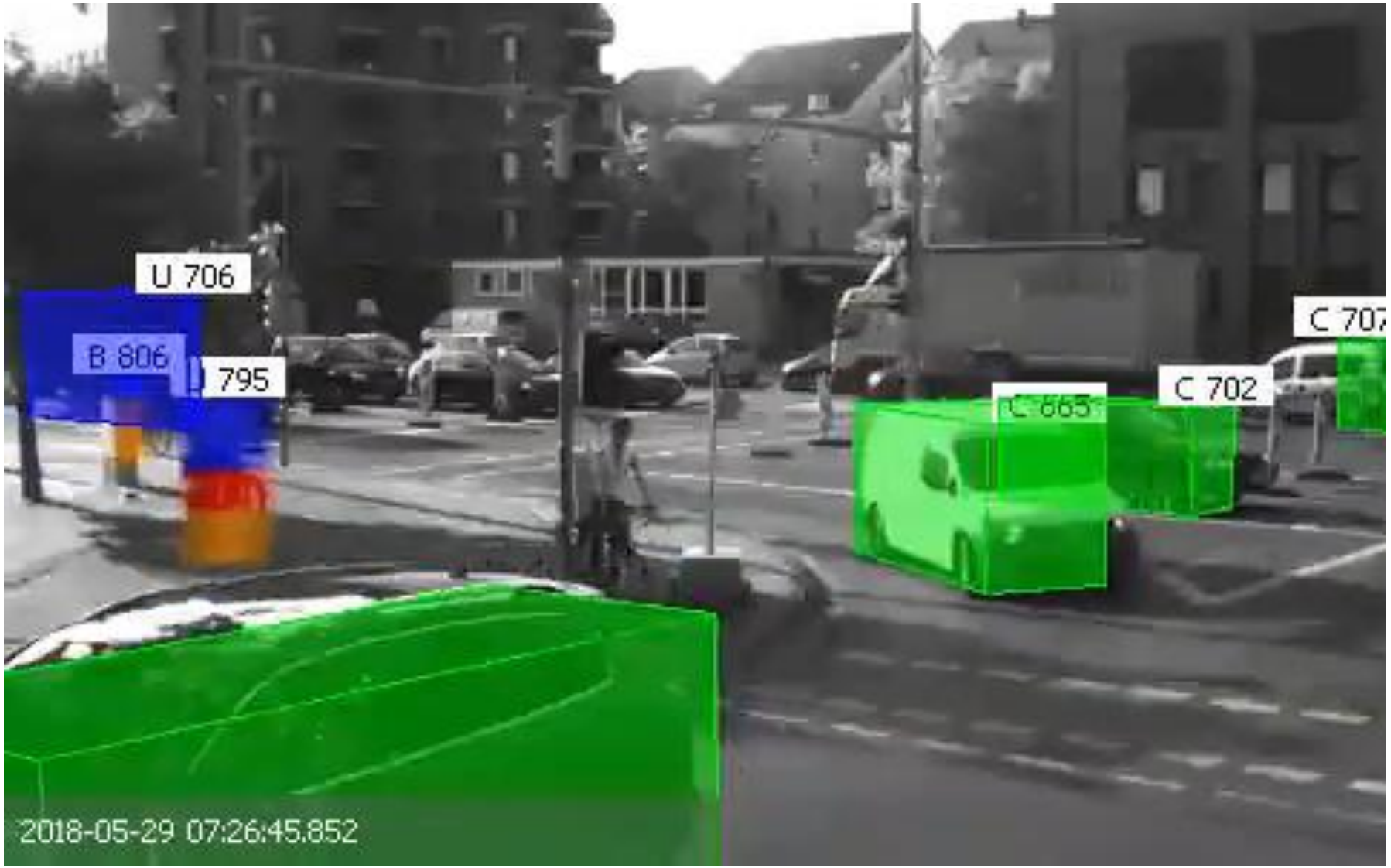
Infrastructure AIM Research Intersection

