Communication and Interaction between Automated
Vehicles and other Road Users

Academic symposium/workshop organized by the

PIRE Project SD-SSCPS

„Science and Design of Societal Scale CPS“

Washington DC, October 30-31, 2018

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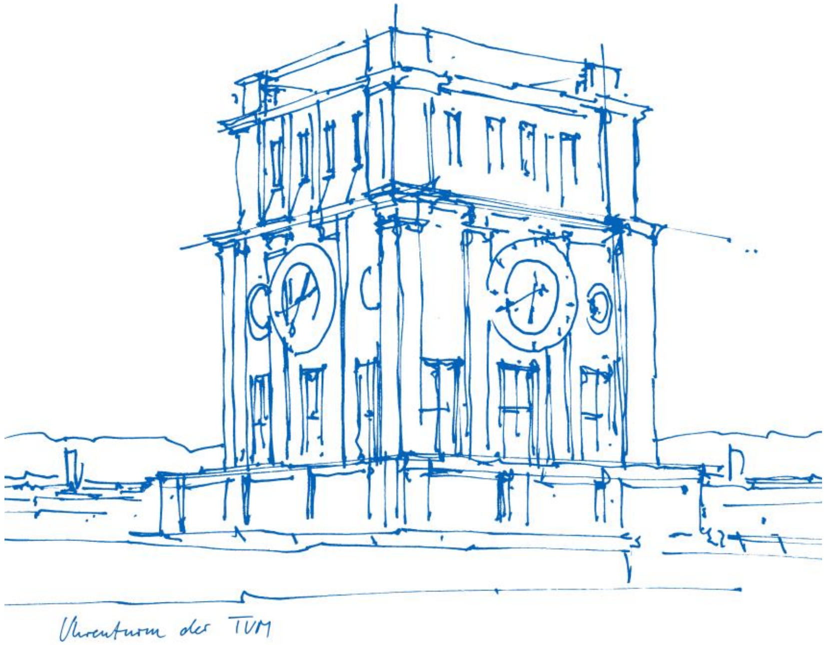
with contributions of J.Schmidtler, J.Reinhart,

C.Gold, D.Damböck, M.Kienle, D.Bortot



KOOPERATIVES HOCHAUTOMATISIERTES FAHREN

What is the driver's state and role?
Integration and Validation of
non-driving related activities
Concept and design of transitions

Gefördert durch:

Bundesministerium für Wirtschaft und Energie

aufgrund eines Beschlusses des Deutschen Bundestages

http://www.ko-haf.de/startseite/

WP3 – Central questions

For how long may the driver attend to non driving related activities?
For how long can the driver stay attentive
How long does it take until the driver can take over the driving task in case of a sudden disturbance?
The heterogeneity of the transitions is increasing – Does the system remain operable?

Ironies of automation

“Automated systems still are man-machine systems, for which both technical and human factors are important.”
(Bainbridge, 1983)

“… the irony that the more advanced a control system is, so the more crucial may be the contribution of the human operator.”

KOOPERATIVES HOCHAUTOMATISIERTES FAHREN

Definition of take-over situations

			Prädizier-barkeit	Dringlich-keit	Kritika-lität	Fahrer-reaktion	
Normalfahrt	Sensorausfall "Total": alles fällt aus	Sensorausfall vor Kurve					2
		Sensorausfall auf Gerade					2
Abfahren von der AB	Spurwechsel auf den Verzögerungsstreifen nicht möglich	Dichter Verkehr					3
Durchfahren eines AB-Kreuz	Spurwechsel im AB-Kreuz nicht mgl.	Dichter Verkehr					3
Auffahren auf die AB	Spurwechsel beim Auffahren auf die AB nicht möglich	Dichter Verkehr					
Engstelle	Engstelle erst durch Umfeldsensorik erfasst						2
Passieren von Gefahrenstellen	Taktische Gefahrenstelle klassifizierbar, aber nicht umfahrbar (Bsp.: Fußgänger, Tiere…) / nicht klassifizierbar	Objekt auf dem eigenen Fahrstreifen (z.B. Unfall)					1
		Objekt auf einem anderen Fahrstreifen (z.B. Unfall)					

1: alles worst case: hoch dringlich, kritisch und komplexe Fahrerreaktion

2: niedrigere Komplexität der Fahrerreaktion, teilweise geringere Kritikalität

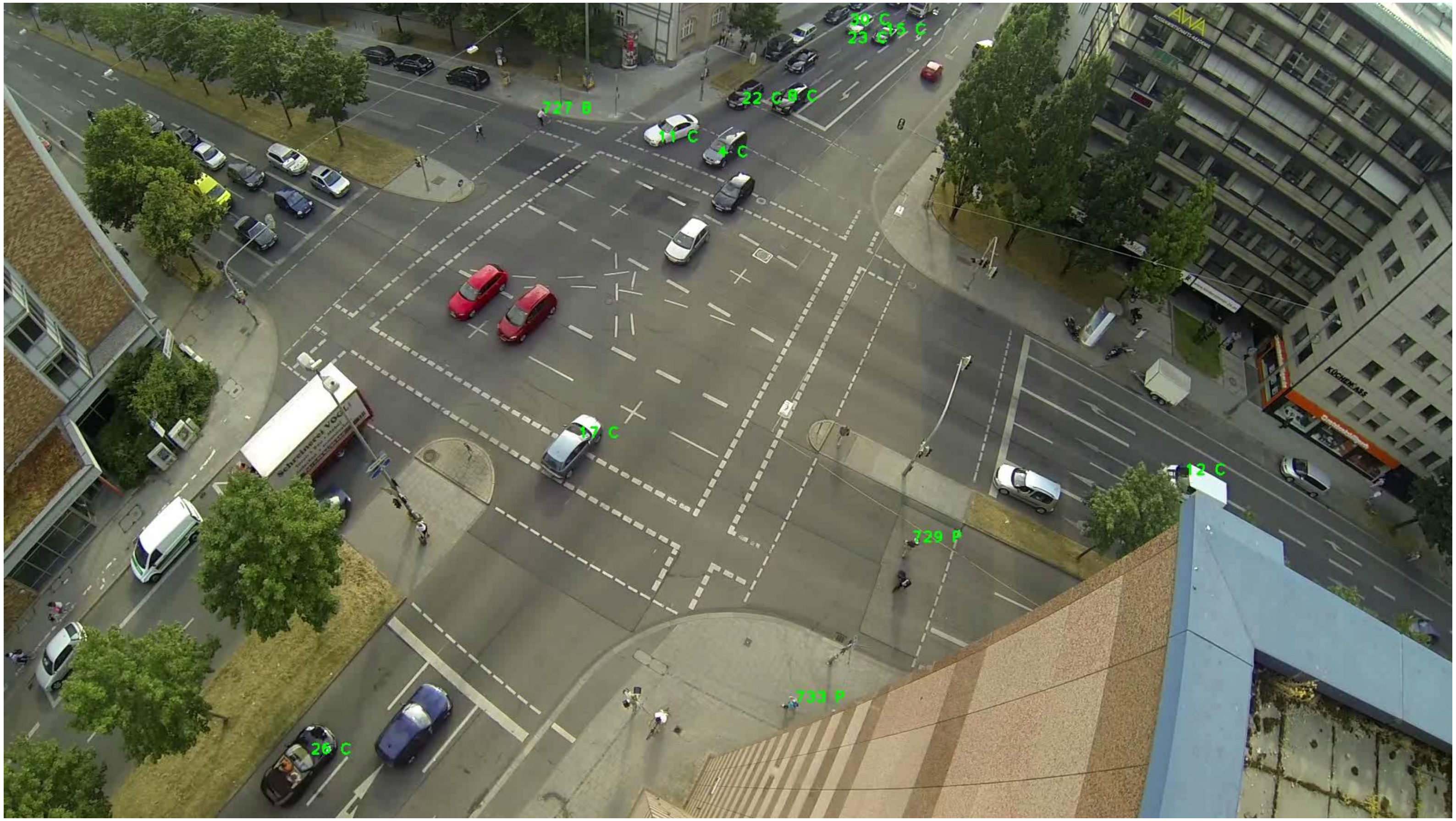
3: höhere Prädizierbarkeit, geringere Kritikalität, Komplexität der Fahrerreaktion hoch

In den empirischen Studien zu Einflussvariablen der Fahrerverfügbarkeit auf die Übernahme sollten mind. je eine Situation der Gruppe 1 und 2 enthalten sein, optional eine Situation der Gruppe 3.

