

# Criticality Analysis

as part of the

## VVMethods Safety Argumentation

Christian Neurohr (Lead VVM Criticality Analysis)

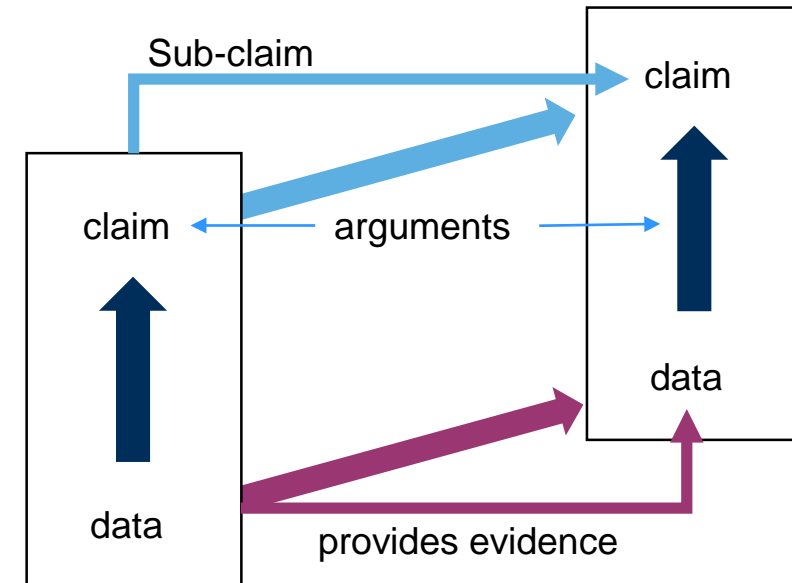


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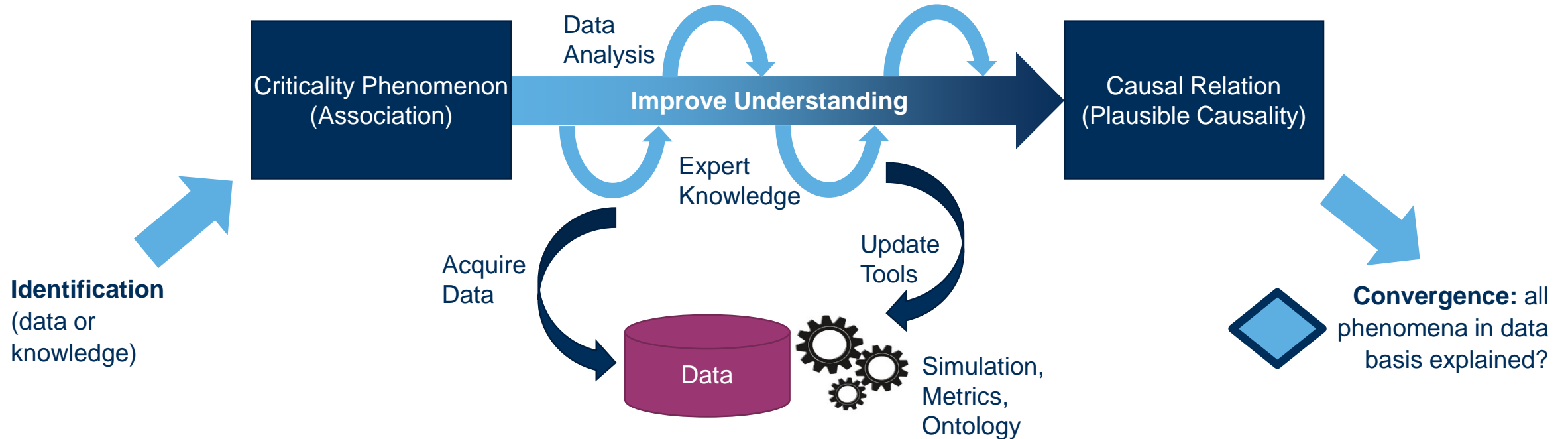
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- The release of automated vehicles requires a **rigorous Safety Argumentation**.
- The VVMethods Safety Argumentation is structured as a **hierarchy of claims** substantiated by sub-claims.
- How to derive the **reasoning for edge cases**?
  - Edge cases appear as combinations of influencing factors, called **criticality phenomena (CP)**, which are analyzed regarding their
    - relevance
    - safety impactwithin the context of the operational domain (OD) & driving task.
- **Claim (of the Criticality Analysis):** we identified and analyzed the relevant **CP** in the OD.



# Criticality Analysis – Basic Concept

C. Neurohr, L. Westhofen, M. Butz, M. H. Bollmann, U. Eberle and R. Galbas, "Criticality Analysis for the Verification and Validation of Automated Vehicles," in *IEEE Access*.



## Assumptions:

- ▶ set of criticality phenomena is limited and manageable → finiteness (of artefacts)
- ▶ relevant phenomena leave traces in growing data basis → completeness (of artefacts)