25 Hz trajectories of all road users (time, position, speed, acceleration, object size and classification)

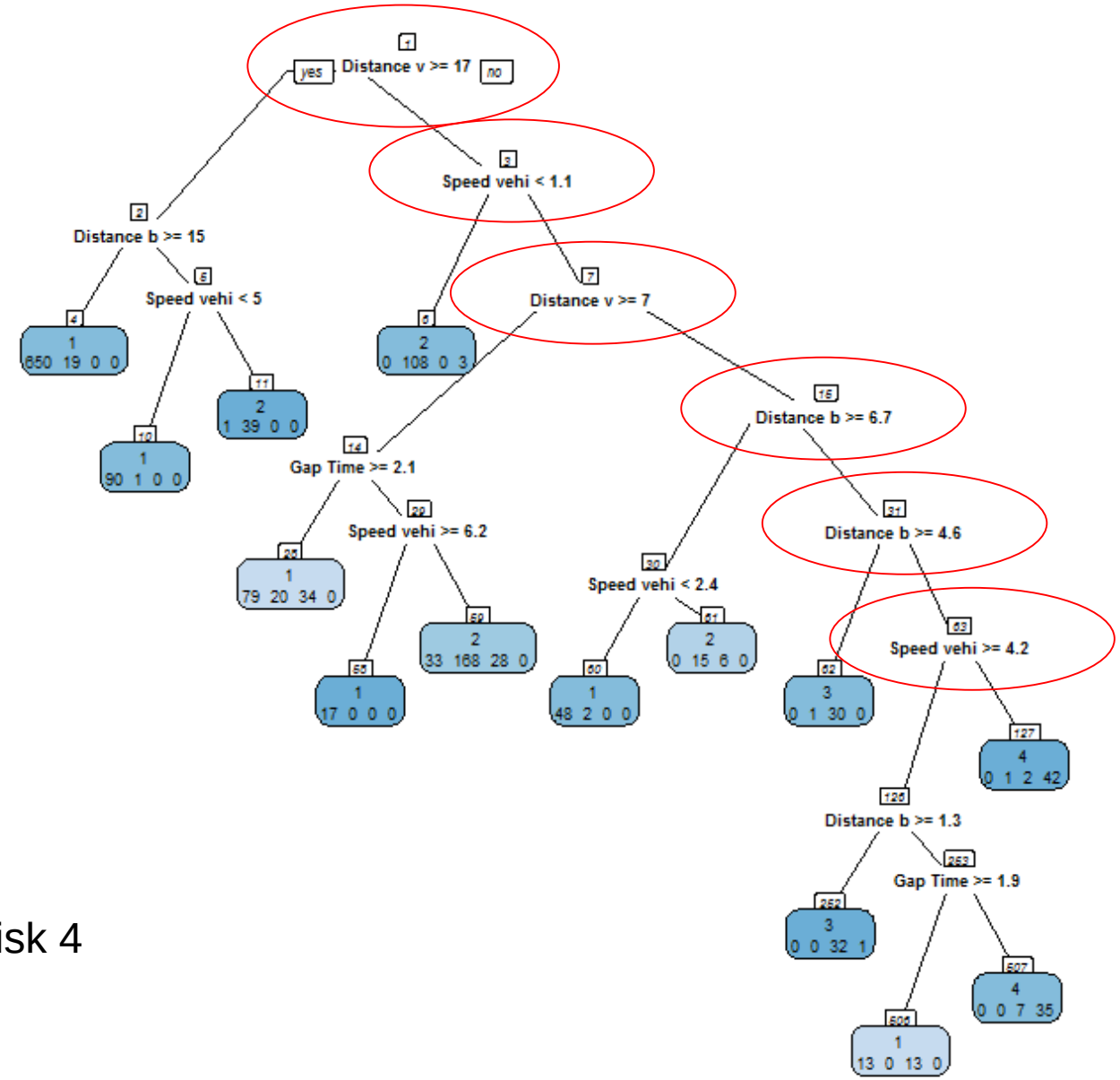




Risk (AR) = 3



- Decision Tree
  - Classify non-linear data
  - CART (R package rpart, complexity = .02)
  - split criterion: Gini diversity index
  - **Easy to interpret (white box)**



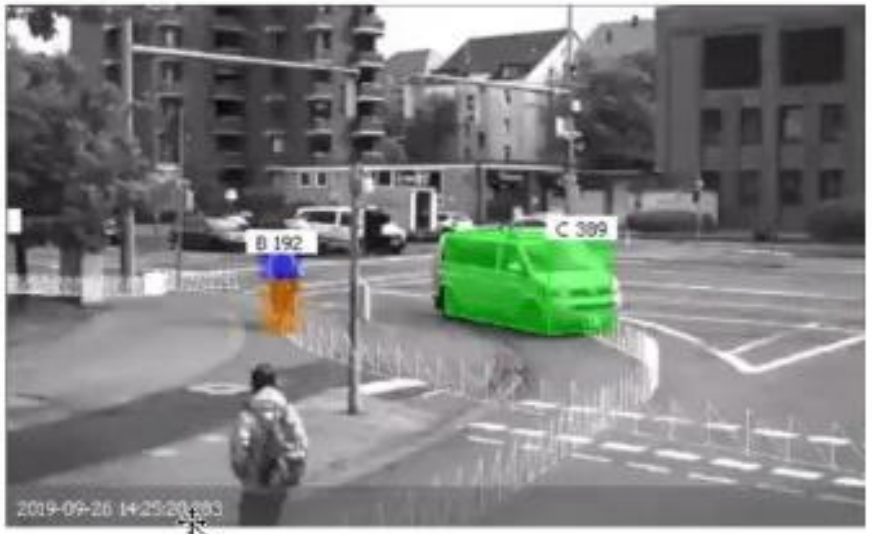
Features:

1. velocity of vehicle
2. way to conflict zone (vehicle)
3. way to conflict zone (bicycle)
4. Gap time predicted

- Accuracy: 88%
- 28 rules (11 splits)
- Ideal tree: no overfitting, but good model for Risk 4

Data collection

- Pre-selection: >1000 scenes by PET < 2.0s
- Manual validation: 55 scenes
- Three authors assess **10** videos of these 55 scenes in detail:
  - Each video segmented into sections with risk classification {0..4}



- 0 – no risk (i.e. no road users observed for the two relations of interest),
- 1 – no conflict, even though a right-turning motorist and a crossing cyclist were present,
- 2 – slight conflict (i.e. only little action necessary to defuse the conflict),
- 3 – severe conflict (i.e. stronger evasive manoeuvre necessary to prevent collision),
- 4 – highest risk; reflecting the state (i.e. a collision is imminent).

e.g. RL-time-diagramme:

Goos, K. (2020)

Sample: N=126

~50/50
Student / Working
Female / male

Use case:
Car turns right and crosses straight ahead bike at the same green phase
Video:
- Start: one of the interaction partners is at the height of the stop line.
- End: approx. 1 sec after the last interaction partner has passed the crossing point
- 6-12 seconds

eigenständiges Starten & Stoppen des Videos

Identification interaction partner

Assessment Risk level Criticality scale

Indication of time & reason for decision in open question

Welcome + Privacy

Demographics + VM Preference

Instruction

Thanks & Bye

Start

30 min

2 x 5 (20% max risk level) = 10 Videos – within subject – randomized order (!)