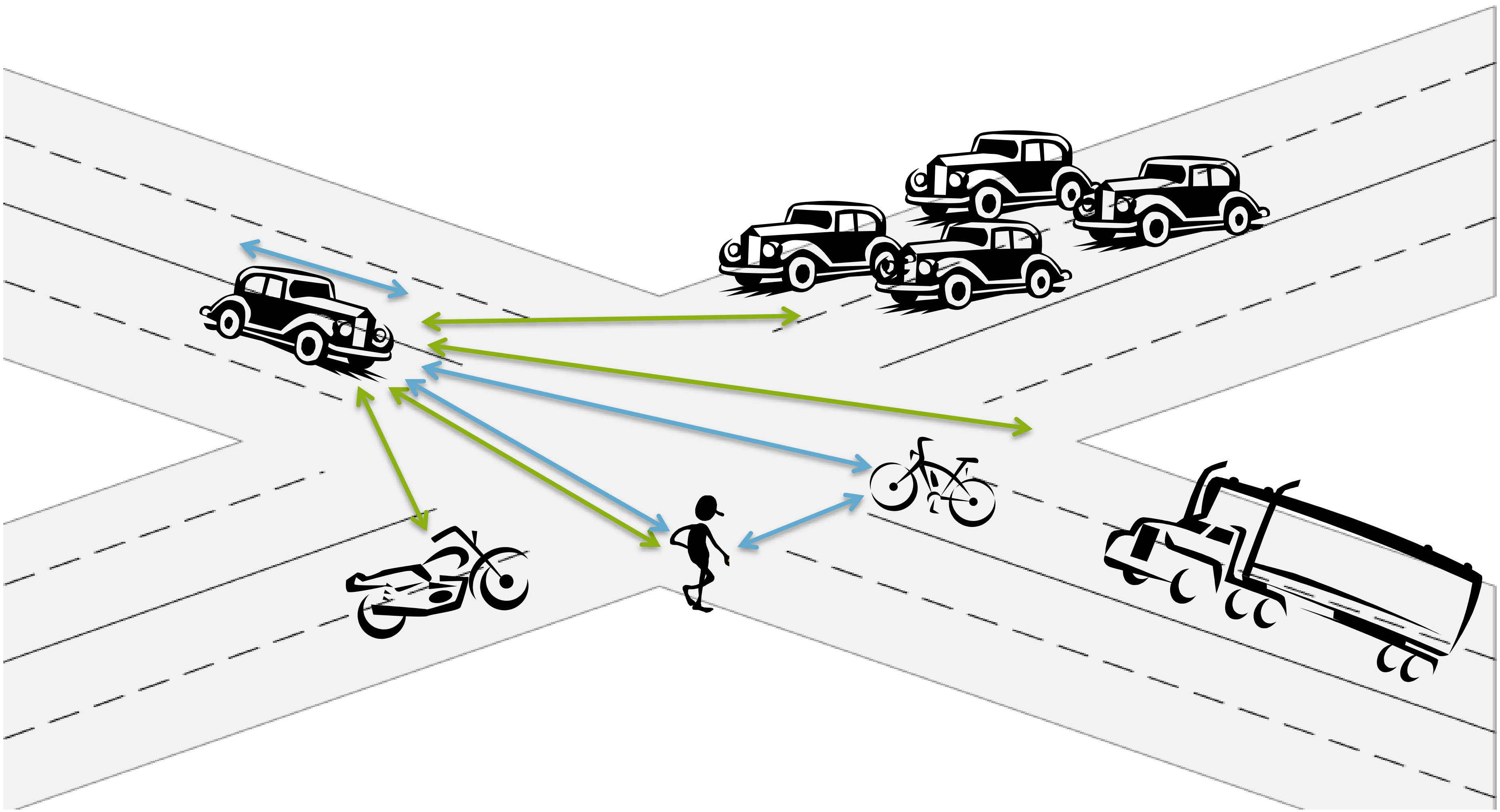
Identification of **six** possible and reasonable take-over situations for the workpackage 3 experiments.

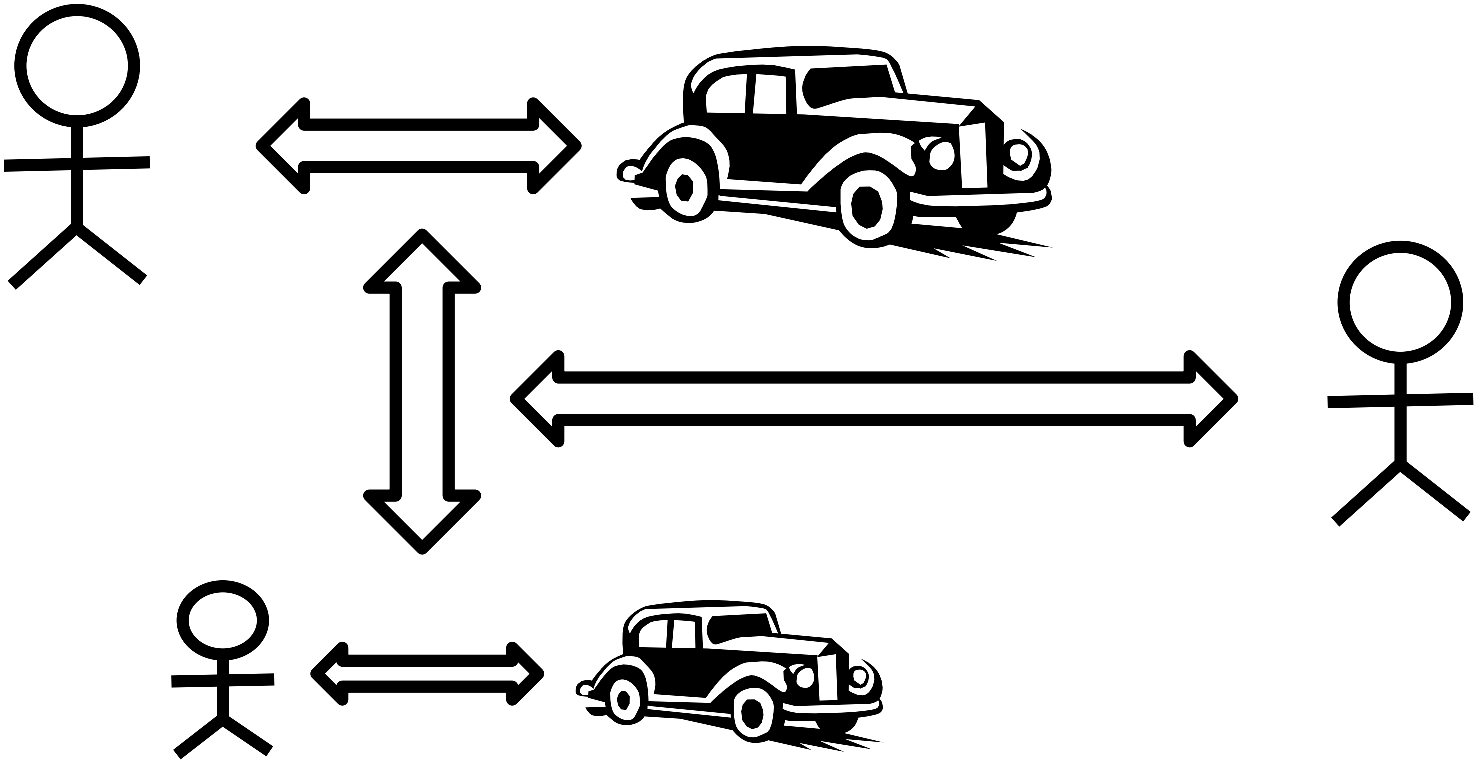
Construction Site			
Urgency	**Predictability**	**Criticality**	**Complexity**
high	low	low – medium	low – medium

