Turning Left at Urban Intersections: Turning Patterns and Gap Acceptance

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Background and Objective

- Turning left between oncoming traffic is one of the most safety-critical traffic manoeuvres (e.g. Sander, 2017)
- Knowledge about factors that influence a driver's decision to turn can support the development of assistance systems and autonomous driving functions to promote safety (e.g. Hubmann et al., 2017; Zhou et al., 2017)

Objective

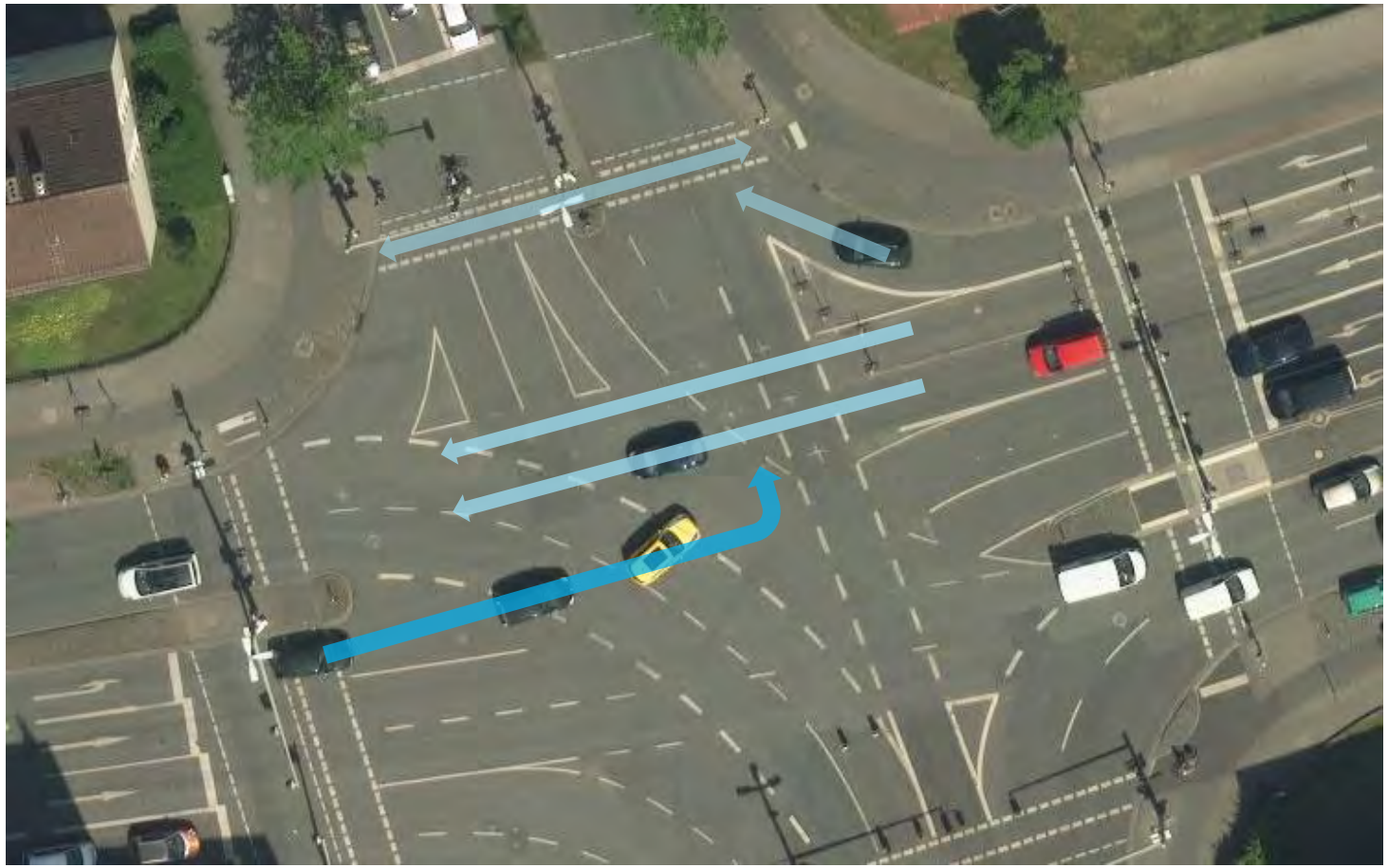
- Describe and understand the interaction behaviour between left-turning and oncoming traffic
- Identify factors that influence a driver's gap acceptance

Available data

- Video and trajectory data collected at the Application Platform for Intelligent Mobility (AIM) research intersection in Braunschweig, Germany

Scenario: Turning Left with Oncoming Traffic

AIM Research Intersection in Braunschweig, Germany



Research Questions and Method

Left turns with PET ≤ 2 s with oncoming traffic
(13 days, n = 3584)