## Example: the criticality phenomenon „occlusion“

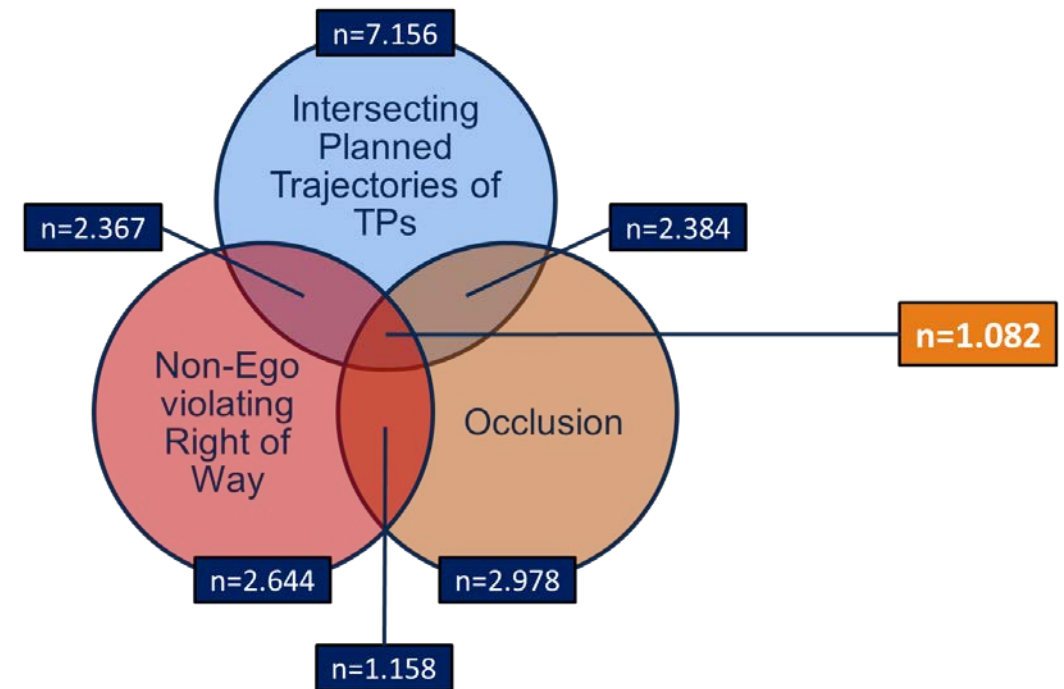
- identify the criticality phenomenon „**occlusion**“
  - find **adequate level of abstraction** and **relevant concretizations**
  - use **ontological representation** to **formalize knowledge**

Absolute Cases	Relative Cases	Criticality Phenomenon	Ontological Classification	Estimated Criticality	Tags
2701	21.79%	Occlusion	Perception	Medium	Limited Perception
573	4.62%	Occluded Pedestrian	Perception	High	Limited Perception, VRU
1031	8.32%	Occluded Bicyclist	Perception	High	Limited Perception, VRU
982	7.92%	Occluded Intersecting Vehicle	Perception	Medium	Limited Perception, Trajectory
0	0%	Occluded Obstacle	Perception	Medium	Limited Perception, Obstacle
n.i.	n.i.	Occluded Lane Markings	Perception	High	Limited Perception, Lane Markings
221	1.78%	Occluded Traffic Sign	Perception	Depends	Limited Perception, Traffic Sign
n.i.	n.i.	Occluded Traffic Light	Perception	High	Limited Perception, Traffic Light

- check available data basis for **empirical evidence** whether the **phenomenon is relevant**
  - searching the GIDAS database yields
    - **N = 12394 accidents** in **urban areas** involving a passenger car
    - **2701 ≈ 21,79%** are associated with „occlusion“
  - strong indication that „occlusion“ is a **relevant phenomenon**

# Relevance Estimation for Criticality Phenomena

- **Analysis of GIDAS** accident database:
  - Relevant subset of accidents for VVMethods:  $N = 12394$  accidents „cases“
  - Analysis of each case regarding the presence of 116 (out of 166) criticality phenomena
- For each criticality phenomenon identifiable in GIDAS, obtain **absolute** and **relative incidences** in the database
- **Ranking phenomena according to incidences** in GIDAS allows estimation of relevance
- Edge cases appear as **combinations** of **criticality phenomena**



# Causal Analysis of the Safety Impact of Criticality Phenomena

- use causal graphs to represent **hypotheses about** the underlying **causal relation** of phenomena
- Incorporate criticality metrics as to make the **safety impact** of phenomena **measurable**
- Collect **evidences for causal relations** using
  - real-world data
  - synthetic data (simulation)
- iterative **abstraction & refinement** within plausibilisation to improve causal relation