Event based analysis

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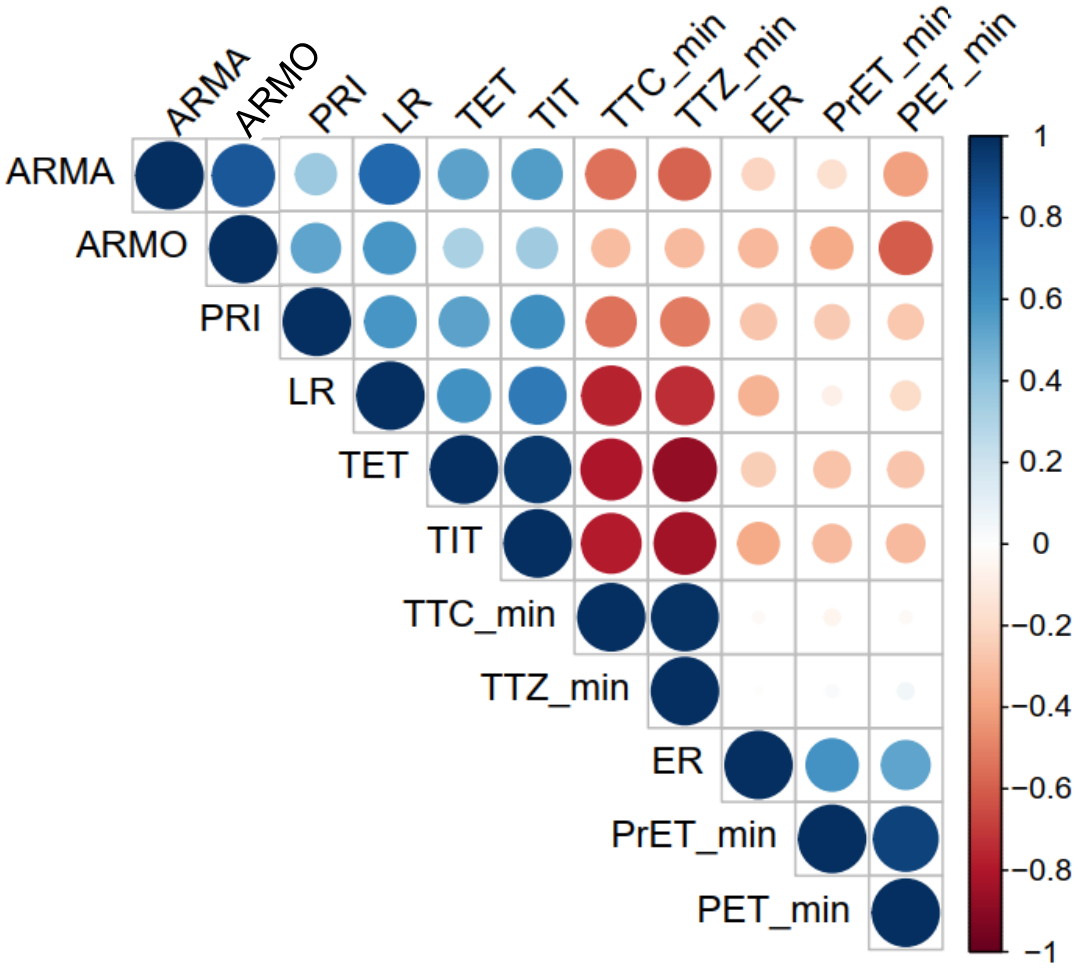
Metrics calculated once for whole interaction



ARMA = Amberlight Risk Maximum
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LR = Layman Rating
ER = Expert Rating

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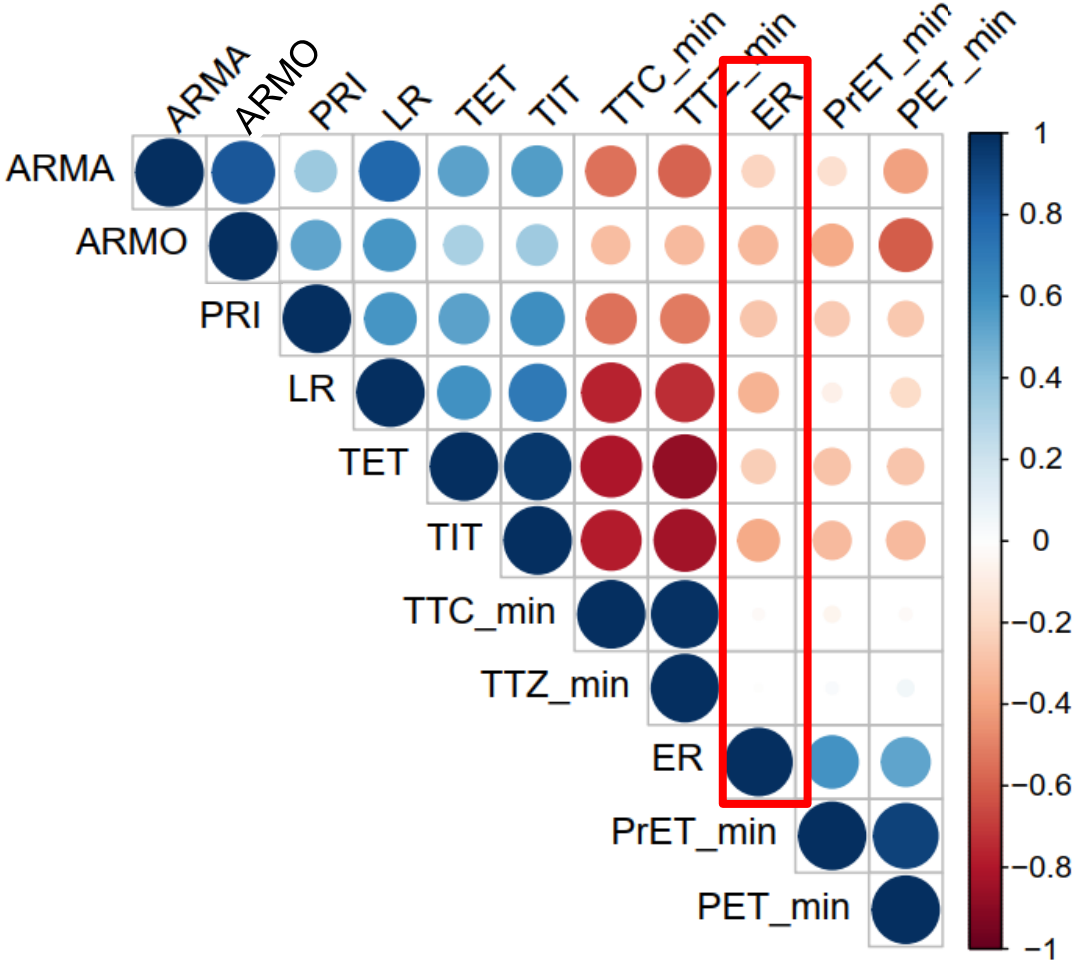