1. Which turning patterns can be observed?

2. Which time gaps in oncoming traffic are accepted/rejected?

3. Which characteristics of oncoming traffic and left-turning vehicles influence gap acceptance?

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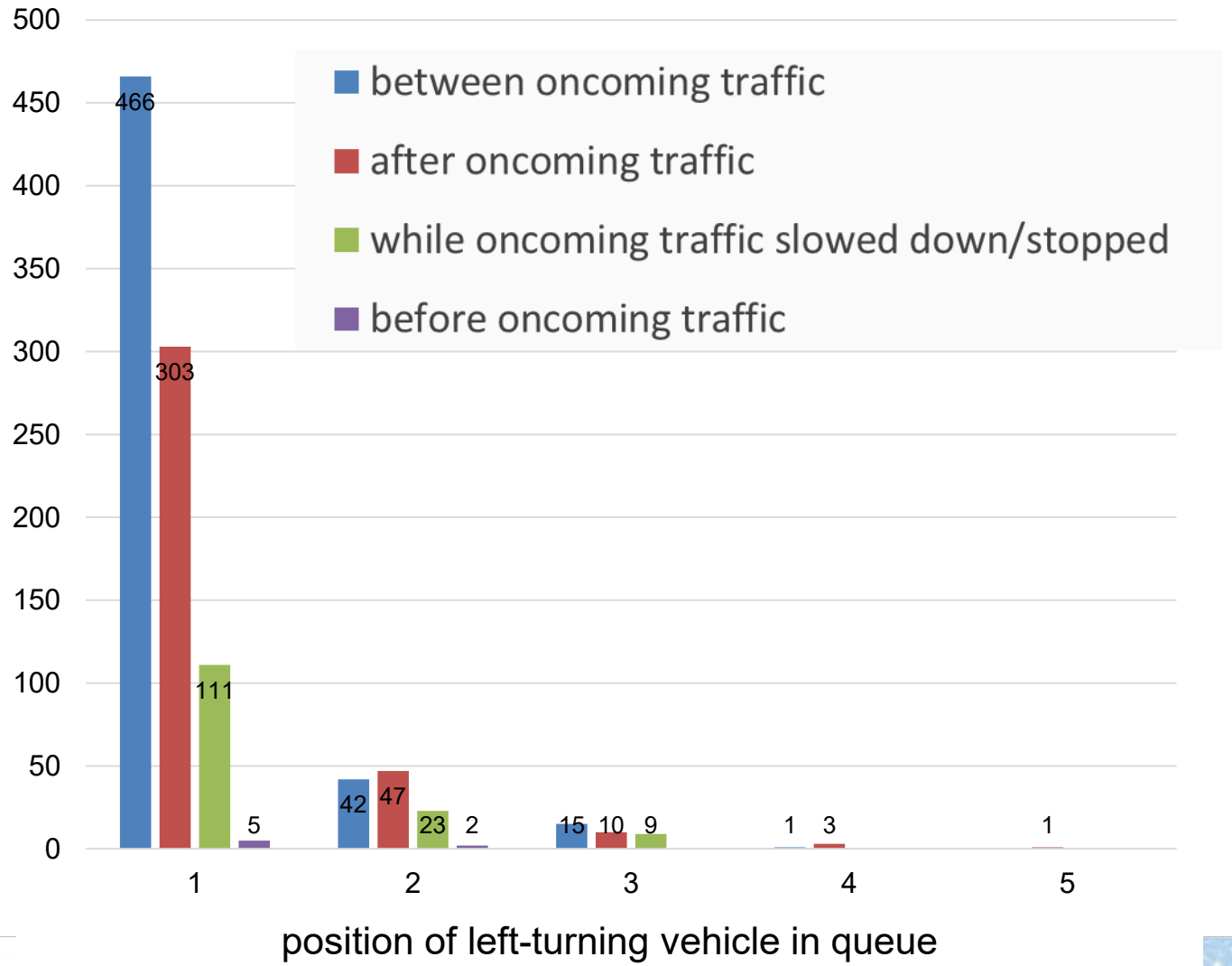
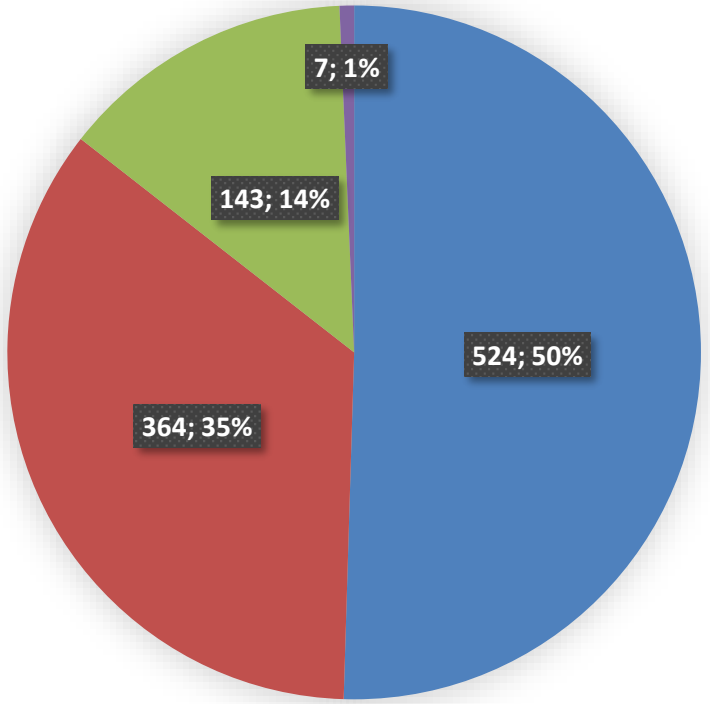
Random selection of 80 left turns per day
(n = 1040)