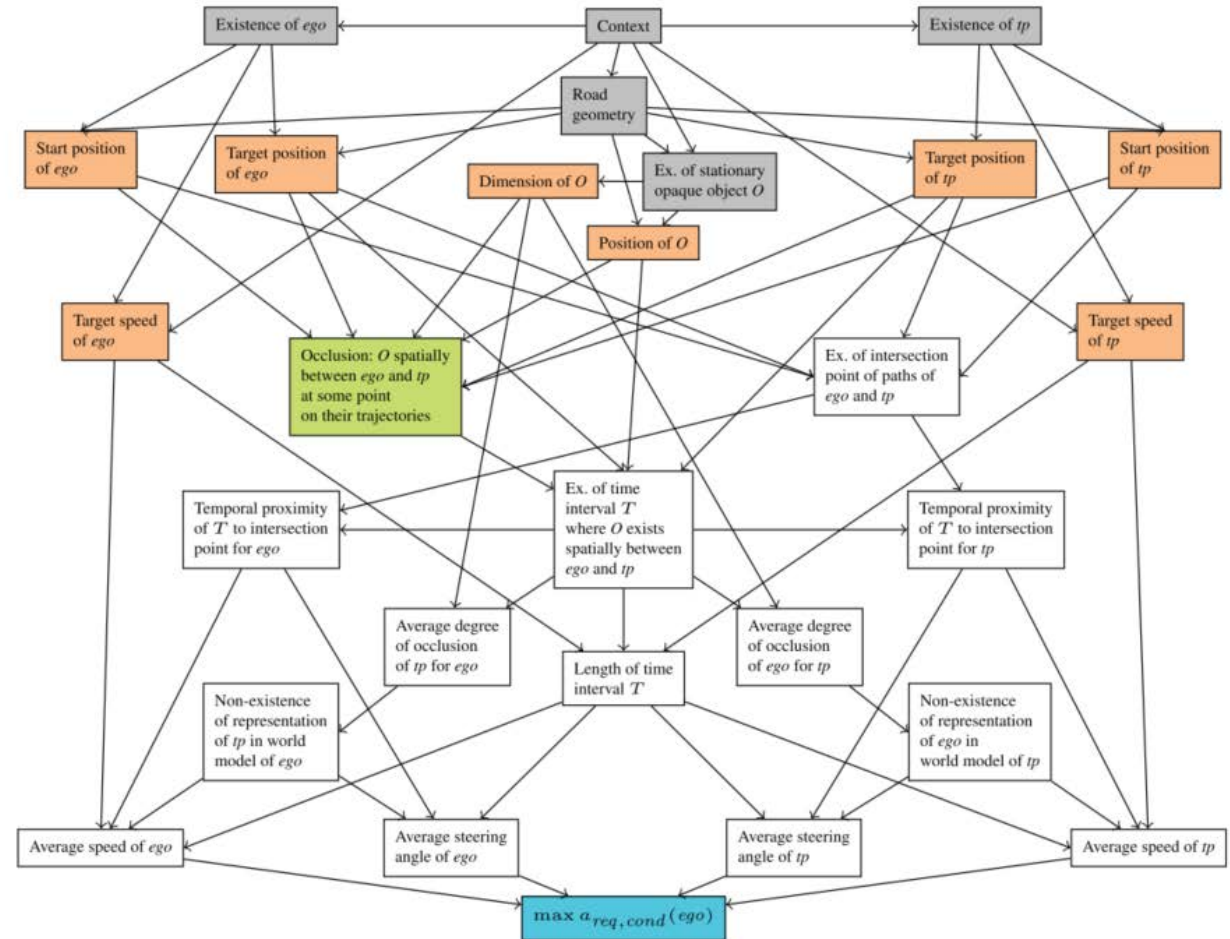


FIGURE 6: Causal relation  $CR_{stat-occ-tp}$ , represented as a DAG, connecting the criticality phenomenon  $CP_{stat-occ-tp}$  to criticality measured via conditional required acceleration ( $a_{req,cond}$ ). Unobserved variables are gray and independent variables are orange. The exposure variable 'occlusion' is marked green. The outcome variable ' $\max a_{req,cond}(ego)$ ' is marked blue.

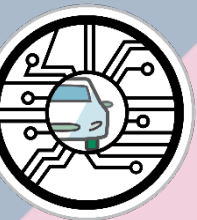


## How does VVM methods deal with edge cases?

- **Criticality Analysis:**
  - identification of criticality phenomena (CP) and estimation of relevance
  - causal analysis of CP regarding their Safety Impact
  - edge cases appear as combinations of CP (workshop discussion!)
- **Safety Argumentation is the KEY!**
  - hierarchy of claims and sub-claims enables rigorous reasoning for the release of AVs
  - artefacts of the Criticality Analysis appear as claims and sub-claims in the Safety Argumentation

# Thank you for your attention!

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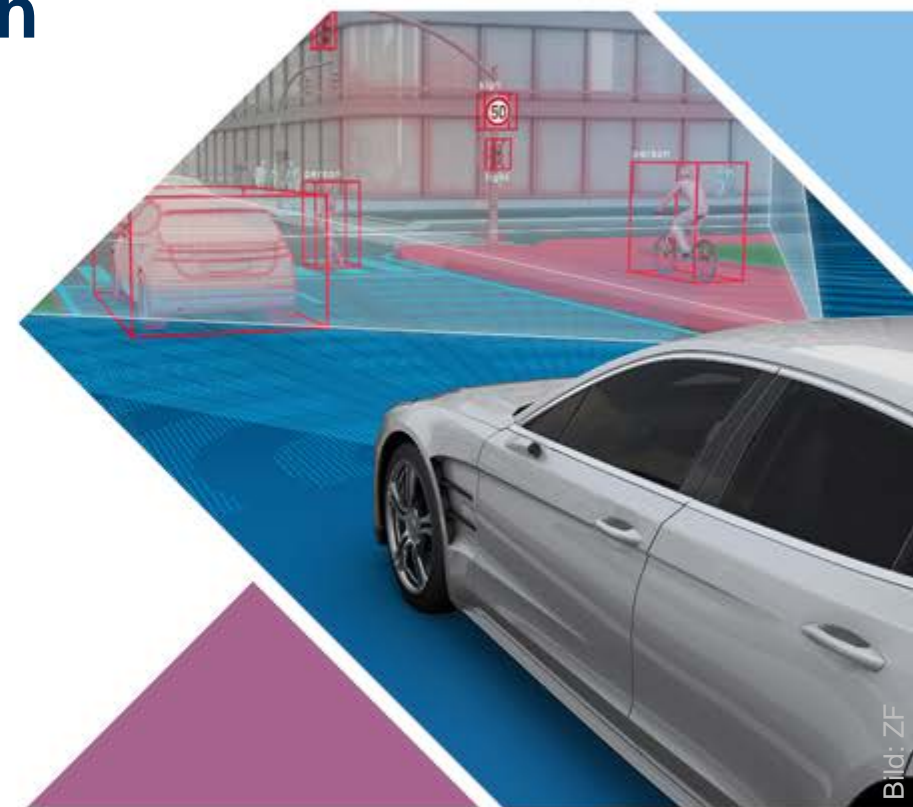
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# Workshop Discussion: VVMethods Approach for dealing with Edge Cases

Christian Neurohr (Lead VVM Criticality Analysis)