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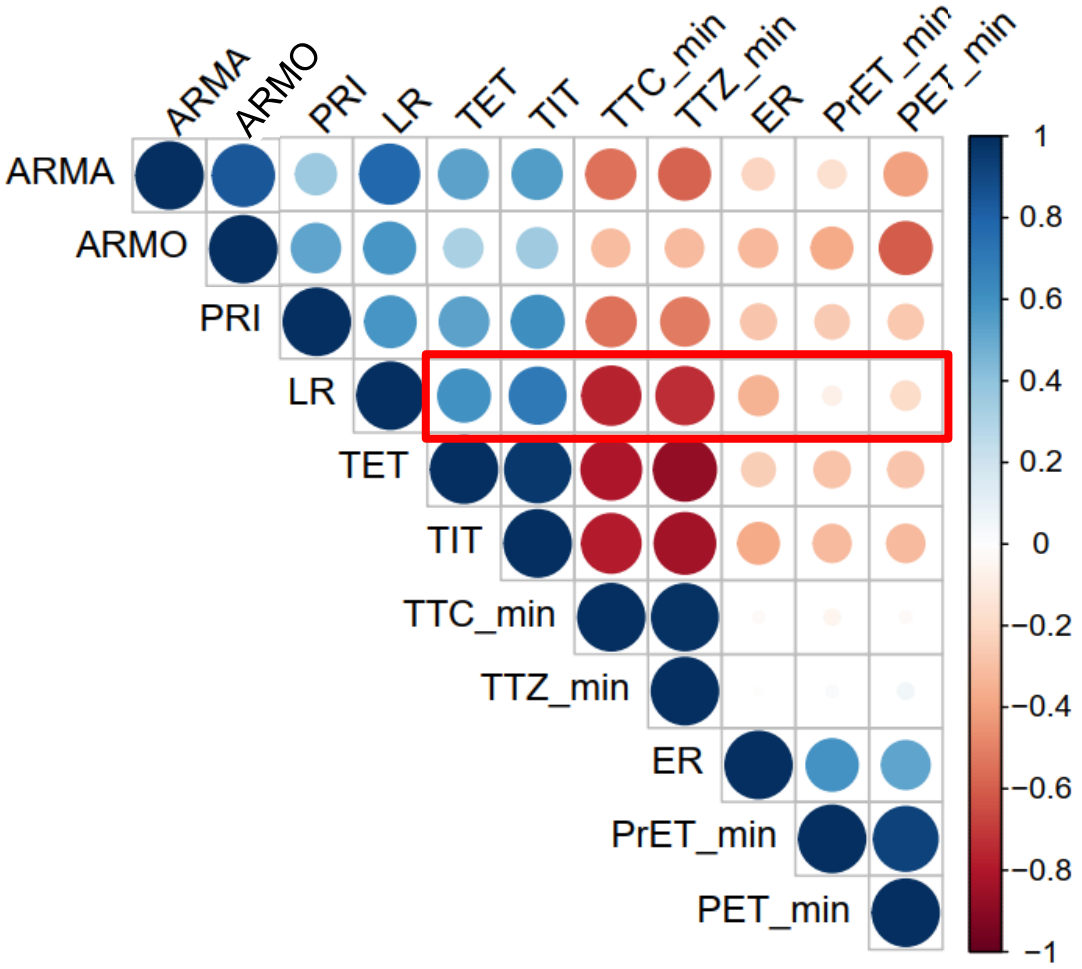

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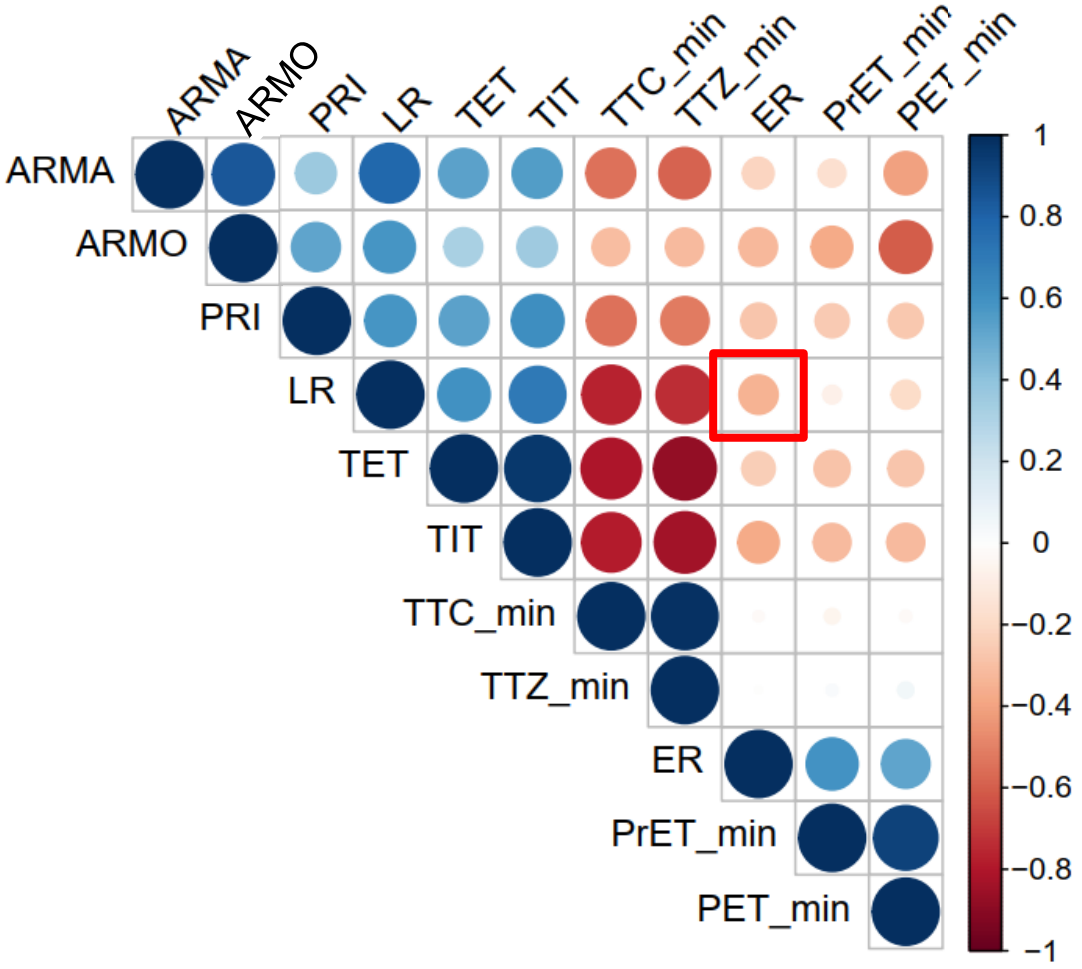