Identified Turning Patterns





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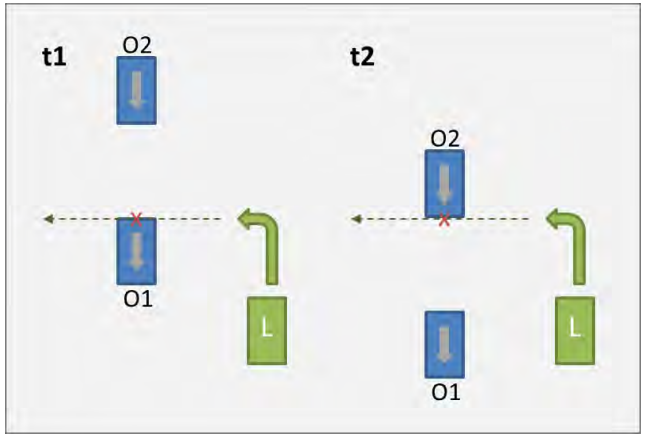
   - Calculation of time gaps
   - Classification as accepted or rejected gap
   - Identifying critical gap by means of logistic regression

Left turns between oncoming traffic (n = 191)

- left-turning vehicle on first position
- of seven days
- between 6 am and 20 pm

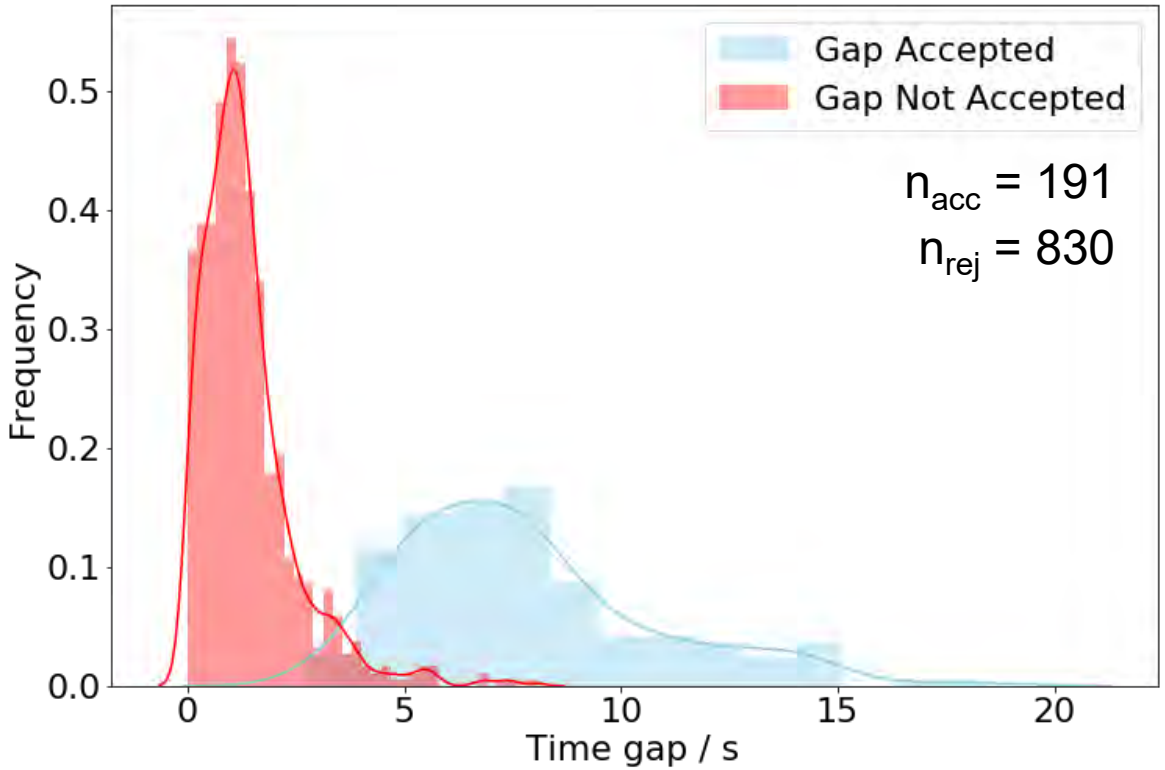
Time Gap, Gap Acceptance, Critical Gap and Logistic Regression

- Time gap = time that passes between departure of rear bumper of first oncoming traffic vehicle (O1) from the left-turn path and arrival of front bumper of following vehicle (O2) at the same point when left-turning vehicle (L) can be assumed to be ready to initiate the left turn (Ragland et al., 2006)
- Gap acceptance = probability of accepting a gap by length of gap (e.g. Ragland et al., 2006)
  - Accepted gap = gap chosen by left-turning vehicle to complete a left turn
  - Gap acceptance curve can be modeled by a logistic function
  - Critical gap = gap value that 50% of drivers would accept (e.g. Dissanayake et al., 2002)
- Logistic models can be used to relate factors to the drivers' gap acceptance decision; model coefficients can be estimated by generalized linear models (e.g. Zhou et al., 2017)