We are able to do this – Why change

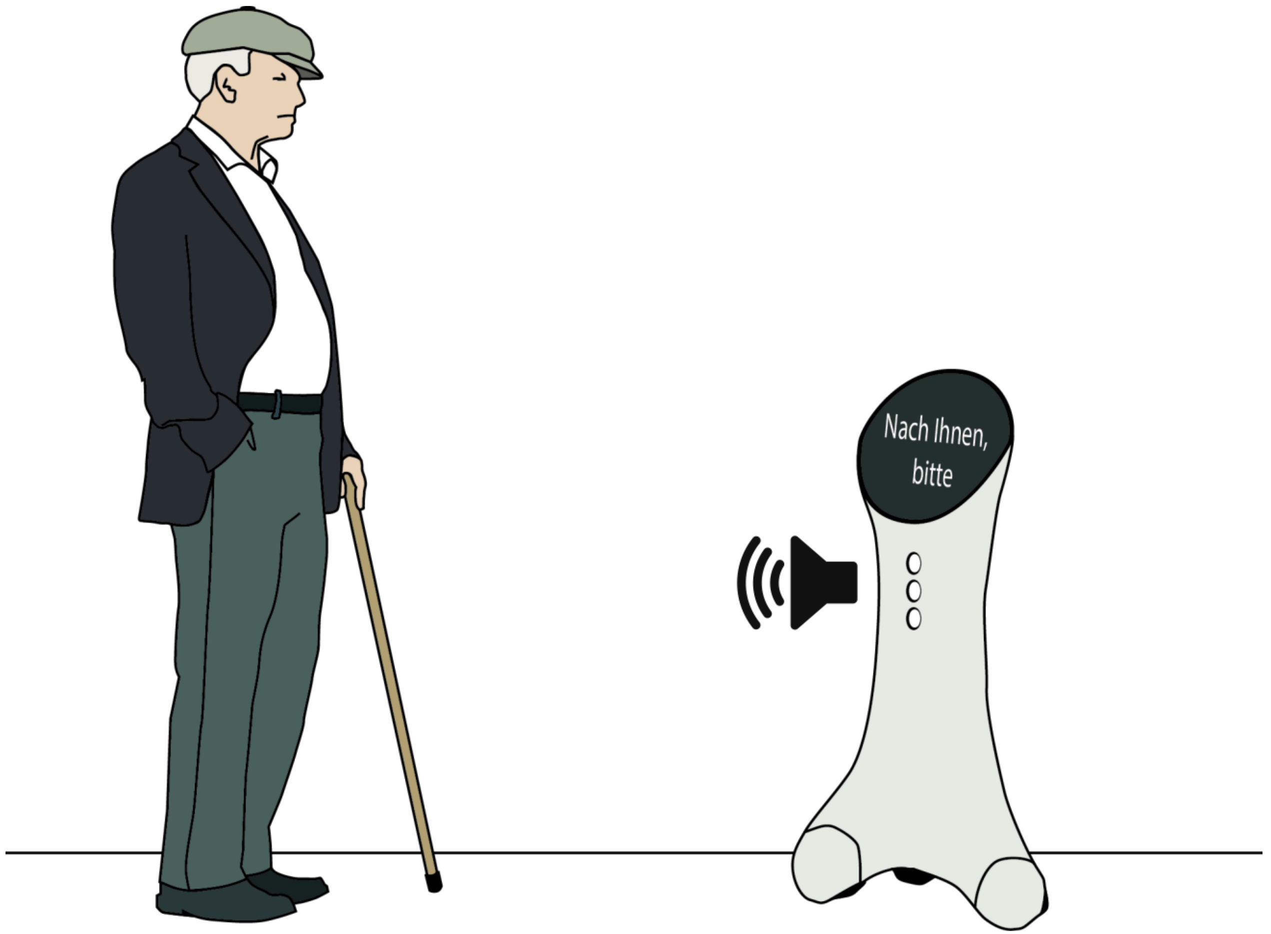


33:40 Sinfonie der Großstadt
https://www.bing.com/videos/search?q=sinfonie+der+gro%c3%9fstadt&&view=detail&mid=12FA1B07F39B9EF726DA12FA1B07F39B9EF726DA&FORM=VRDGAR

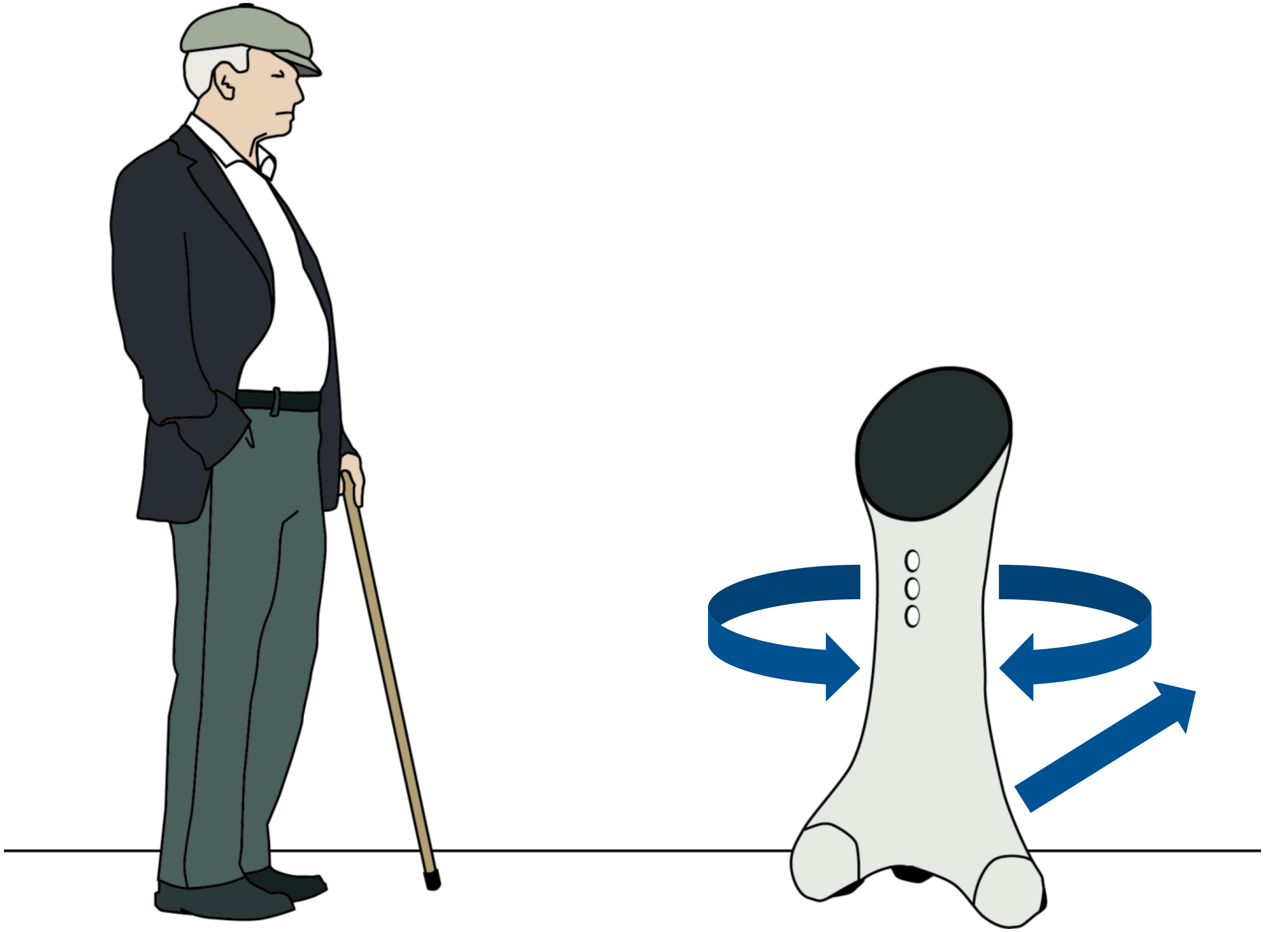




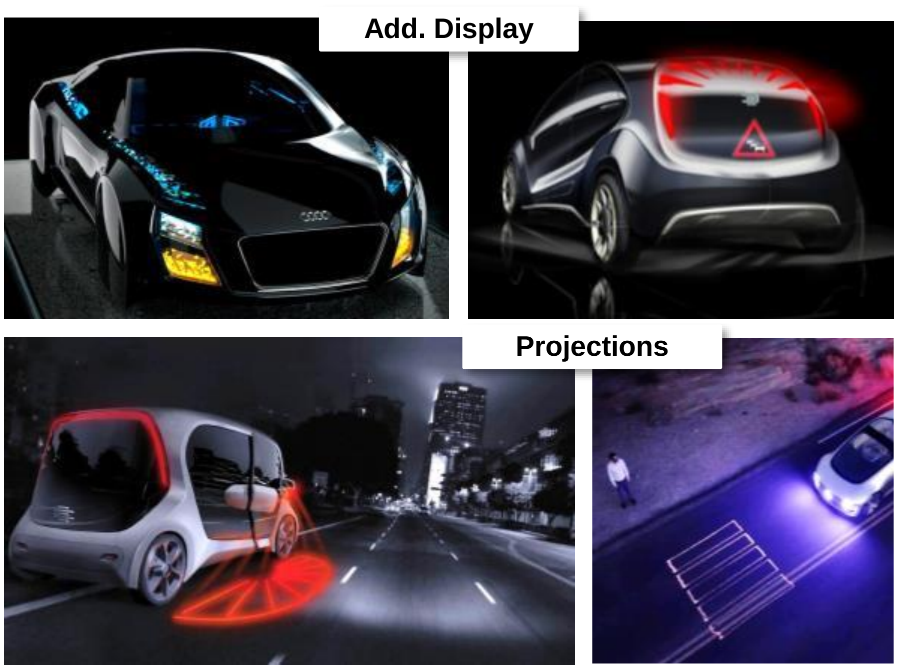
Explicit Communication

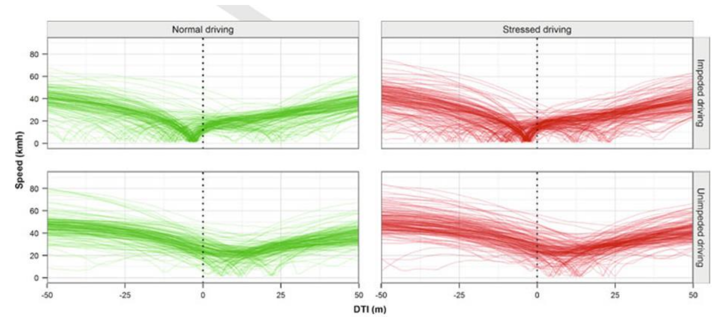


Implicit Communication



Current OEM Concepts





-> everything based on and embedded in a running system

German Activities

- UR:BAN (Driver Assistance in urban areas) (2012 - 2016)
- BaSt „Kommunikation zwischen Verkehrsteilnehmern: Einfluss zunehmender Fahrzeugautomatisierung“
- IMAGINE (Cooperative Manouvers on Motorways) (2016 - 2020)
- Pedsival – Validation of Pedestrian Simulators (IFSSTAR – TUM) (2017 ->)