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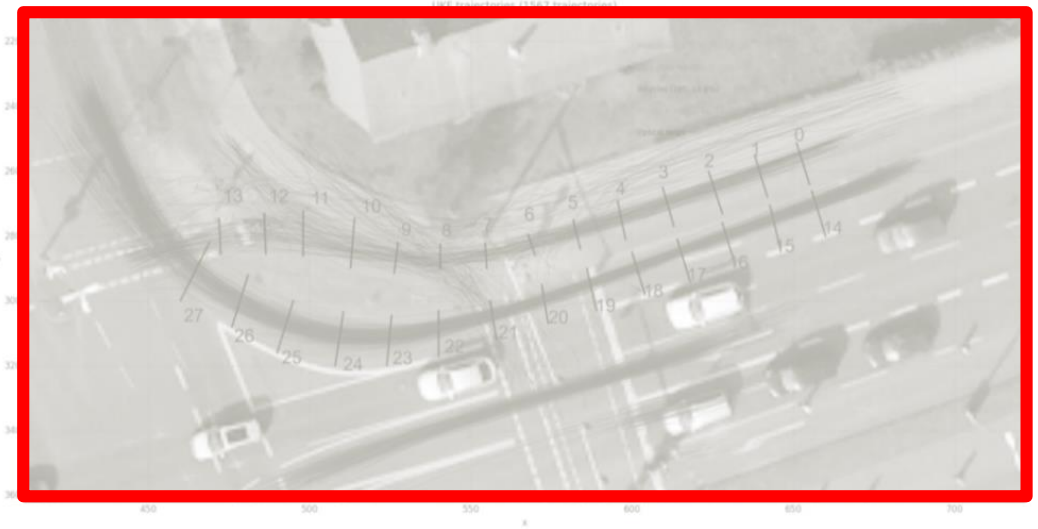
LR = Layman Rating
ER = Expert Rating

Event based

Calculated once per event



TIT TET PET PRI TTC_min

Rating by Humans

Time based

Calculated per each time step

AR TTC TTZ PrET

Aggregated Human Ratings

DLR

Pooled Laymen Rating (PLR)

Rating by volunteers in online study

DLR

Amberlight Risk (AR)

Risk estimated with DLR algorithm

TTC

Seconds until collision

TTZ

TTC to zebra crossing

Predicted Encroachment Time (PrET)

