Task A / WP 1　Research Summary

Human Factors : HMI and User Education CAD GermanyJapan HF

Oct 2022

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Realization of safe, secure, and smooth communication between automated driving vehicles and surrounding traffic participants

Understanding communication

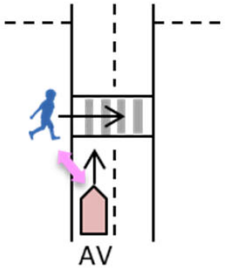
Low-speed automated driving (transportation and logistics services)

Communication

Pedestrian

- Single path
- Intersection
- Parking

(shared space)

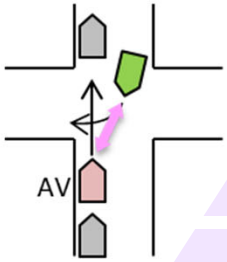


Communication

Design guidelines

- Intent to communicate
- means of communication
  - Vehicle behavior
  - External HMI
  - Roadside facility
  - Road marking
- Traffic participant education

Driver



Evaluation of effectiveness

social acceptability

Security

Smooth traffic

safety

Influence of attributes of traffic participants

Influence of transportation society and culture

Effects of eHMIs on interaction between automated vehicles and pedestrians

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Key conclusions from our studies

eHMIs influence pedestrians' interaction with vehicles.

Traffic context (e.g., traffic regulation, model behavior) helps to interpret eHMIs correctly.

Motion dynamics of the vehicle (e.g., approach speed) remain an important factor in interactions when eHMIs are present. At the same time, eHMIs can have effects even when they are not activated.

Messages about an AV's intention (e.g., I am yielding) can lead to safer crossing behavior than messages about an AV's current behavior (e.g., I am braking).

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WP1
– TU Chemnitz (TUC)

CAD JAPAN & GERMANY HUMAN FACTORS

Scan for project website & publications

The focus of TUC within the scope of the CADJapanGerman:HF project was the **interaction between automated vehicles (AVs) and cyclists investigating formal and informal communication signals**.

Therefore, we re-analysed data of a naturalistic cycling study (NCS) and conducted three simulation studies.

NCS Data: After identifying appropriate interaction scenarios for analysis (i.e., non- and little regulated traffic contexts), an annotation system was developed. The analysis on this basis showed that the majority of interactions did not take place in 1:1 situations, cyclists' behaviour is affected by the prevailing infrastructure, same manoeuvres (e.g., evasion) lead to qualitatively different results in different situations, and the mere speed may not be sufficient to derive the intended behaviour. Further studies should also take pedal frequency into account.

Simulation Study I: From a car driver's perspective, we investigated the effect of speed and vehicle size of an oncoming vehicle on drivers' gap acceptance. With higher speeds and smaller vehicle size, smaller (i.e. more hazardous) gaps were chosen. Specifically when interacting with cyclists, gaps were riskiest implying for AVs to apply greater gaps in order to ensure efficient traffic flow and to reduce cyclists' uncertainty. For individual cases, explicit communication signals could resolve complex situations.

Simulation Study II: From a cyclist's perspective, we investigated the effect of speed and vehicle size of an oncoming vehicle on cyclists' gap acceptance and crossing decision to examine whether findings of Simulation Study I can be confirmed. The study is completed and is currently in the data analysis phase.

Simulation Study III: We evaluated the potential of a trimodal cyclist warning system (CWS) to increase cycling safety. The use of the CWS resulted in significant earlier brake reactions on the part of the cyclists in critical situations compared to rides without the CWS. This finding not only implies that HMIs are an effective way for to align behaviours between AVs and cyclists, they also indicate the latest time for AVs to react as an informal communication signal.