- inter:ACT EU-Project (Designing cooperative interaction of automated vehicles with other traffic participants in mixed traffic environments) (2017 - 2021)
- DFG SPP (2016 ->). Interaction between AV and VRU (Prof. Krems)
- Konvoy Project
- KOLA – Kooperativer Laserscheinwerfer (11/2016 - 10/2019)
- Unicaragil – Autonomous Driving
- @city – Urban Automated Driving (2018 ->)

Publication Fuest et al. (2017): Taxonomy of Relevant Traffic Situations

- classifies the **interaction** between an automated vehicle (AV) and a human road user (HRU)
- provides an overview over relevant **attributes** and related **value facets** that may influence the **communication** between the AV and the HRU
- can be used to choose attributes and value facets which are relevant for a specific research question

Taxonomy - Application

“How quickly can the AV’s intention regarding the ***right of way*** *be expressed by using a* ***targeted design of the trajectory****?”*

Right of way

AV’s intention regarding right of way

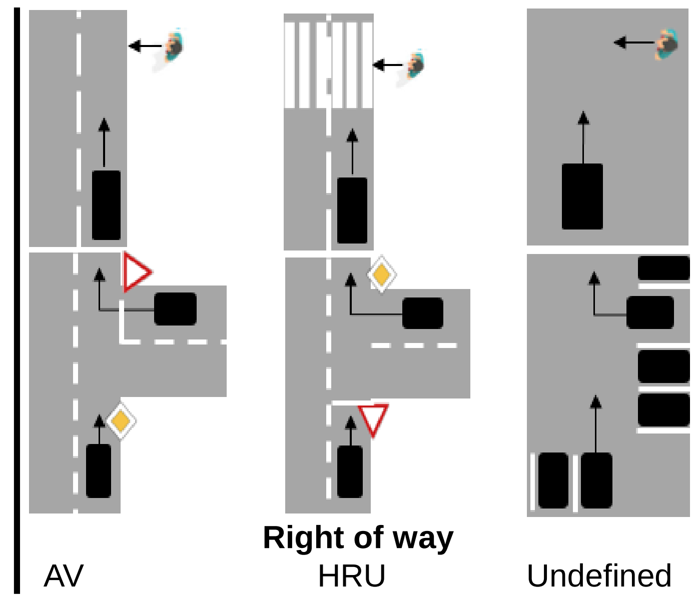
HRU character

Longitudinal distance

Speed AV

Attention HRU

Impairment of the HRU’s perception



Taxonomy - Benefits

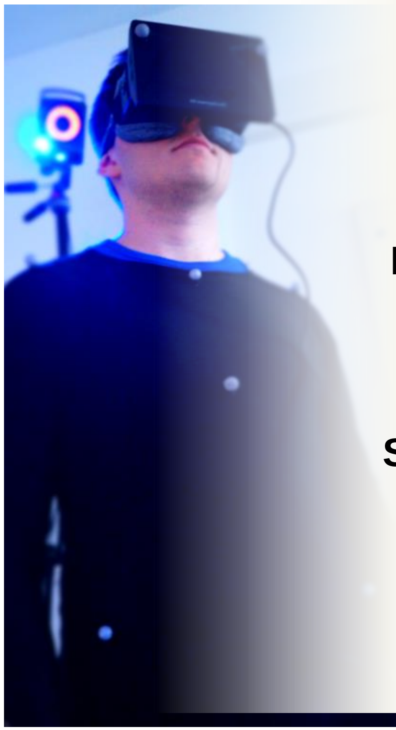
- facilitates a systematic definition of traffic situations, which ensures that all **relevant aspects** are addressed when eliciting requirements or validating concepts
- helps to **identify potential confounders** and to increase the **comparability** between different studies

Reference

Fuest, T. / Sorokin, L., Bellem. H. & Bengler, K. (2017). Taxonomy of traffic situations for the interaction between automated vehicles and human road users. In Applied Human Factors and Ergonomics. In Proceedings of the 8th International Conference on Applied Human Factors and Ergonomics (AHFE 2017) and the Affiliated Conferences, July 17-21, Los Angeles, USA. In press

Song, Y. E.; Lehsing, C.; Fuest, T.; Bengler, K.: External HMIs and their Effect on the Interaction Between Pedestrians and Automated Vehicles. Intelligent Human Systems Integration, Springer International Publishing, 2018 Dubai

Lab Study Dietrich et al.: Pedestrian Simulator



Platform using Unity and any supported HMD and Motion Tracker

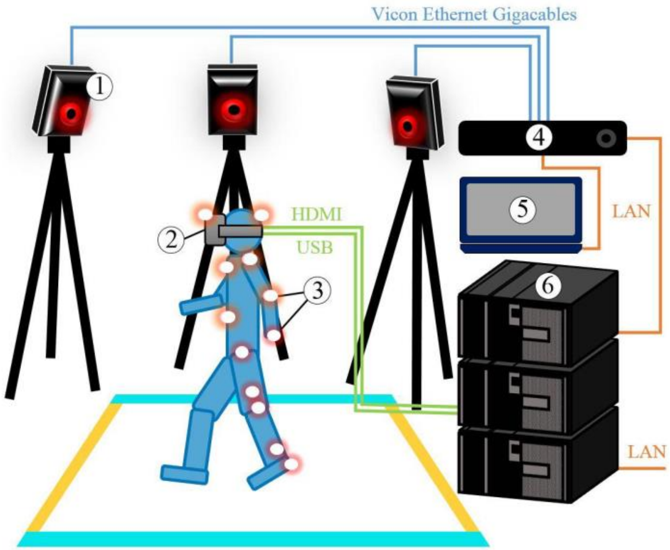
Simple generation of different traffic scenarios

Full control of traffic related variables

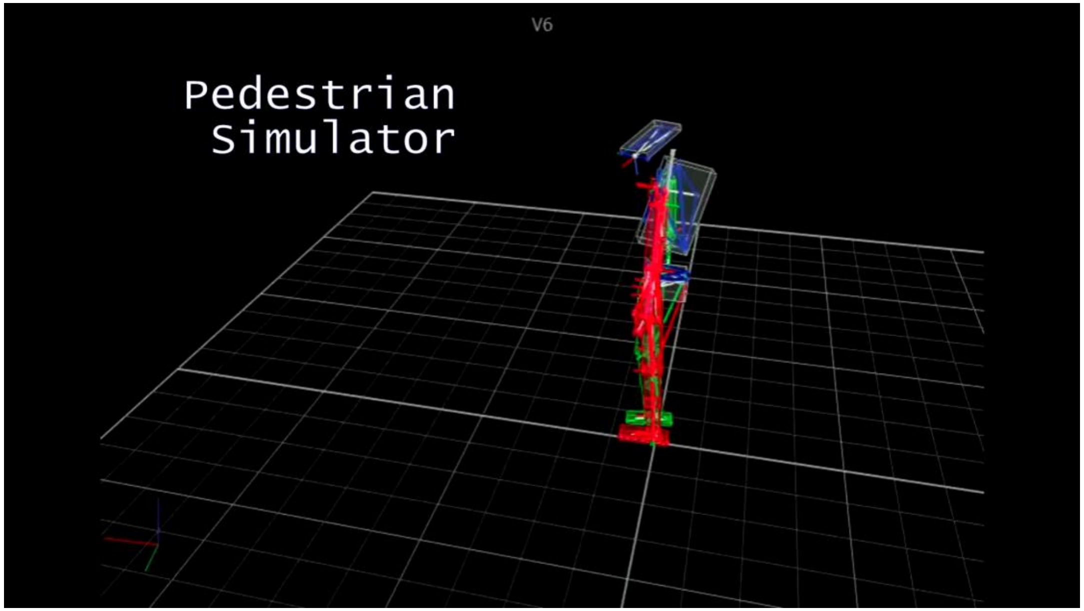
- How to implement a methodology to investigate interaction and cooperation between traffic participants? (non-assisted cars, assisted cars, VRUs)
- Definition of suitable analysis tools and metrics to quantify interaction and cooperation

Pedestrian Simulator – UR:BAN

UR:BAN



Research on Interactions between Vehicles and VRUs



Lab/Method:

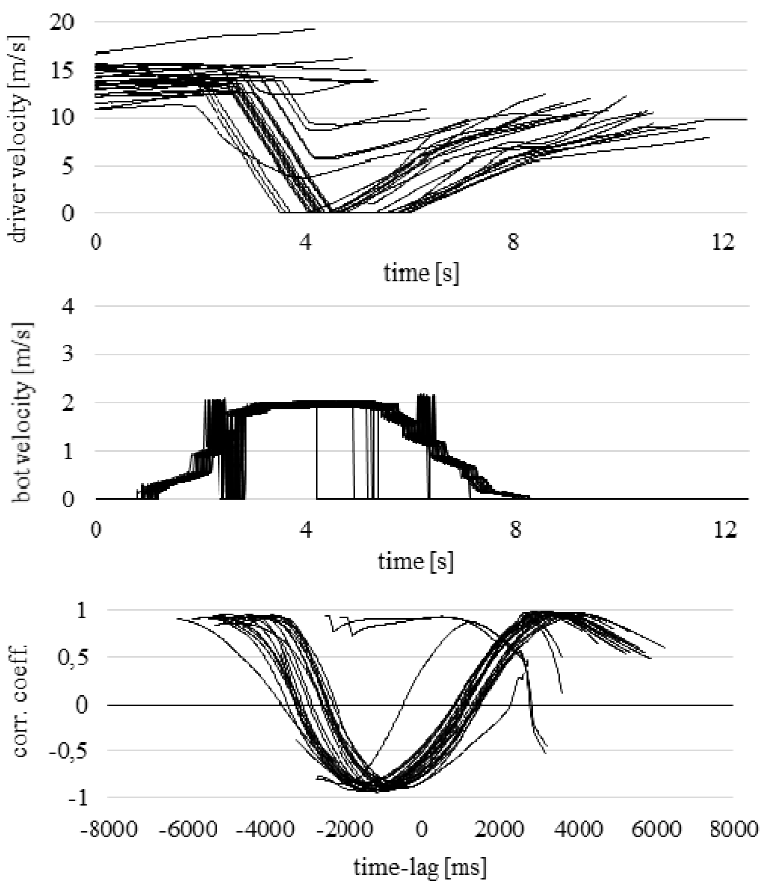
UR:BAN Connected Simulation

(Lehsing, Kracke, Bengler 2015)