Estimated PET based on speed and trajectory

Pooled Laymen Rating

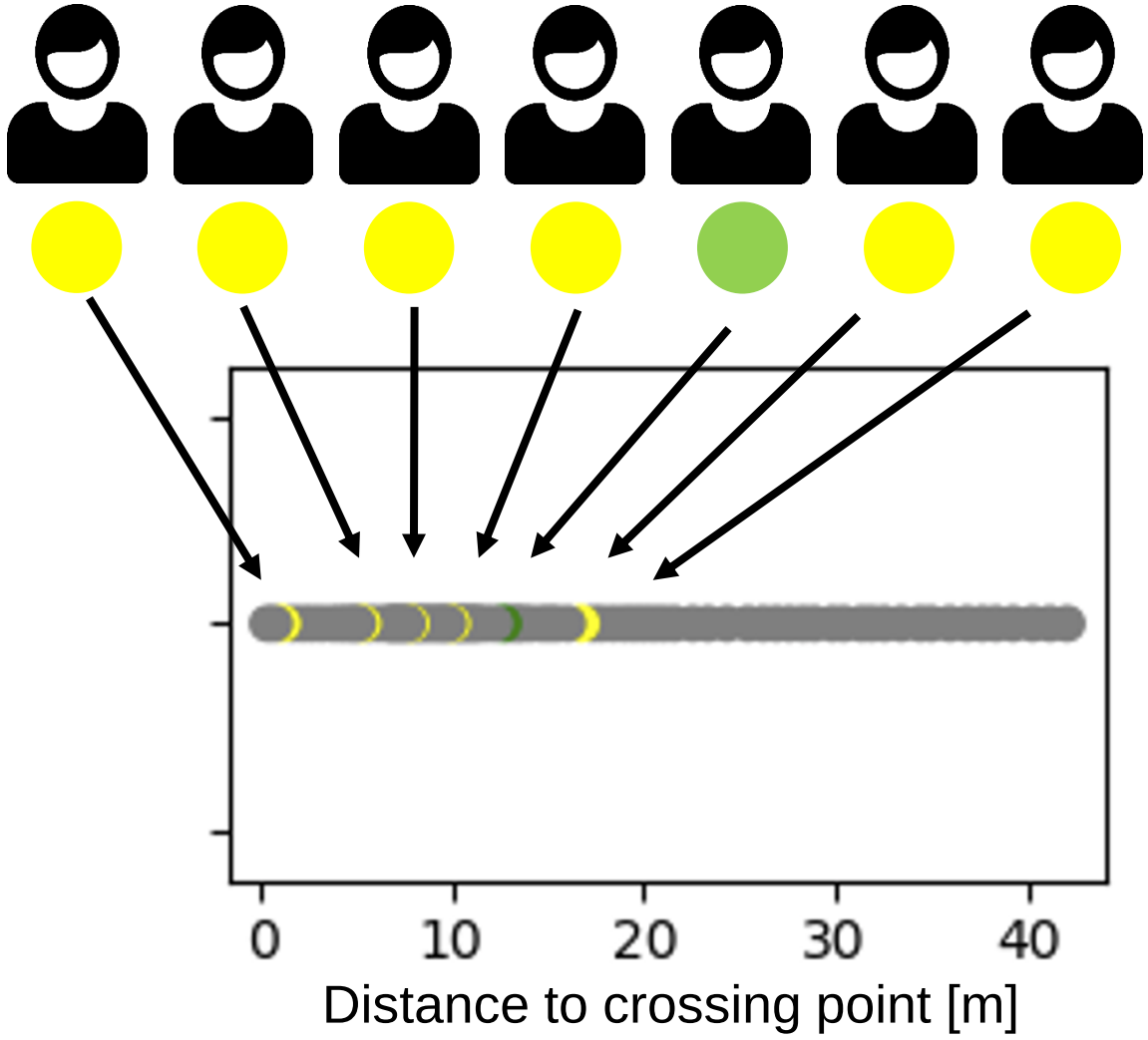
126 people rated each video

Aggregate all ratings per video

(use mean for overlaps)

Each rating has position for decision

Do this for 10 videos



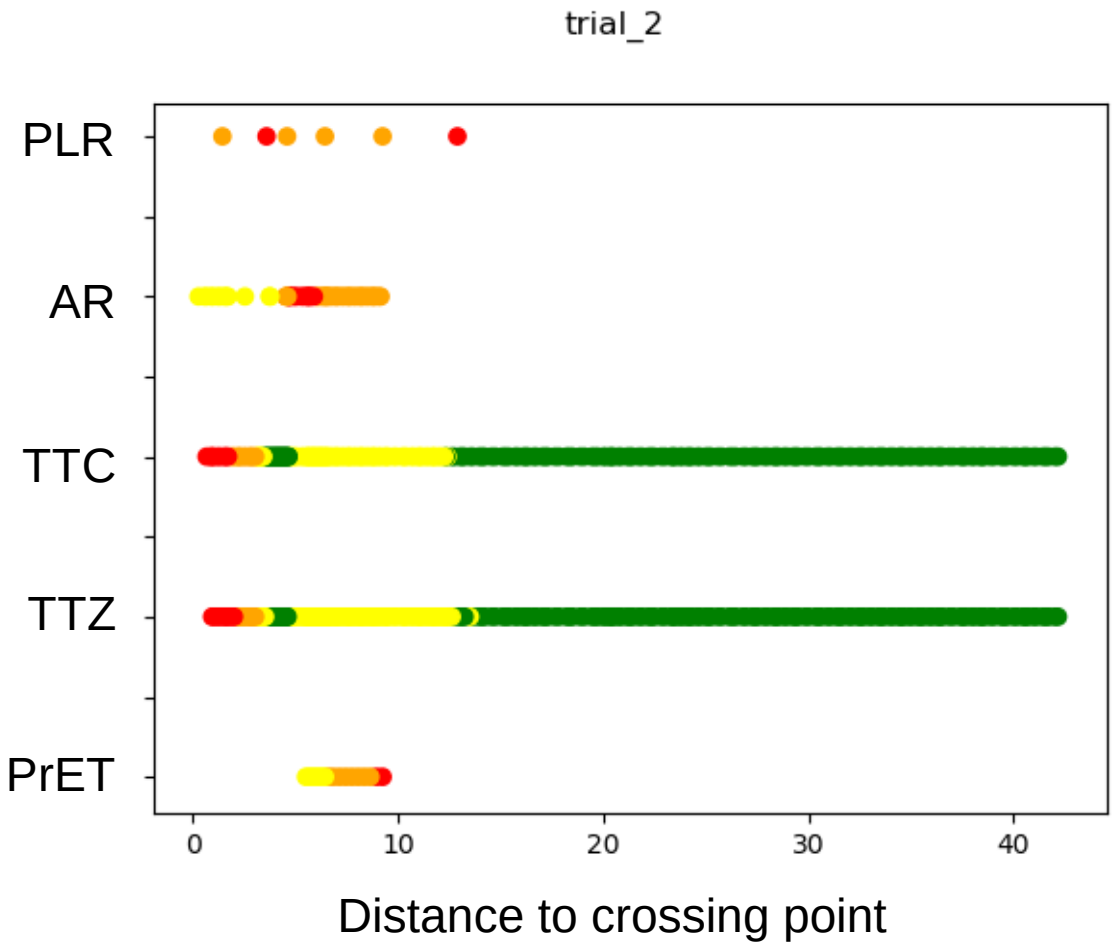
LR

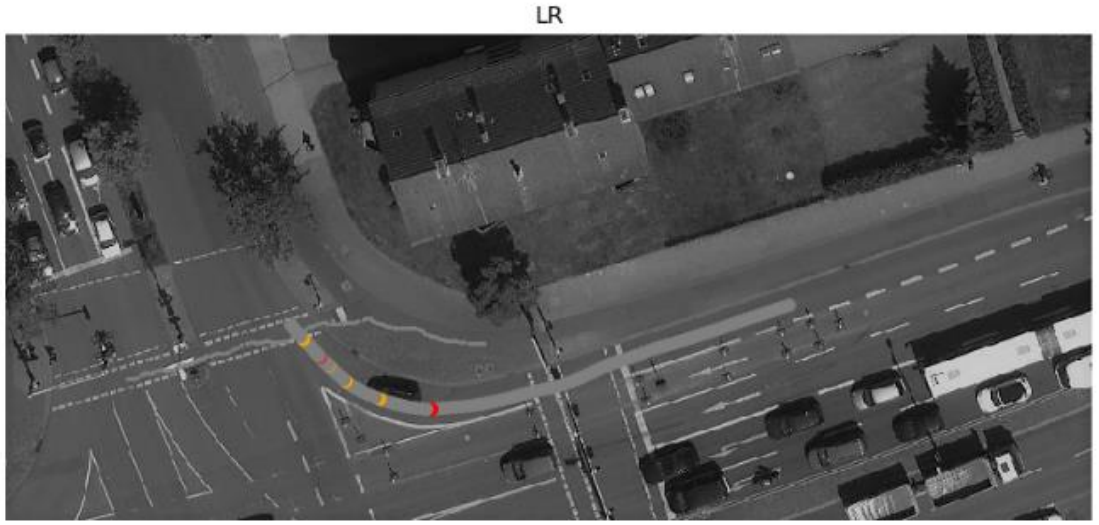
		AR	Pooled Layman Rating (PLR)	TTC	TTZ	PrET
	Very uncritical	0	< 4	> 3	> 3	> 3
	uncritical	1	4 - 6	1.5 - 3	1.5 - 3	1.5 - 3
	So-so	2	7 - 10	0.5 - 1.5	0.5 - 1.5	0.5 - 1.5
	Critical	3				
	Very critical	4	> 10	< 0.5	< 0.5	< 0.5