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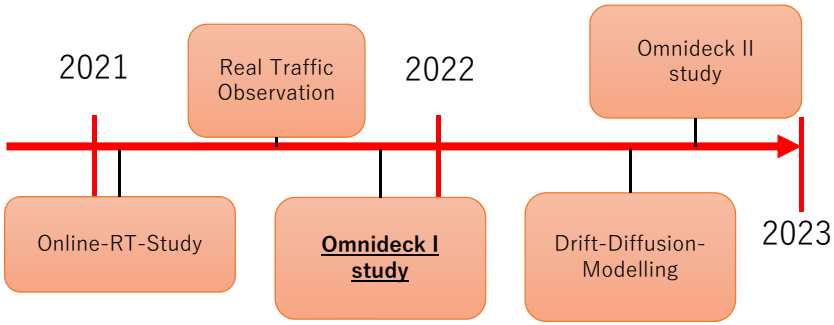
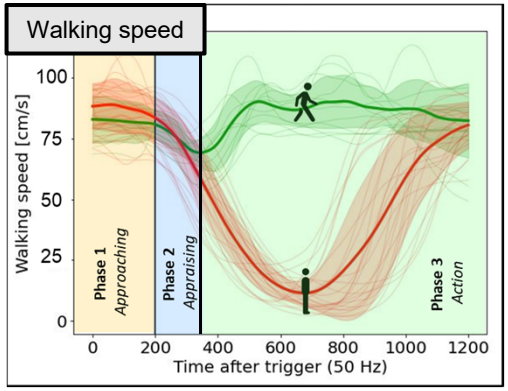
Task A/WP 1:External communication at low speeds	
Background	Automated vehicles (AVs) will increasingly participate in **urban mixed traffic**. In this context, **communication between the AV and vulnerable road users (VRU)**, e.g. pedestrians is essential -especially in unregulated situations. For this, **external HMIs** can be displayed by the AV.
Research goal	**Interaction and communication patterns** between AV and VRUs in urban traffic are investigated. Based on this, design recommendations and guidelines for eHMIs and road infrastructure are formulated.
Method	Traffic observation, virtual reality studies, expert workshops, literature review
Results	• A group of VRU shows different and more complex behavior and interaction patterns than a single VRU • An AV addressing a single VRU vs. a group of VRU must adhere to different parameters (to be fomulated) • eHMIs must be understood unambiguously, both for a group or a single VRU, and be consistent with the AVs driving behavior

Website

Project results: CAD GermanyJapan HF – DLR

WP 1: Modeling pedestrians' decision-making and behavior in road crossings





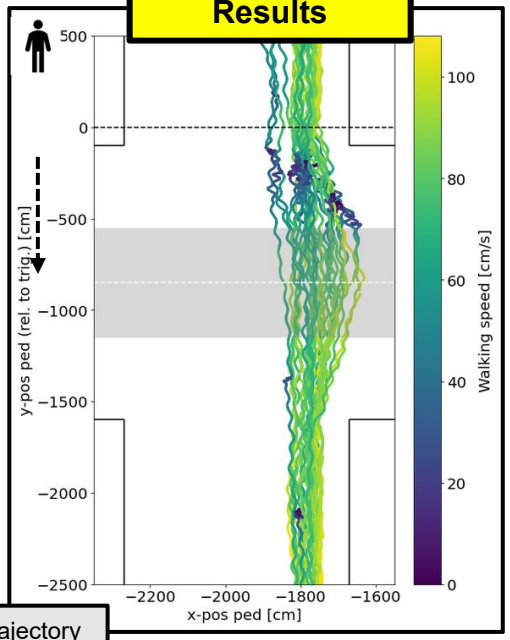
VR study in Omnideck walking simulator

- *N* = 36 (11 female, 25 male)
- Age: *M* = 28.7 y, *SD* = 7.5 y
- **Measure pedestrians' behavior during crossing decisions**
- Research design: 3x2x3 within-design with two repetitions and the following **independent variables**:
  - Vehicle's speed: 30, 40, 50 km/h
  - Driving direction: From left (45 %), from right (45 %), no car (10 %)
  - Vehicle's TTA: 11 s, 13 s, 15 s (from left), 14 s, 16 s, 18 s (from right)
- **Dependent variables**: Crossing decision, walking speed & trajectory, head-, eye-, body- and hand-movements, qualitative questionnaire

Methods

Omnideck simulator

Results



Trajectory analysis

German Aerospace Center (DLR)

Project results: CAD GermanyJapan – DLR
WP1: Design of eHMI communication strategies for different vehicle types