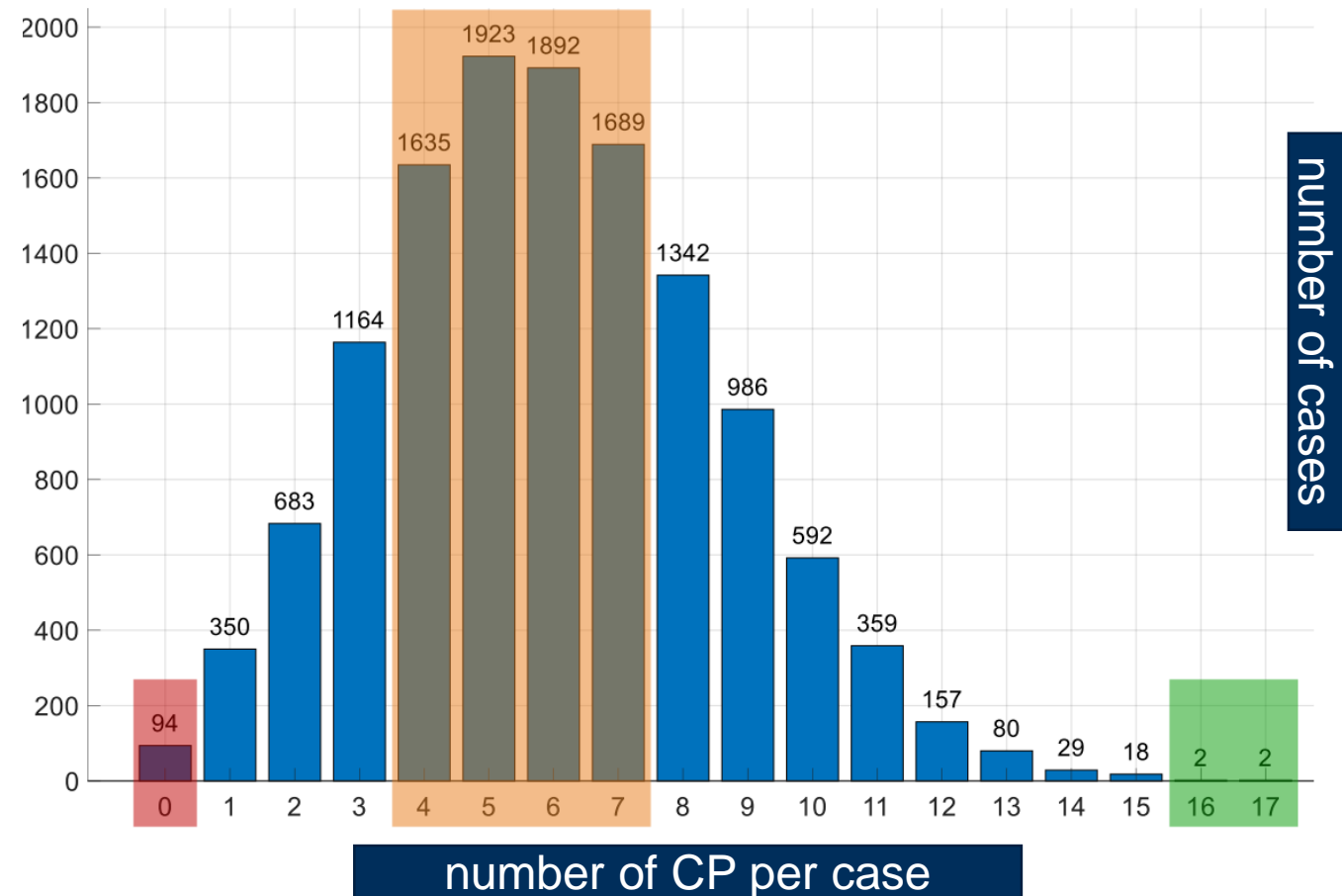
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# Edge Cases as Combinations of Criticality Phenomena

- Accidents in (human) traffic are **multi-causal**.
- After filtering out abstraction/refinement relations ...
  - most accidents (~55%) in urban areas feature **between 4 and 7 CPs** per case
  - 94 accidents feature no CP; either **not relevant for AVs** or due to **incompleteness of CP collection**
  - 4 special „loaded“ cases with **more than 15 CP** will be discussed in the afternoon session