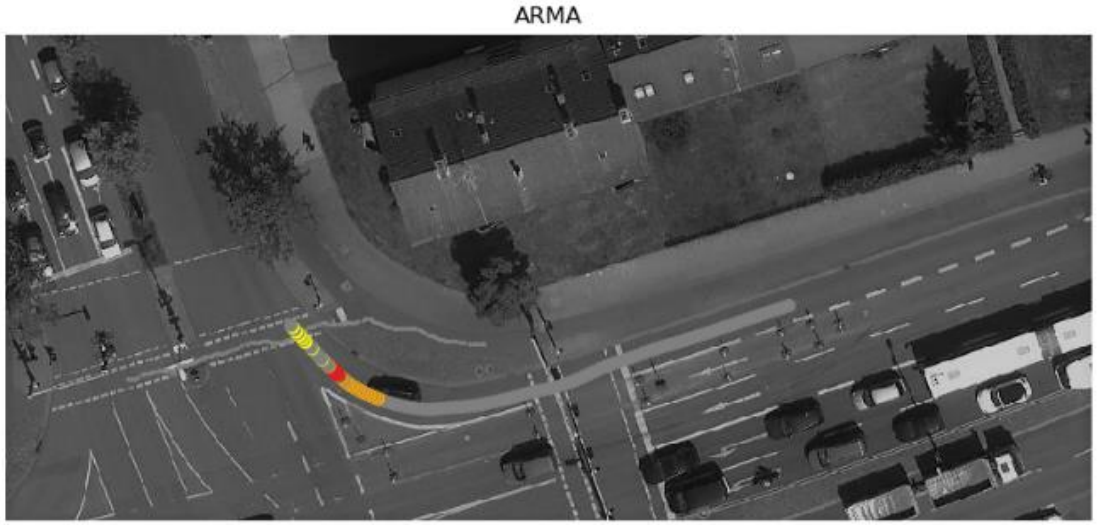
What values are critical?

Help define metric target values:

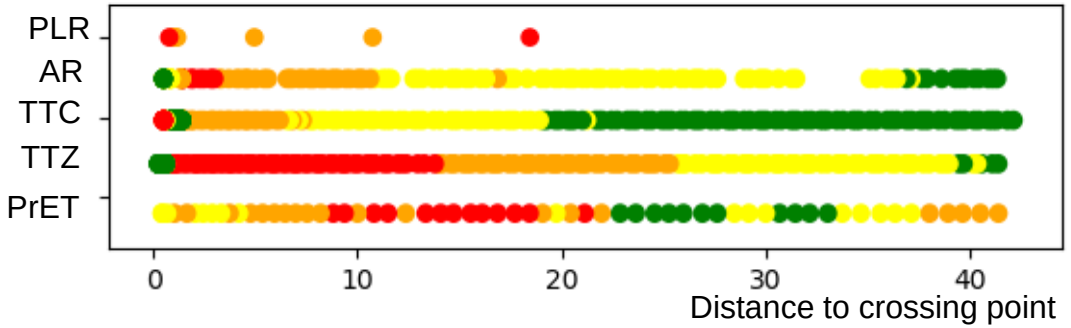
Readthedocs.io https://criticality-metrics.readthedocs.io/en/latest/