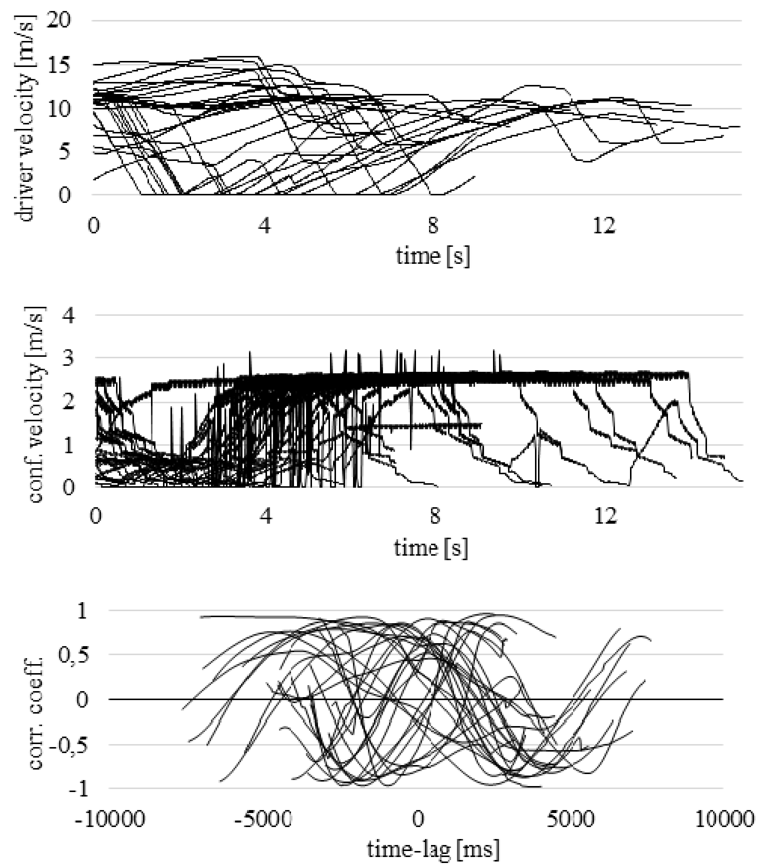
Results – Free Lane

Programmed pedestrian vs. car

Human pedestrian vs. car



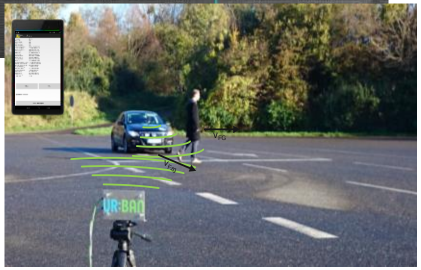
$R_{XY}(\tau)$



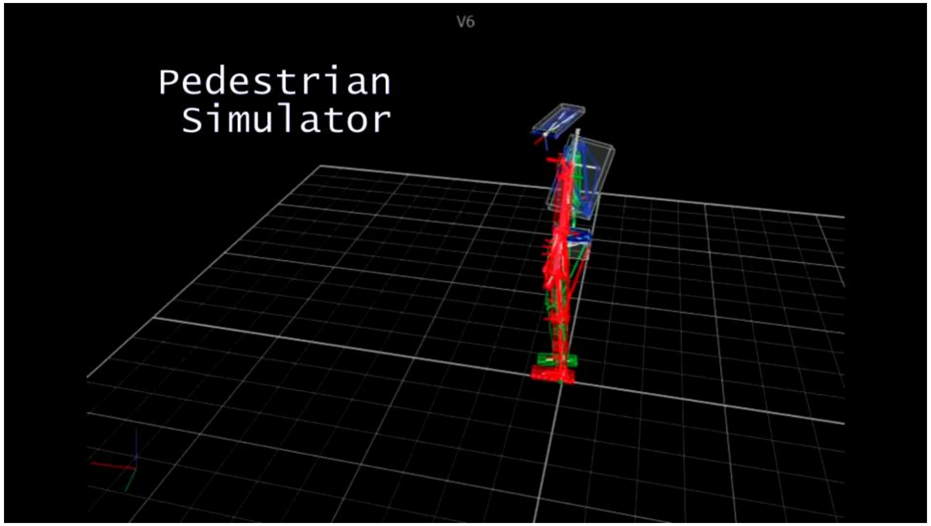
(Lehsing, Kracke, Bengler 2015)

Research on Interactions between Vehicles and VRUs

Field Data



Testbed Aachen



Pedestrian Simulator TU München

Pedestrian Simulator – Research Questions

How do pedestrians perceive different types of automated vehicles?

What **implicit** and **explicit** communication strategies of automated vehicles are intuitive and comprehensible for pedestrians?

Design

Timing

Message

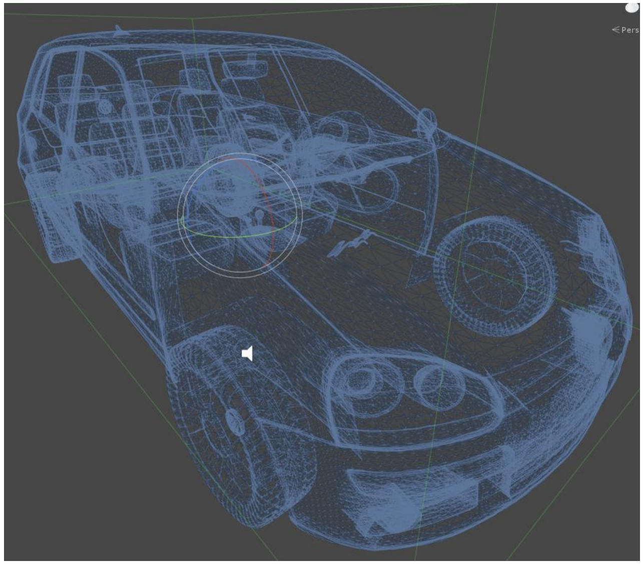
Position

Lighting

AV Simulation - Unity

Kinematic movement of Vehicles

Path Following with changable inputs for speed, acceleration and jerk



Controllable Pitch, Roll and Yaw

Standard vehicles have independent simplified dynamics

Simplified AI

Vehicles brake to avoid collisions along predefined path

Drag and Drop…

to import virtual environments and vehicle models as well as creating multiple paths

Pedestrian Simulator - Scenarios

- Simple implementation of behavioral routines, such as braking and evasive maneouvres
- Animations of various external HMI concepts
- Evaluation of outward appearance of automated vehicles

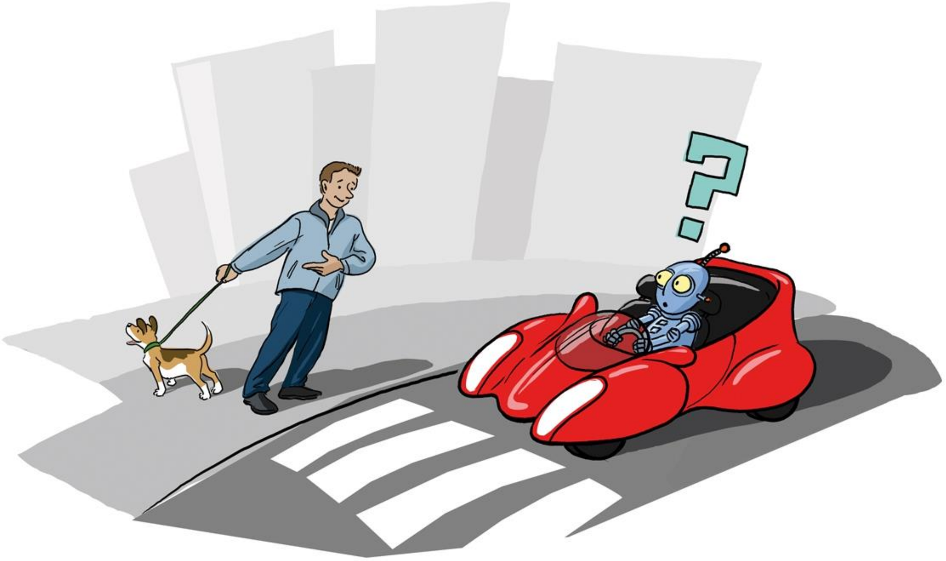


https://nemo-responsive-image.live.cf.public.springer.com/v1/resize/width/%7Bwidth%7D/%7Bpixel_ratio%7D/url/http:/resource-cms.springer.com/springer-cms/rest/v1/img/6509180/v3/4by3