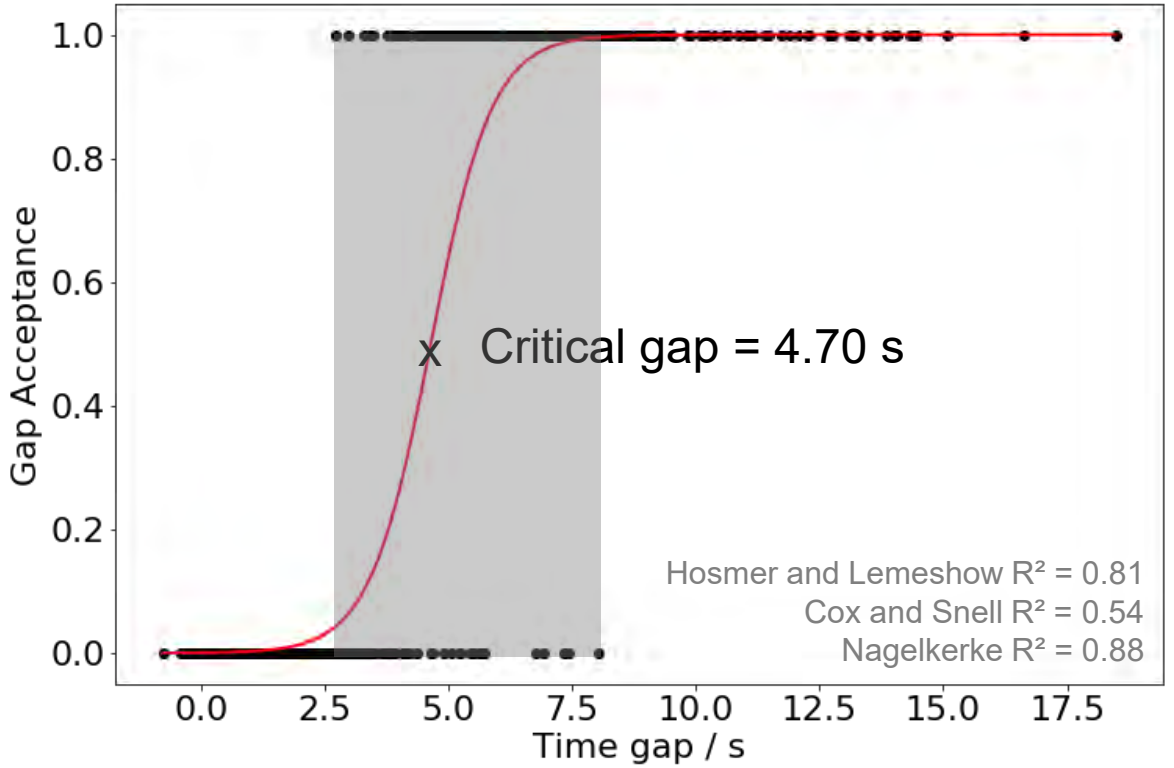


time gap = t2 – t1

Gap Acceptance and Critical Gap



„Ambiguous“ gaps



- Gaps larger than 8.03 s were accepted
- Gaps smaller than 2.74 s were rejected

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3. Which characteristics of oncoming traffic and left-turning vehicle influence gap acceptance?
   - Calculation of characteristics
   - Identification of significant factors by means of logistic regression

„Ambiguous“ gaps (n = 140)