trial_2
PLR
AR
TTC
TTZ
PrET
0
10
20
30
40
Distance to crossing point

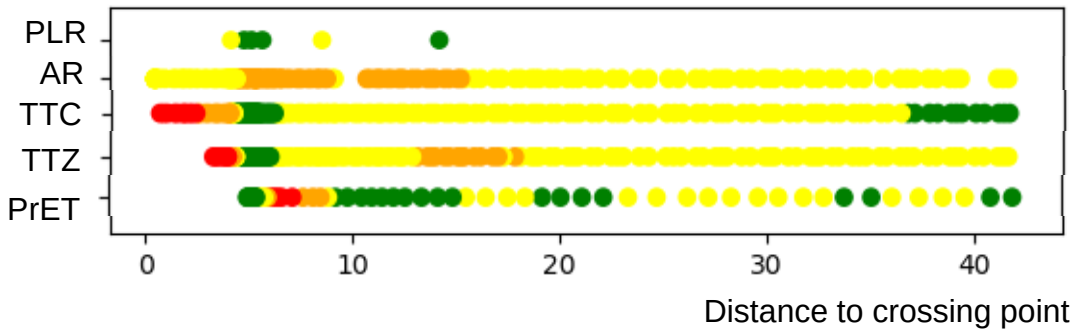

LR


ARMA

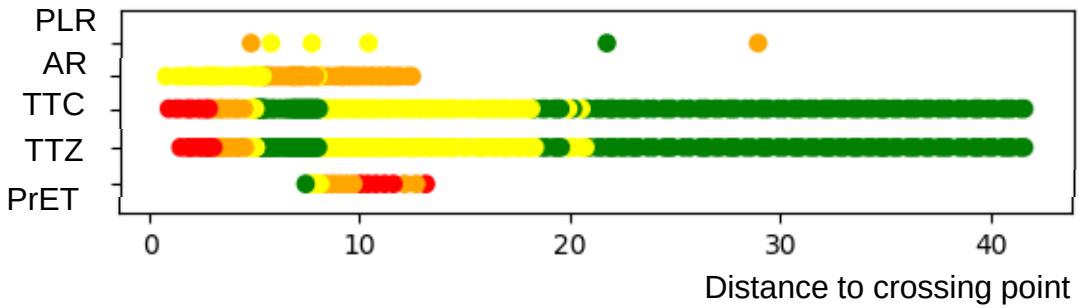
trial_1367



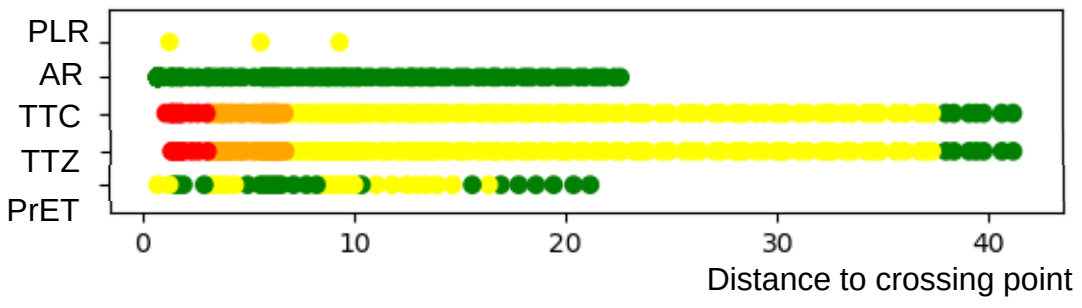
trial_2464



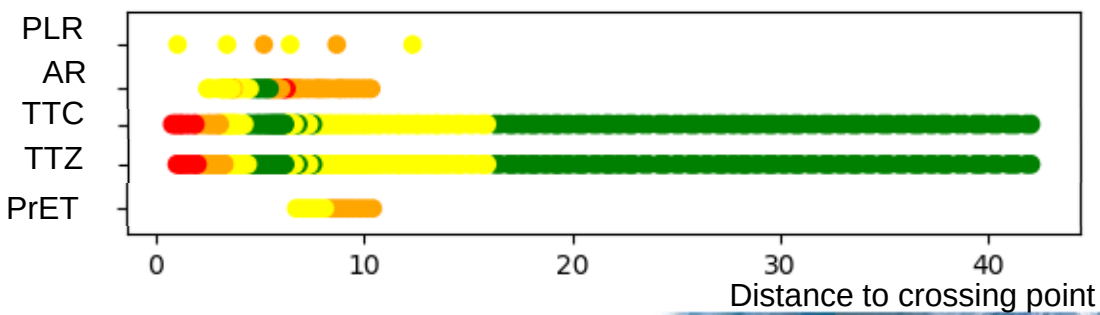
trial_2232



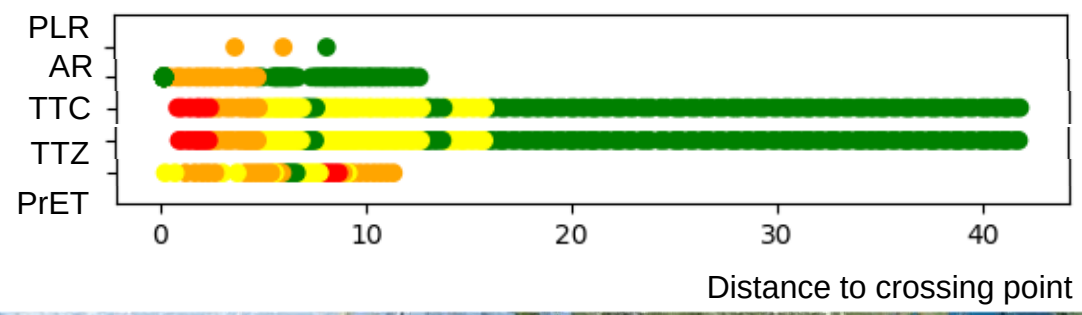
trial_2276



trial_210



trial_2317



Conclusions

- Based on subjective video ratings by humans as criterion, this work shows that the minimum of the popular TTC together with the ARMA are well suited to predict criticality for cyclist-vehicle interactions at intersections as perceived by volunteers.
- However, the human ratings did not always agree. More research is needed to investigate why and which subjective risk rating is suited best for a given situation.

- No obvious relation between pooled human ratings (mean) and time based criticality metrics
- But human ratings show moments of decision for a given criticality for an event

Outlook

- There may be even better metrics than the ones we have which may be based on higher level aspects of the interaction than just distance, trajectory, speed and acceleration.
- We need value ranges for criticality level for many metrics

Thank you for your attention!

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- Westhofen, L., Neurohr, C., Koopmann, T., Butz, M., Schütt, B., Utesch, F., Neurohr, B., Gutenkunst, C., & Böde, E. (2022). Criticality Metrics for Automated Driving: A Review and Suitability Analysis of the State of the Art. *Archives of Computational Methods in Engineering*. https://doi.org/10.1007/s11831-022-09788-7

PRI and PRI_improved

- Definition:

ΔT is the difference between TTC and Ts (Ts is Time to Stopping with current velocity and a constant deceleration).

$$T_{si} = T_r + \frac{V_{i(v)}}{a_b}$$

Reaction time

$$PRI = \sum_{TTZ_D} \left(V_{impact_i}^2 \cdot \Delta T_i \right)$$

$$V_{impact} = \sqrt{V_v^2 - 2 \cdot a_b \cdot (Dy - V_v \cdot T_r)}$$

V_{impact} is the velocity when the car reaches the conflict zone with the current velocity and a constant deceleration.

In the decelerating process, the reaction time T_r is considered. **However, it is not sensible to consider the reaction time at each time instant as in the paper, because the driver needs the reaction time only at the beginning of the braking maneuver, not at each second in the whole process.**