# Edge Case #1: Car vs. Pedestrian (featuring 16 CP)

## ➤ Environment

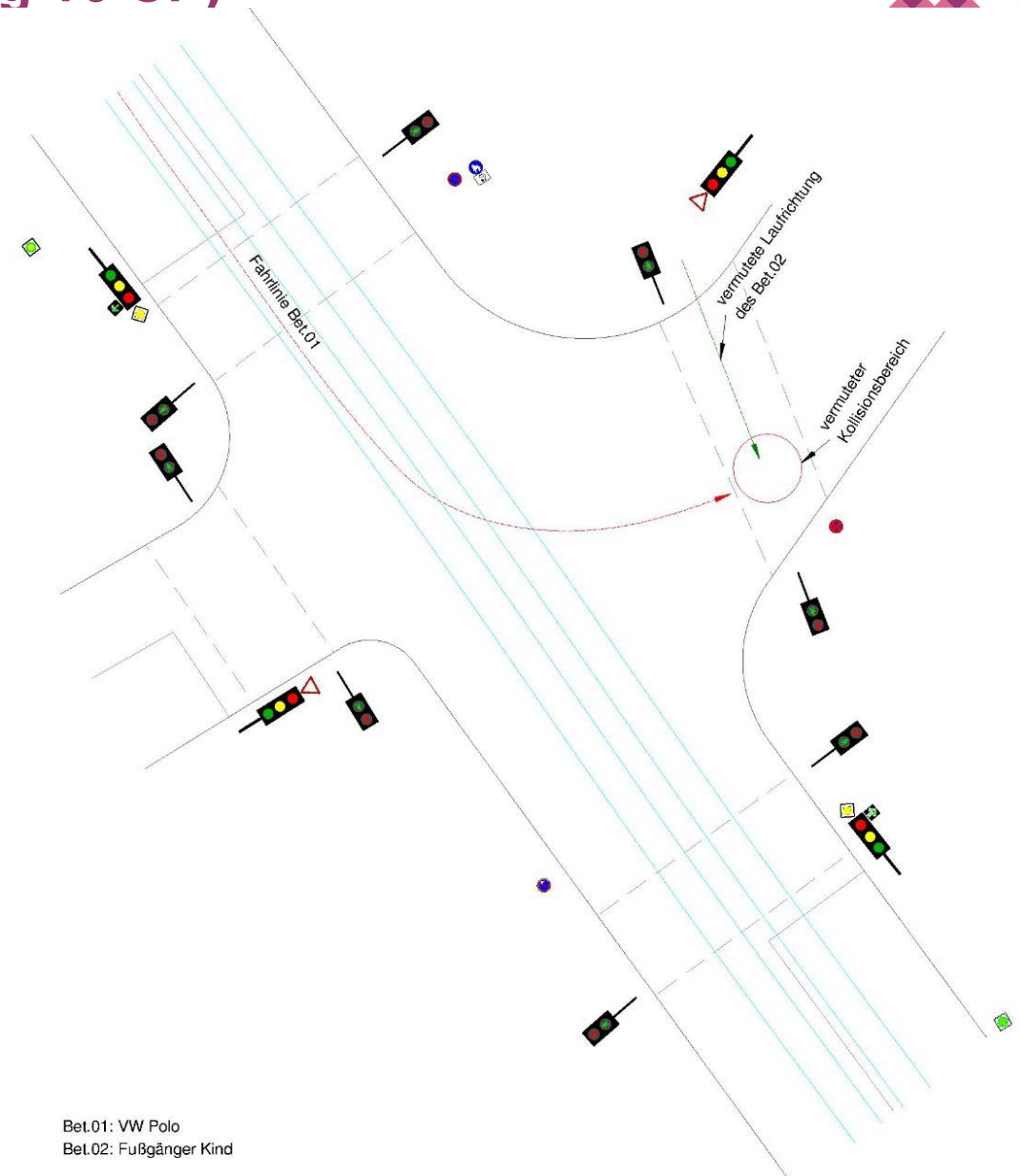
- Rain
- Reduced Friction on Road
- Limited Global Light Source

## ➤ Infrastructure

- Intersection
- Pedestrian Crossing
- Degraded Road Quality
- Degraded Lane Markings
- Intersecting Tram Rails

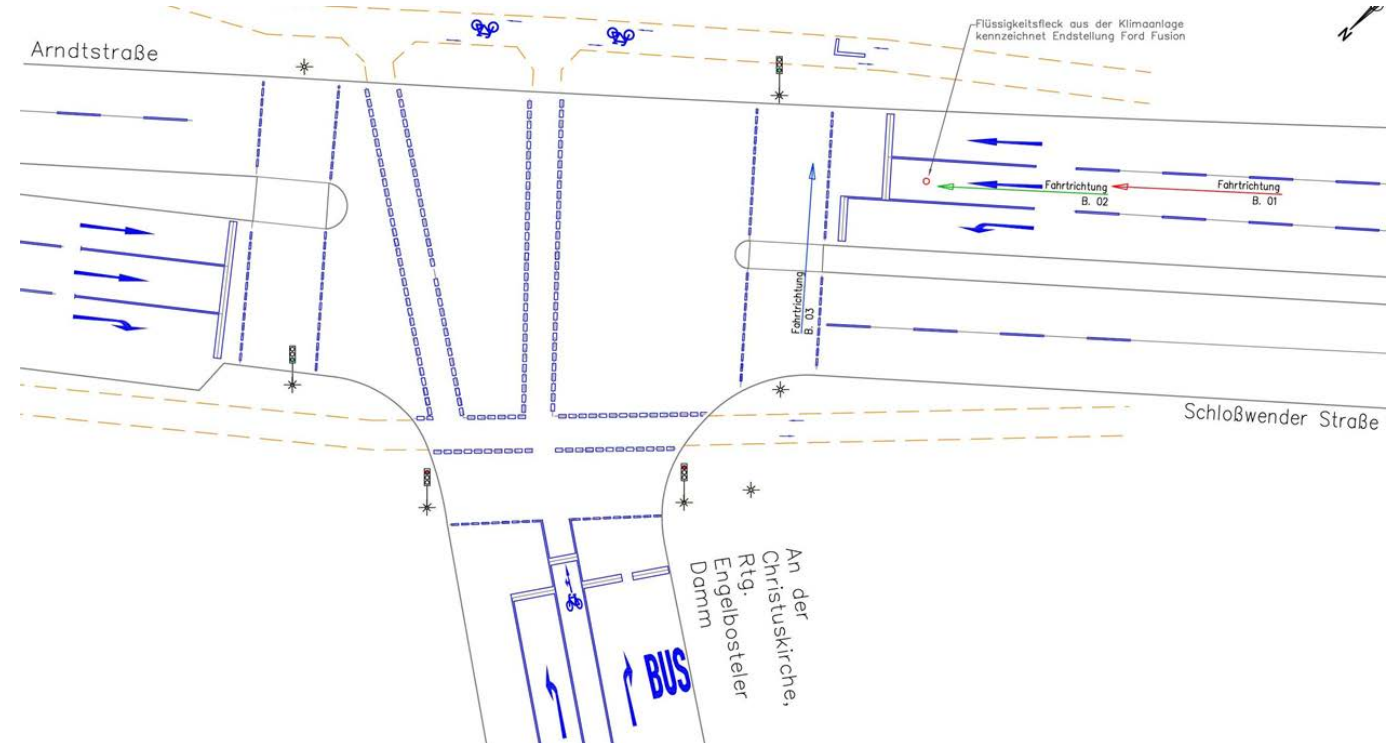
## ➤ Involved Actors, Maneuvers, Misconduct

- Intersecting Planned Trajectories of TPs
- Presence of VRUs with Road Access
- Presence of URUs with Road Access
- Dark Clothing of VRU
- Pedestrian crossing Road directly
- Non-Ego-TP running a Red Traffic Light
- Non-Ego-TP violating Right of Way
- Strong Braking Maneuver of Ego/Non-Ego-TP