- one gap per left-turning vehicle

Factors Influencing Gap Acceptance

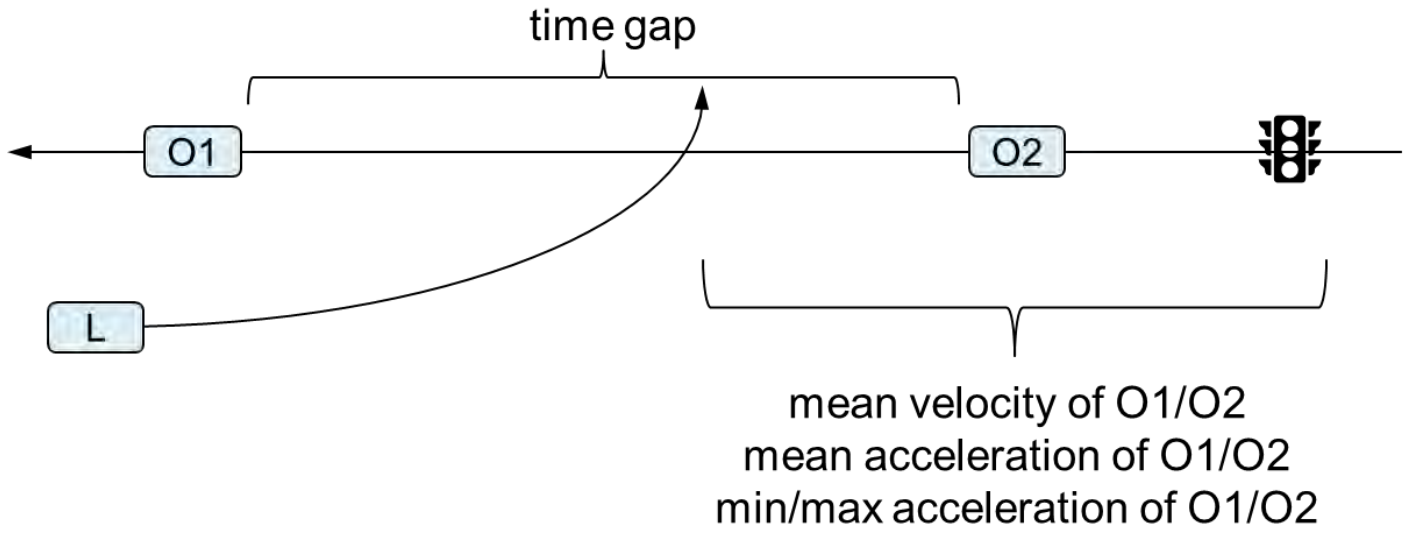
- Gap-related factors
  - Gap duration (e.g. Alexander et al., 2002)
  - Rejected and accepted gap number (e.g. Zhou et al., 2017)
  - Mean and total time of rejected/accepted gaps (e.g. Zhou et al., 2017)
- Driver-related factors
  - Driver age (e.g. Staplin & Lyles, 1991)
  - Gender (e.g. Yan et al., 2007)
  - Personality (e.g. Pollatschek et al., 2002)
- Traffic-related factors
  - Speed of oncoming traffic (e.g. Davis & Swenson, 2004)
  - Waiting time of left-turning vehicle (e.g. Devarasetty et al., 2012)
  - Lane number (e.g. Zhou et al., 2017)
- Environmental factors
  - Weather conditions (e.g. Zhody et al., 2010)
  - Visibility conditions (day/night) (e.g. Dissanayake et al., 2002)

Dynamics between oncoming traffic and left-turning vehicle?

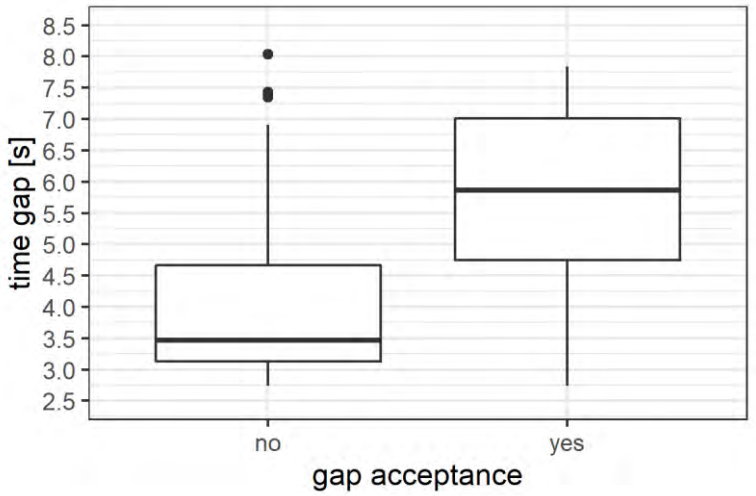
Does the Behaviour of Oncoming Vehicles Influence Drivers‘ Gap Acceptance?

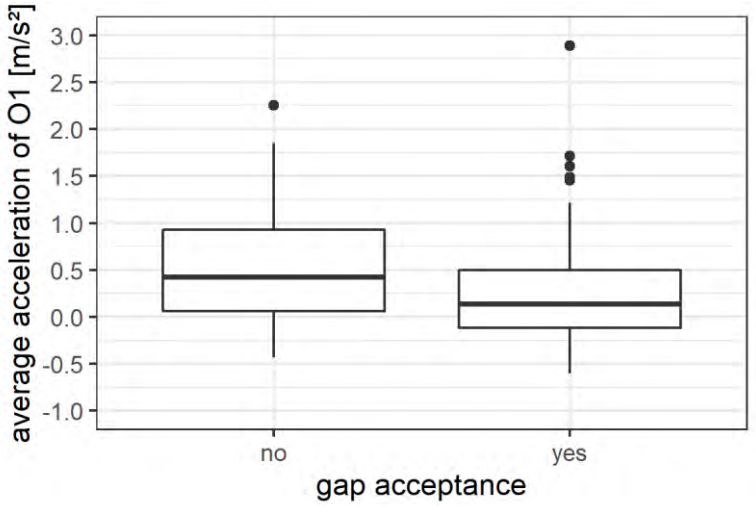
Parameter	Estimate (SE)
Intercept	-6.14* (2.64)
Time gap	1.08*** (0.20)
Average velocity O1	-0.16 (0.13)
Average acceleration O1	-2.82* (1.09)
Minimal acceleration O1	1.01 (0.62)
Maximal acceleration O1	0.54 (0.48)
Average velocity O2	0.27° (0.14)
Average acceleration O2	-2.83* (1.35)
Minimal acceleration O2	0.11 (0.49)
Maximal acceleration O2	0.51 (0.48)