Legible Movements of automated mobile Systems

Communication of Intentions, Actions and system states

- Explicitly via displays etc.
- Implicitly via movements



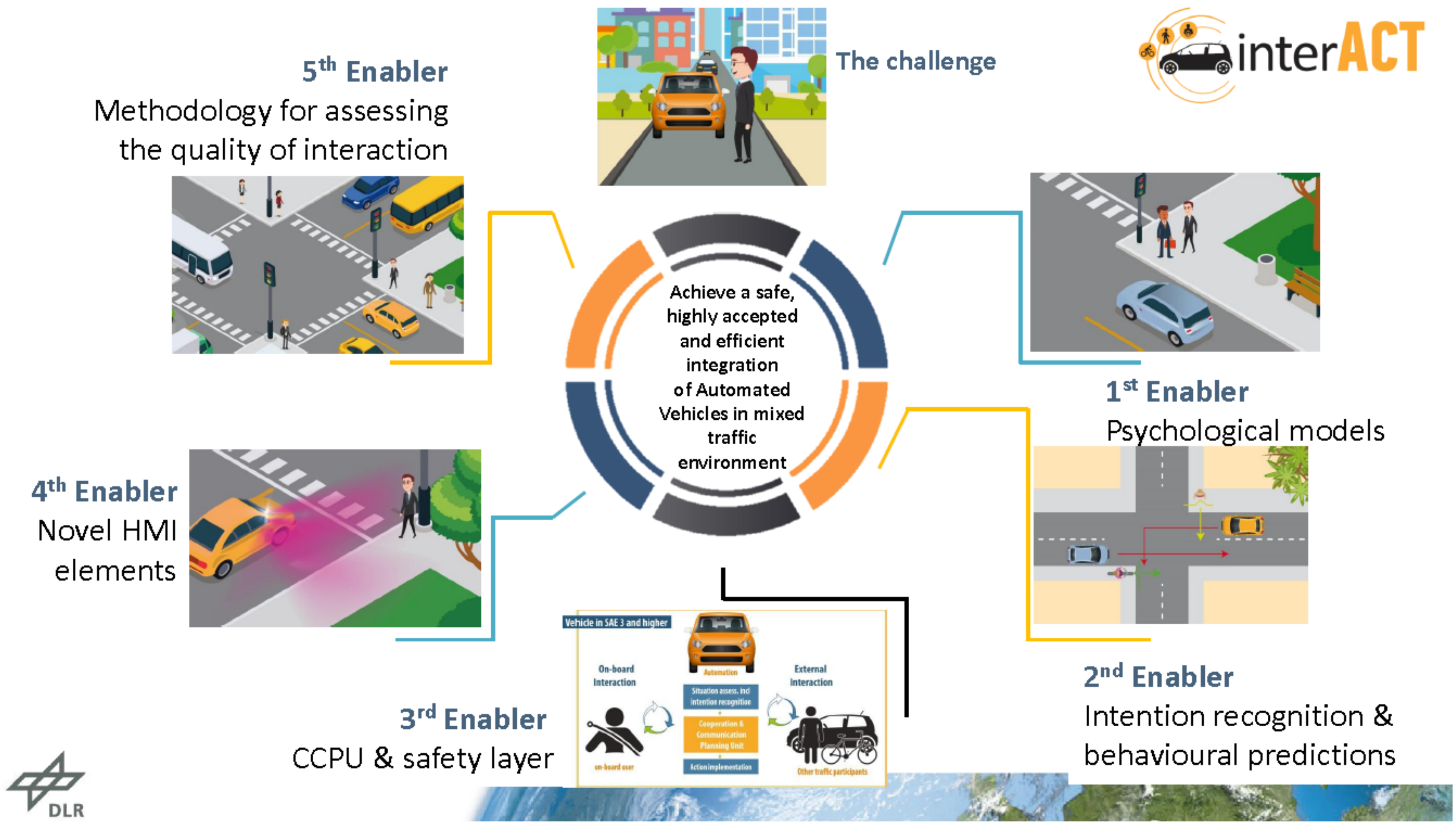
Legibility – “Robot behavior is legibile if:

- (factor 1) a human observer or interactor is able to understand its intentions, and
- (factor 2) the behavior met the expectations of the human observer or interactor.”

  (Lichtenthäler & Kirsch, 2016)

Reading:

Lichtenthäler, C., & Kirsch, A. (2016). **Legibility of Robot Behavior : A Literature Review**. Retrieved from https://hal.archives-ouvertes.fr/hal-01306977/



https://www.interact-roadautomation.eu/

Dietrich Plattform

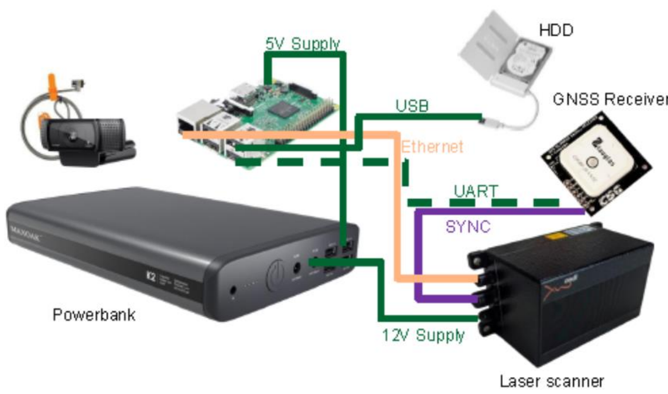


Figure 21: System structure of the ibeo LUX observation box

To synchronize the LiDAR measurements with video observation and observation protocols, the accurate UTC timestamp provided by GNSS receiver was also recorded on the HDD.

Figure 22: Depiction of the finalized prototype used by Observers in Leeds

interACT D2.1 Interactions in Traffic Version 0.7 Date 31/08/17 Page | 33

Dietrich, A.; Ruenz, J.: Observing Traffic -- Utilizing a Ground Based LiDAR and Observation Protocols at a T-Junction in Germany. Proceedings of the 20th Congress of the International Ergonomics Association (IEA) 2018, Springer, Cham, 2018

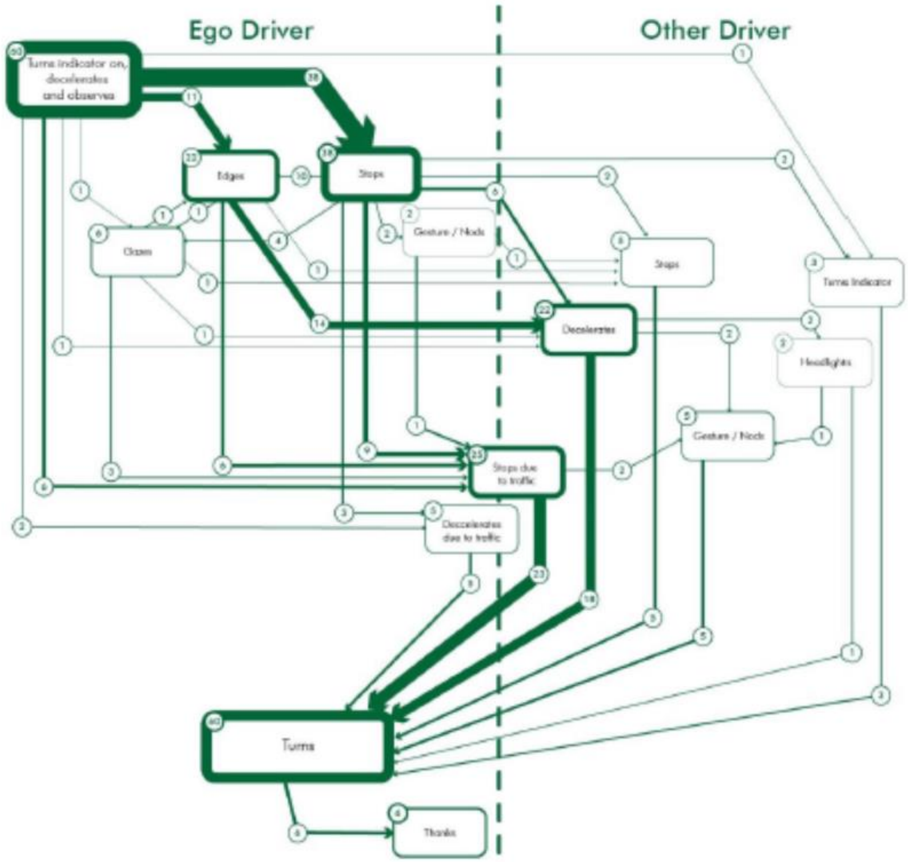


Figure 39: Sequences of observed signals/cues in interactions between drivers relevant to right turns

Design considerations for automated vehicles

Which information could be needed by other road users?