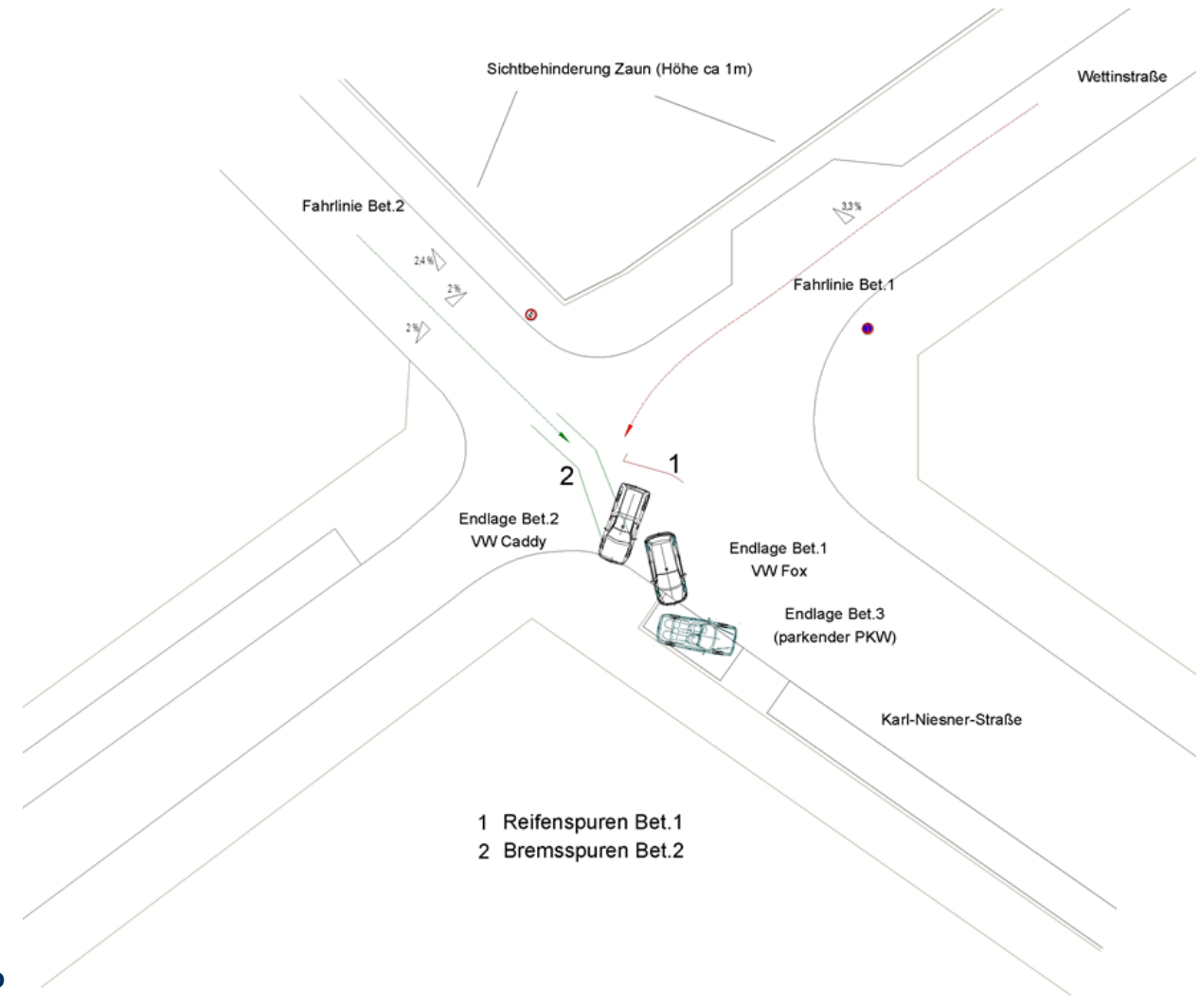
# Edge Case #2: Car vs. Car vs. Pedestrian (featuring 17 CP)

- **Environment**
  - Wind
- **Infrastructure**
  - Intersection
  - Pedestrian Crossing
  - Degraded Road Quality
- **Involved Actors, Maneuvers, Misconduct**
  - Intersecting Planned Trajectories of TPs
  - Presence of VRUs with Road Access
  - Impaired VRU with Road Access
  - Presence of URUs with Road Access
  - Occluded Pedestrian
  - Pedestrian crossing Road directly
  - Dark Clothing of VRU
  - Non-Ego-TP running a Red Traffic Light
  - Non-Ego-TP violating Right of Way
  - Strong Braking Maneuver of Ego/Non-Ego-TP
  - Strong initial Braking Maneuver of Ego/Non-Ego-TP
  - Small Distance to Front
  - Small Distance to Back