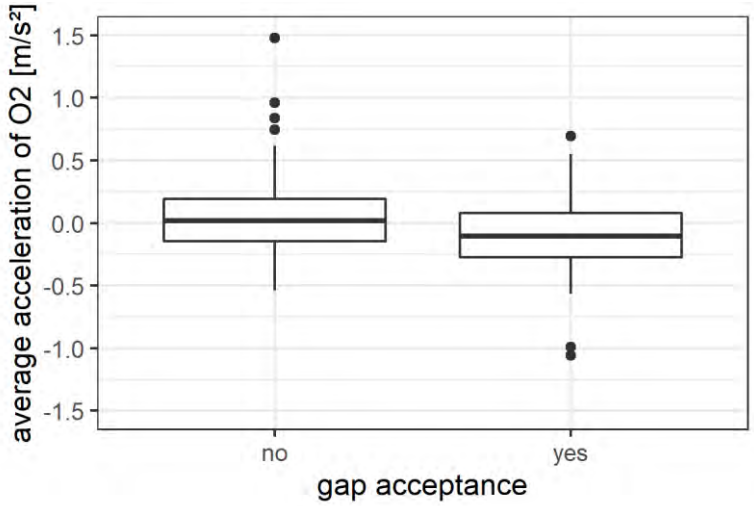
*** p < .001, ** p < .01., * p < .05, ° p < .10



Significant Predictors: Time Gap, Average Acceleration, Average Velocity







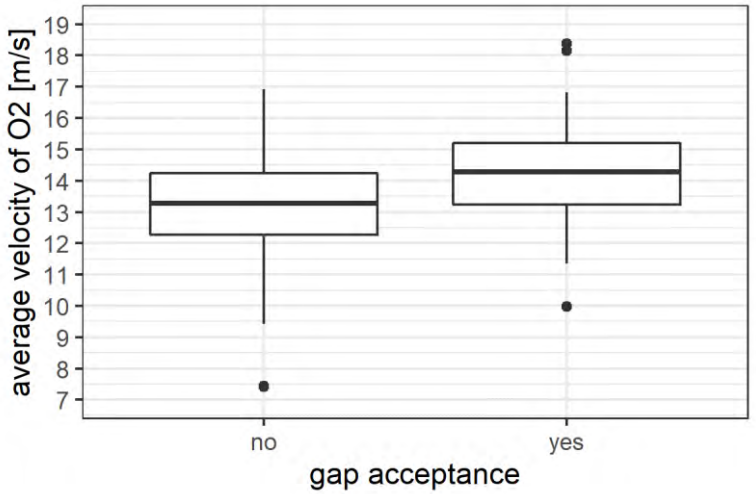
Accepted gaps are characterized by

- Larger time gaps
- Lower acceleration (O1 + O2)
- Higher velocity (O2)

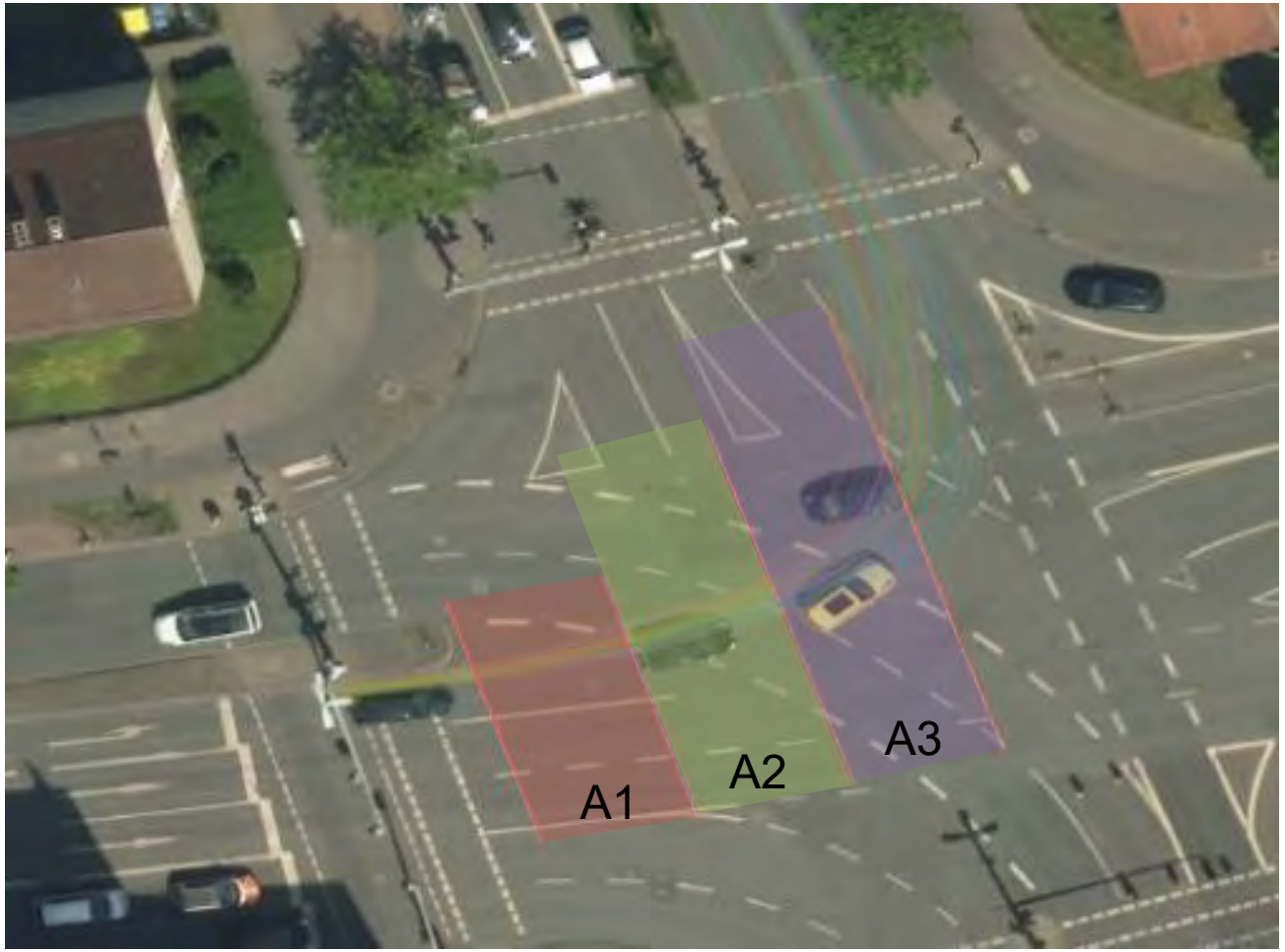
→ oncoming traffic might adapt behaviour