- Category A: **Vehicle driving mode**
  - Automated or manually driven vehicle
- Category B: **Vehicle's next manoeuvres**
  - E.g. Vehicle will start moving
- Category C: **Perception of environment**
  - E.g. pedestrian is detected
- Category D: **Cooperation capability**
  - E.g. Vehicle willing to cooperate, gives right of way

Cited from *Schieben, Wilbrink, Kettwich, Madigan, Louw & Merat* (2018): Designing the interaction of automated vehicles with other traffic participants: Design considerations based on human needs and expectations. Cognition, Technology and Work. pp 1-17. https://doi.org/10.1007/s10111-018-0521-z

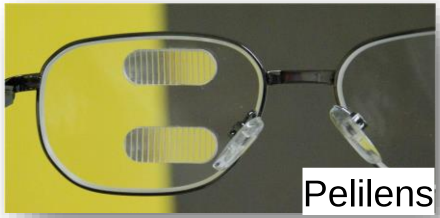
RECHTE DER INHALTE VERBLEIBEN BEIM LEHRSTUHL FÜR ERGONOMIE TU MÜNCHEN

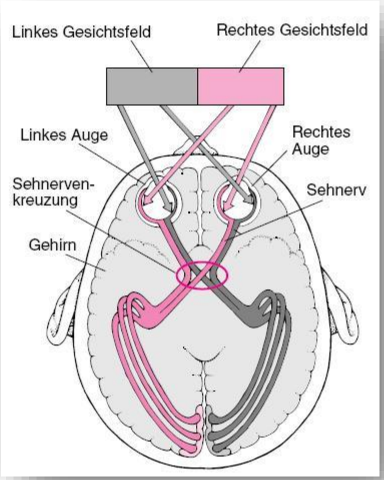
Overall findings

- The occurrence and necessity of interactions depends on the situation and a variety of **other factors**, such as traffic density, time of day and specific traffic conditions
- **Explicit communication (e.g. gesturing, flashing lights etc.) happens rarely** - most potential interaction-demanding situations are resolved before they actually arise, mostly by adjusting *kinematic motion*
- **Cooperation, communication** and thus **interaction** between human road users takes place at **low speeds**, usually below 20 km/h
- At **higher speeds, conflict avoidance** is predominant – pedestrians use large enough inter-vehicle gaps to cross without expecting the second vehicle to adapt

Current Activities

- Influence of Hemianopia on Interaction behavior
- Quantification using simulation
- Evaluation of assistance systems





Hemianopia

Quadrantanopia

Impaired Vision and Individual Mobility

Increase of average age

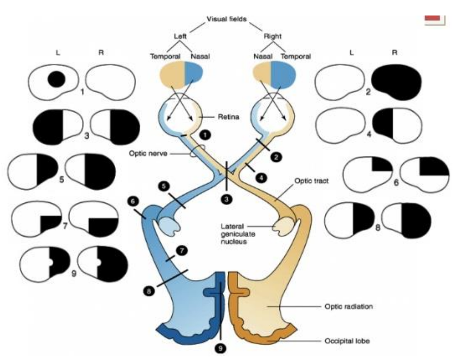
Correlation between age and vision

Increase of impaired vision at ages > 55+

Vision as basis for driving task

→ Impaired mobility with increasing age

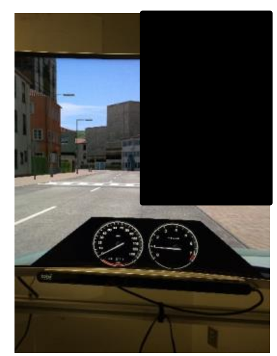
Cooperation between TUM Chair of Ergonomics und Harvard Medical School
Investigation of interaction performance with Katarakt, Anopia in urban traffic (esp. Interaction with pedestrians)

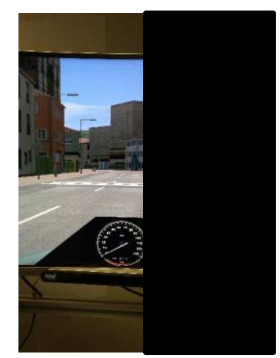


Locations of impairment


normal


Katarakt

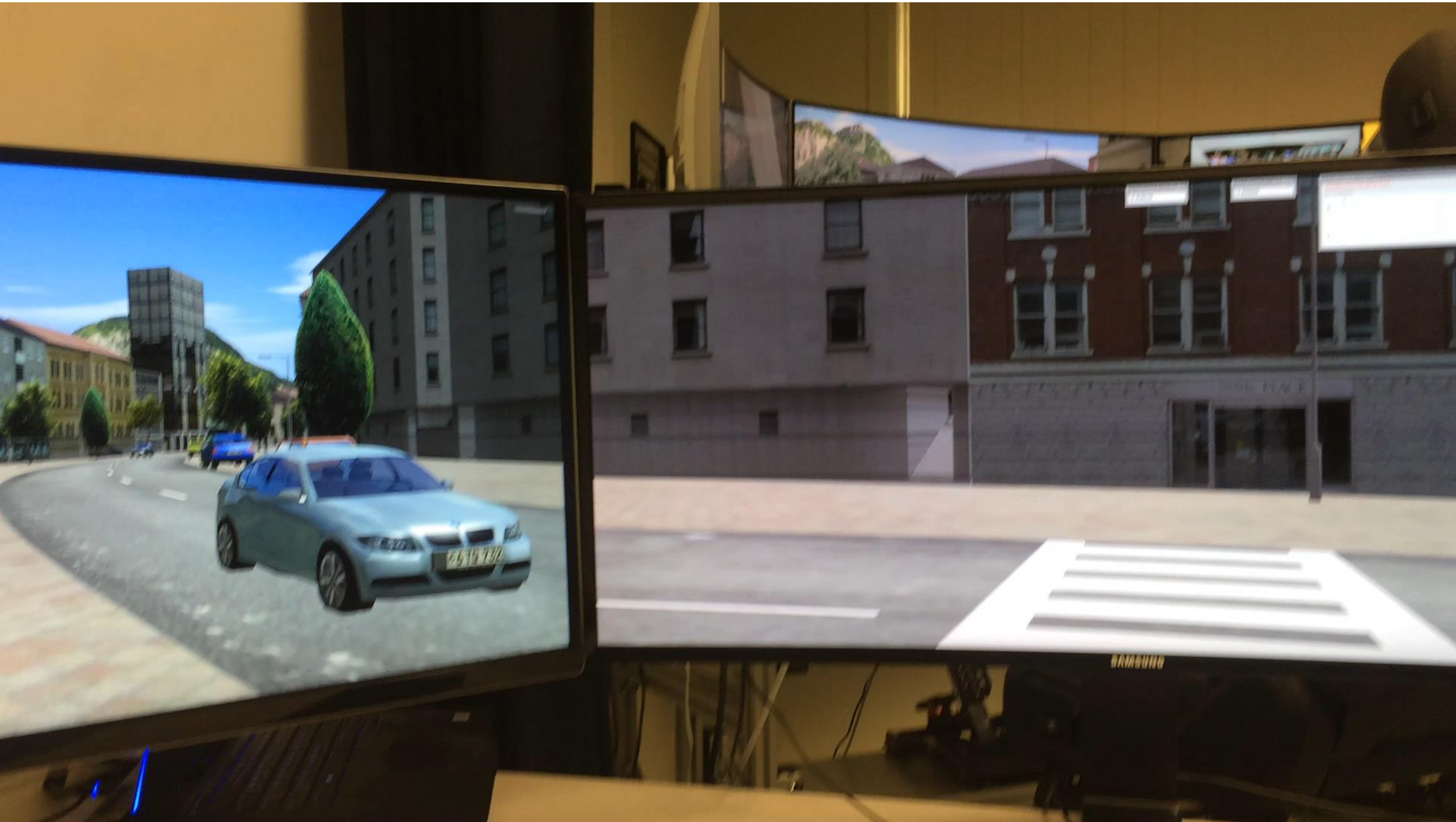

Quadranopsie


Hemianopsie

Simulated Impairment Study

Simulated Impairment Study

Simulated Impairment Study



Simulated Impairment Study

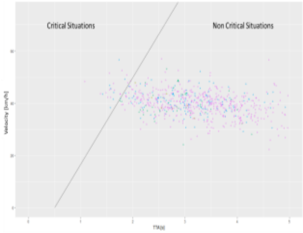
- RQ: What is the influence of a changed visual performance on Interaction behavior?