# Edge Case #3: Car vs. Car vs. Parking Car (featuring 17 CP)

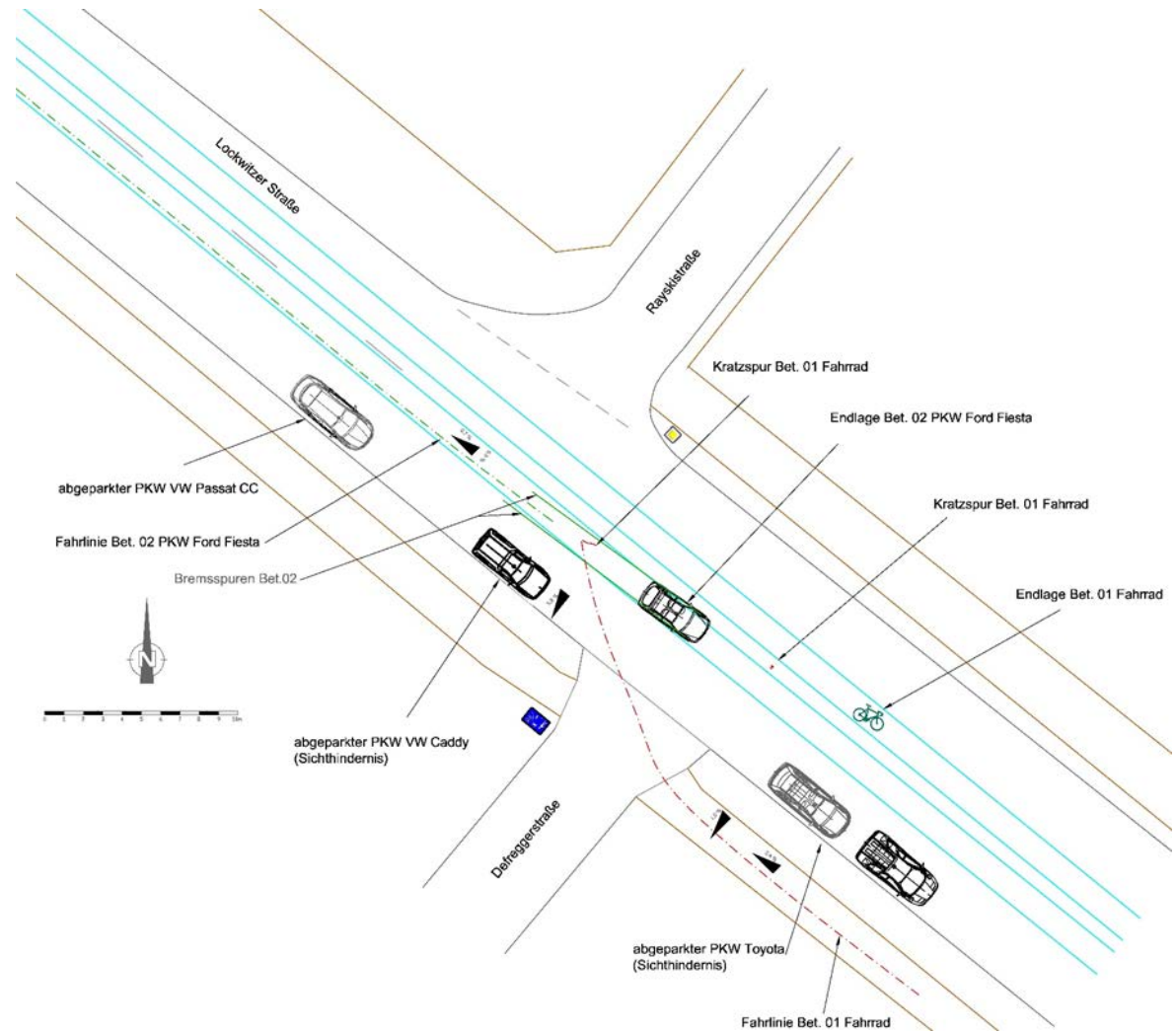
- **Environment**
  - Extreme (change in) Temperature
- **Infrastructure**
  - Intersection
  - Bad Road Surface
- **Perception**
  - Occluded Traffic Sign
  - Occluded Intersecting Vehicle
  - Occluded Vehicle
- **Involved Actors, Maneuvers, Misconduct**
  - Intersecting Planned Trajectories of TPs
  - Non-Ego-TP violating Right of Way
  - Non-Ego-TP aggressive driving
  - Passing of Parking Vehicle
  - Non-Ego-TP impaired driving ability
  - Excessive Speed of Non-Ego-TP
  - High Relative Speed
  - Presence of URUs with Road Access
  - Strong Braking Maneuver of Ego/Non-Ego-TP
  - Interaction with Emergency Vehicles