→ left-turning drivers might underestimate velocity

(e.g. Davis & Swenson, 2004)



Does the „State“ of the Left-turning Vehicle Influence the Drivers‘ Gap Acceptance?



- Average velocity
- Average acceleration
- Minimal/maximal acceleration
- Average heading

of left-turning vehicle in areas 1, 2 and 3

Significant Predictor: Left-turning Vehicles' Velocity in Area 2 and 3

	Area 1			Area 2			Area 3		
	Coeff.	Std. Error	Z value	Coeff.	Std. Error	Z value	Coeff.	Std. Error	Z value
Intercept	-0.12	1.58	-0.08	-2.33	1.63	-1.43	-1.00	1.23	-0.82
Average velocity	0.15	0.18	0.80	0.52	0.18	2.81**	0.71	0.24	2.96**
Average acceleration	0.45	0.90	0.50	-0.17	0.68	-0.24	-0.93	0.67	-1.36
Minimum acceleration	-0.46	0.49	-0.94	-0.27	0.38	-0.70	-0.21	0.37	-0.56
Maximum acceleration	0.03	0.52	0.05	0.46	0.35	1.30	0.32	0.40	0.80
Average heading	-0.05	0.08	-0.57	0.02	0.06	0.26	-0.03	0.03	-0.77

*** <.001, ** <.01, *<.05, ° <.1

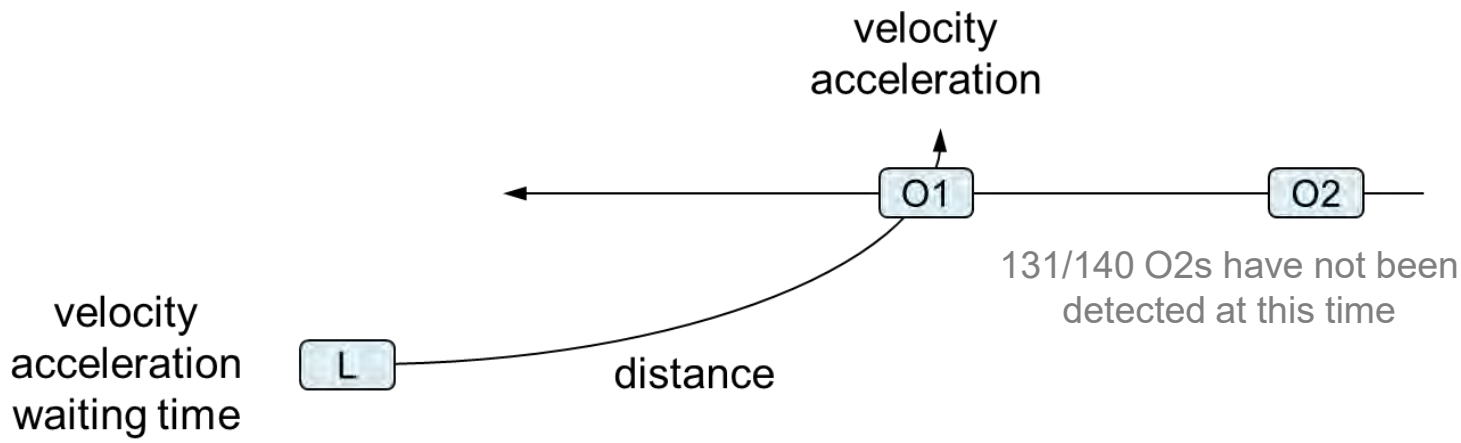
- Average velocity of left-turning vehicles in area 2 and 3 predicts gap acceptance
- Higher average velocity if gap is accepted

Does the „State“ of the Left-turning Vehicle in Relation to Oncoming Traffic Influence Drivers‘ Gap Acceptance?