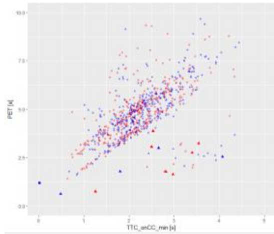
+

=

• UV:	Type of pedestrian	(Realistic vs. BOT)
	Type of scenario	(directed vs. Non directed)
	Visual ability	(normal vs. reduced)

• AV:	TTC, PET, DST_3	(classical analytics)
	KKK, Lag	(Time series analysis)
	FT, BBPerc, FBT	(Visual behavior)
	DOCTOR / STCT	(Traffic conflict analysis)



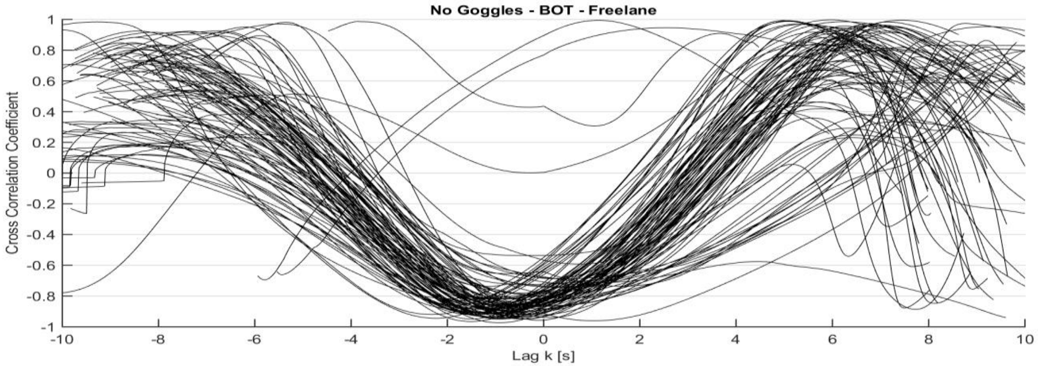


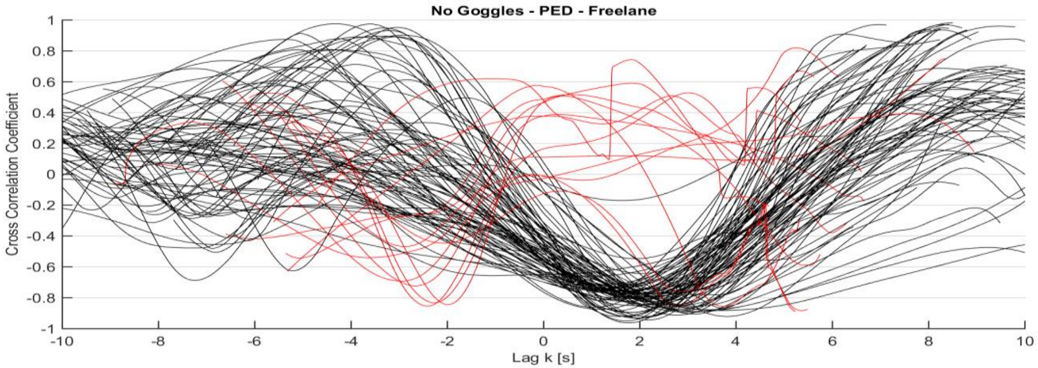
Simulated Impairment Study

Analysis – TTC_{min}

Simulated Impairment Study

Cross correlations





Christian Lehsing

Definition der Automationslevels - SAE

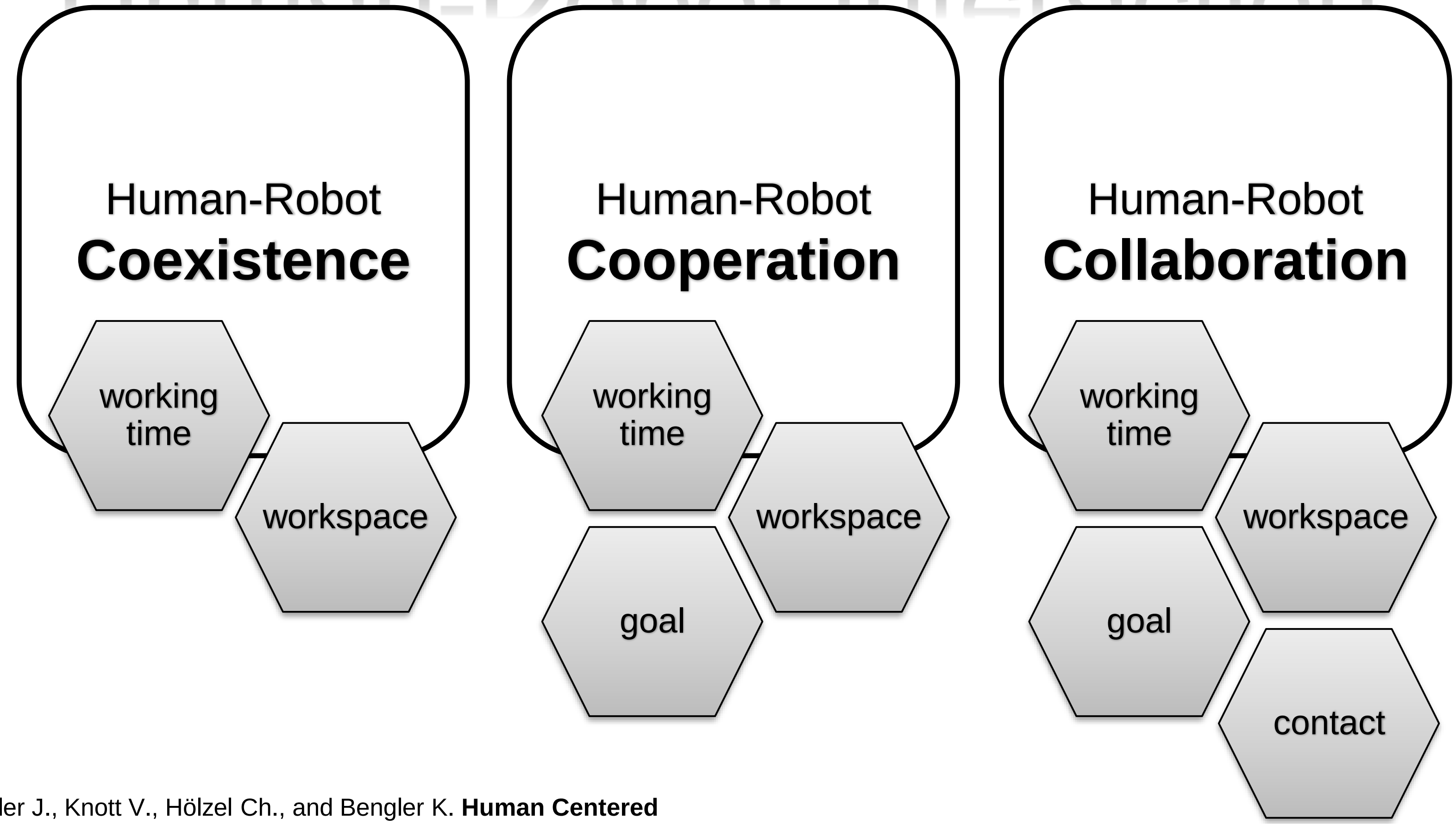
Summary of Levels of Driving Automation for On-Road Vehicles

This table summarizes SAE International's levels of *driving* automation for on-road vehicles. Information Report J3016 provides full definitions for these levels and for the italicized terms used therein. The levels are descriptive rather than normative and technical rather than legal. Elements indicate minimum rather than maximum capabilities for each level. "System" refers to the driver assistance system, combination of driver assistance systems, or *automated driving system*, as appropriate.

The table also shows how SAE's levels definitively correspond to those developed by the Germany Federal Highway Research Institute (BASt) and approximately correspond to those described by the US National Highway Traffic Safety Administration (NHTSA) in its "Preliminary Statement of Policy Concerning Automated Vehicles" of May 30, 2013.

Level	Name	Narrative definition	Execution of steering and acceleration/ deceleration	Monitoring of driving environment	Fallback performance of *dynamic driving task*	System capability (*driving modes*)	BASt level	NHTSA level
***Human driver* monitors the driving environment**								
0	No Automation	the full-time performance by the *human driver* of all aspects of the *dynamic driving task*, even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a	Driver only	0
1	Driver Assistance	the *driving mode*-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	Human driver and system	Human driver	Human driver	Some driving modes	Assisted	1
2	Partial Automation	the *driving mode*-specific execution by one or more driver assistance systems of both steering and acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	**System**	Human driver	Human driver	Some driving modes	Partially automated	2
***Automated driving system* ("system") monitors the driving environment**								
3	Conditional Automation	the *driving mode*-specific performance by an *automated driving system* of all aspects of the *dynamic driving task* with the expectation that the *human driver* will respond appropriately to a *request to intervene*	System	**System**	Human driver	Some driving modes	Highly automated	3
4	High Automation	the *driving mode*-specific performance by an *automated driving system* of all aspects of the *dynamic driving task*, even if a *human driver* does not respond appropriately to a *request to intervene*	System	System	**System**	Some driving modes	Fully automated	3/4
5	Full Automation	the full-time performance by an *automated driving system* of all aspects of the *dynamic driving task* under all roadway and environmental conditions that can be managed by a *human driver*	System	System	System	**All driving modes**	-	

Human-Robot Interaction



Schmidtler J., Knott V., Hölzel Ch., and Bengler K. **Human Centered Assistance Applications for Manufacturing Systems of the Future**, to appear in *Occupational Ergonomics (special issue)*, 2015.

Conclusions

- Current taxonomies of AD do not take into account cooperation between traffic participants
- Implicit communication plays a dominant role for interaction between traffic participants
- There is a dilemma of consistency of eHMI of the near future and the existing knowledge for their design and usage
- No clear indication can be given for explicit communication
- Explicit communication should not be the remedy for insufficient realization of AV functionality
- Need for investigations on drivers with special characteristics