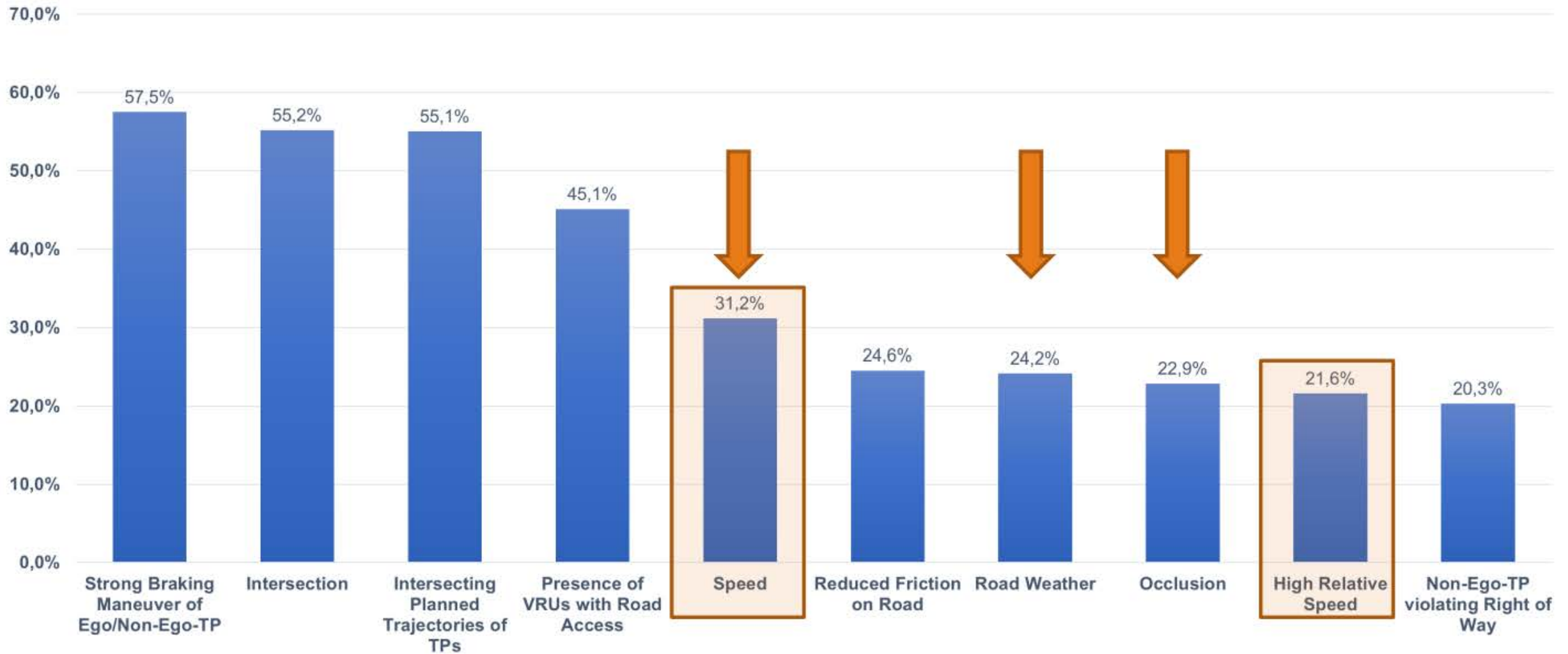


# Edge Case #4: Car vs. Bicyclist (featuring 16 CP)

- **Environment**
  - Extreme (change in) Temperature
- **Infrastructure**
  - Intersection
  - Bad Road Surface
  - Degraded Road Quality
- **Perception**
  - Occluded Bicyclist
- **Involved Actors, Maneuvers, Misconduct**
  - Intersecting Planned Trajectories of TPs
  - High Relative Speed
  - Non-Ego-TP violating Right of Way
  - Lane Closure
  - Passing of Parking Vehicle
  - Risky Lane Change of Non-Ego-TP
  - Bicycle Lane Change onto Road
  - Wrong-Way Bicyclist
  - Strong Braking Maneuver of Ego/Non-Ego-TP
  - Presence of VRUs with Road Access
  - Dark Clothing of VRU
  - Non-Ego-TP on Wrong Non-Driveable Lane

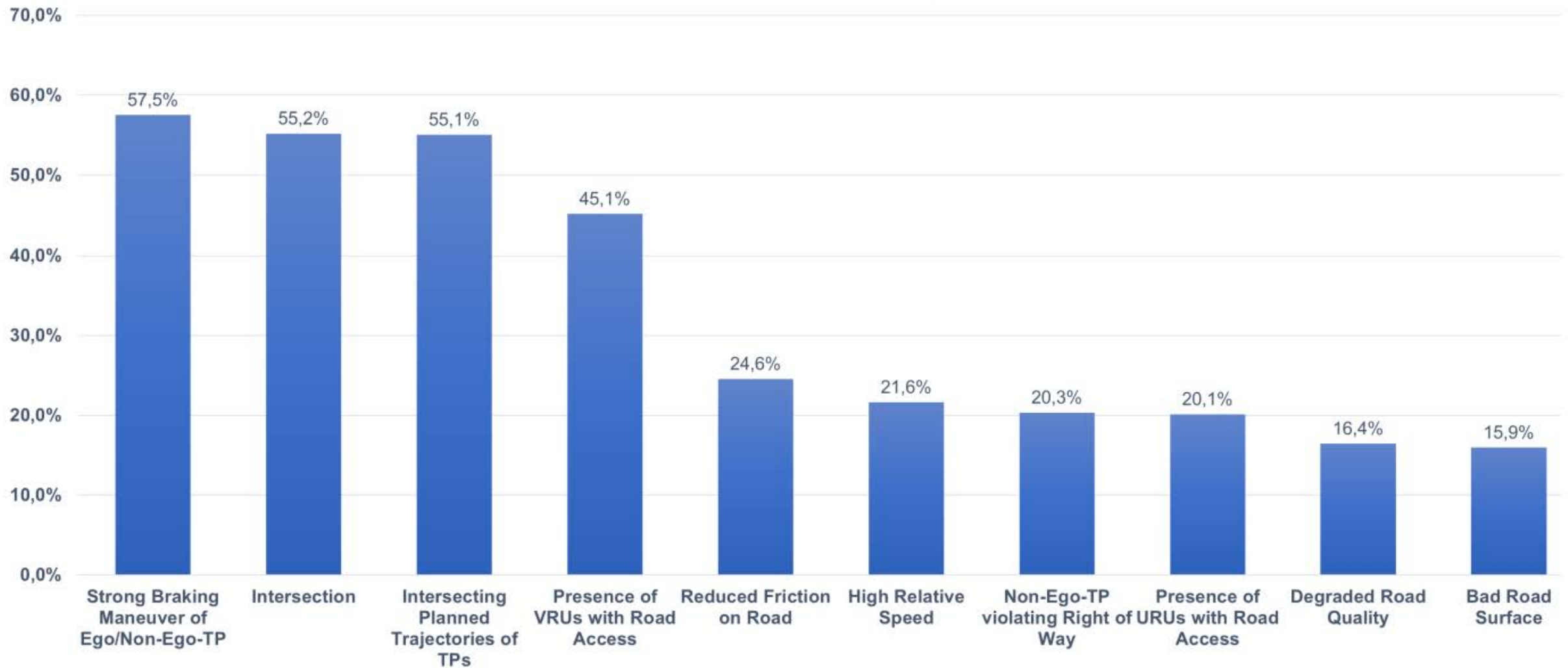


# Top Criticality Phenomena



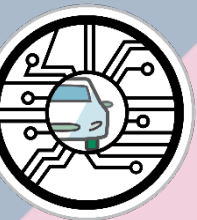


# Top Criticality Phenomena (no abstractions)



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