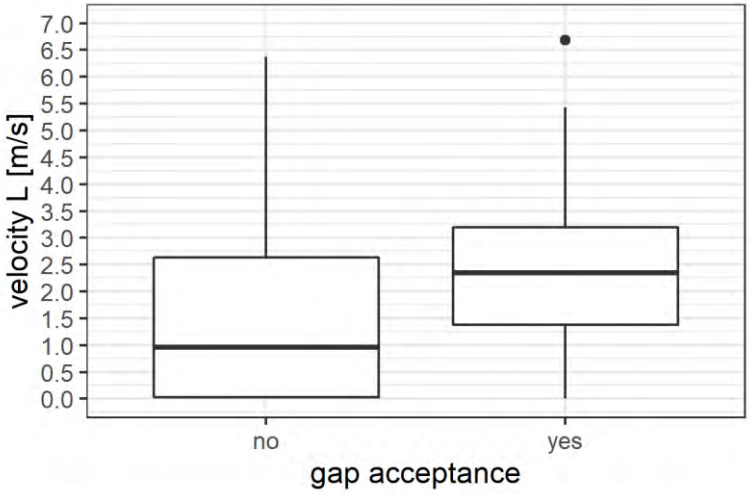
Point in time: **O1 crosses future path of L**

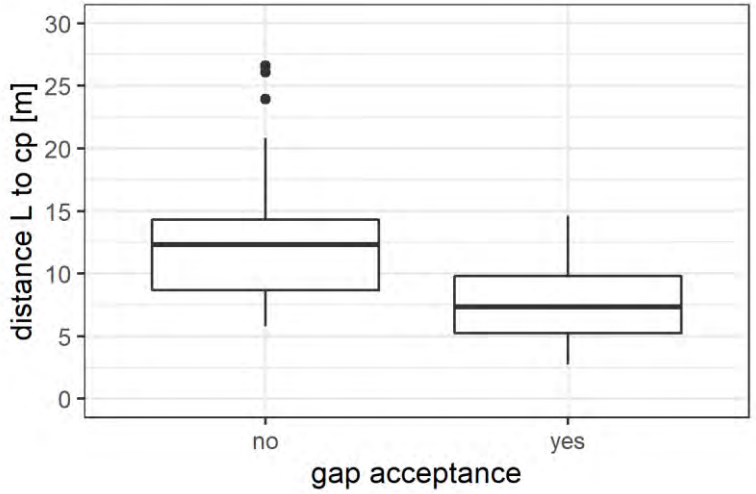
Parameter	Estimate (SE)
Intercept	0.85 (3.12)
Distance to CP L	-0.73*** (0.18)
Velocity L	1.73*** (0.45)
Acceleration L	2.56** (0.88)
Waiting time L	0.19 (0.16)
Velocity O1	0.21 (0.19)
Acceleration O1	0.13 (0.78)

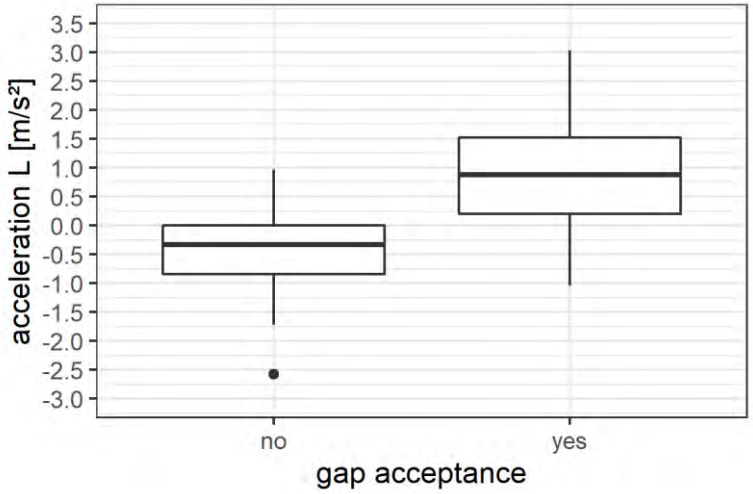
*** p < .001, ** p < .01., * p < .05, ° p < .10



Significant Predictors: Distance to CP, Velocity and Acceleration of L when O1 Crosses Future Path of L







Accepted gaps are characterized by

- Higher velocity
- Shorter distance to crossing point
- Higher acceleration

→ by the time O1 crosses path of left-turning vehicle, decision to turn seems to be made

Summary and Application of Results

Gap acceptance was predicted by the

- Behaviour of oncoming traffic (time gap, velocity, acceleration) → adaption, underestimation
- Behaviour and position of left-turning vehicle (velocity, acceleration, distance) → decision making

Predicting a left-turning vehicle's behavior, i.e. gap acceptance, will help…

…oncoming traffic to

- prepare safety maneuvers
- adapt driving behavior to support left-turning vehicles

…left-turning vehicles by

- sending support messages at an appropriate time, e.g.
  - before the decision to turn is made
  - if a safety-critical decision was made

Thank you for your attention!

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