INTRODUCTION

- Need of **communication abilities of automated vehicles (AVs)** for a safe future interaction with pedestrians especially with larger sized AVs
- Two efficient communication solutions for AVs:
  - **Dynamic human-machine interfaces (dHMIs)** transmit implicit information via, e.g., vehicle dynamics
  - **External human-machine interfaces (eHMIs)** positioned on the AV' s outside transmit explicit information
- Interplay of both communication tools especially for an

Figure 1: Presented automated bus in the online studies

METHODS

- **Video-based experimental online studies**
- **Realistic vehicle study** on DLR campus in Braunschweig, Germany

Dependent variables:

- Pedestrians' willingness to cross, trust, perceived safety
- Pedestrians' crossing behavior, e.g., crossing initiation time (realistic vehicle study)

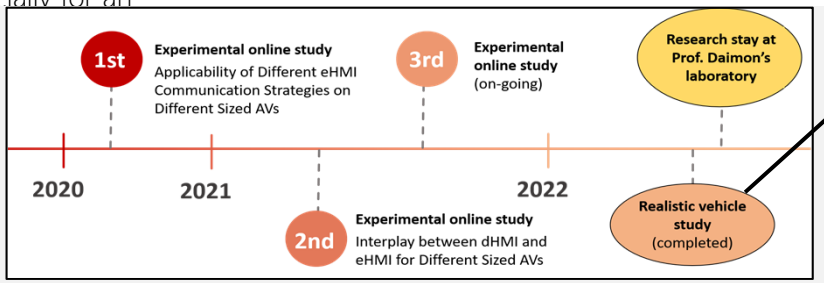
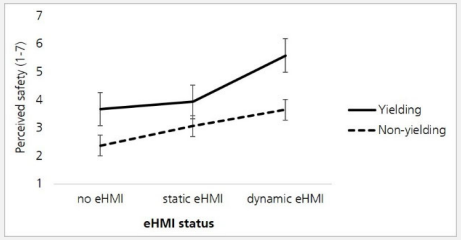


Figure 2: eHMI prototype applied on the test vehicle

RESULTS & DISCUSSION

- Pedestrians' willingness and trust was higher when a dynamic eHMI was presented compared to static eHMI or no eHMI
- For the most safety-critical condition (dynamic eHMI indicated falsely that the vehicle yielded), pedestrians' willingness and trust was high even though it presented contradictory signals
- Pedestrians tended to rely on explicit communication via the dynamic eHMI rather than on vehicle behavior (dHMI)



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PUBLICATIONS:

Lau, M., Le, D. H., & Oehl, M. (2021). Design of External Human-Machine Interfaces for Different Automated Vehicle Types for the Interaction with Pedestrians on a Shared Space. In N. L. Black, W. P. Neumann, & I. Noy (Eds.), *Lecture Notes in Networks and Systems. Proceedings of the 21st Congress of the International Ergonomics Association (IEA 2021)* (Vol. 221, pp. 710–717). Cham: Springer International Publishing.

Lau, M., Jipp, M., & Oehl, M. (2022). One Solution Fits All? Evaluating Different Communication Strategies of a Light-based External Human-Machine Interface for Differently Sized Automated Vehicles from a Pedestrian's Perspective. *Accident Analysis & Prevention, 171,* 106641. doi:10.1016/j.aap.2022.106641

Lau, M., Jipp, M., & Oehl, M. (2021). Investigating the Interplay between eHMI and dHMI for Automated Buses: How Do Contradictory Signals Influence a Pedestrian's Willingness to Cross? In *13th International Conference on Automotive 2021* (pp. 152-155). New York, NY, USA: ACM.

Lau, M., Jipp, M., & Oehl, M. (2022). Toward a Holistic Communication Approach to an Automated Vehicle's Communication With Pedestrians: Combining Vehicle Kinematics With External Human-Machine Interfaces for Differently Sized Automated Vehicles. *Frontiers in psychology, 13*

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WP1: Communication with surrounding road users

- Investigation of interaction and cooperation patterns between AV and drivers
- Identification of requirements for the communication behavior of AV
- Development of communication strategies to facilitate safety and efficienty in mixed traffic

Goal → facilitate safe and efficient interaction with automated vehicles (AVs)

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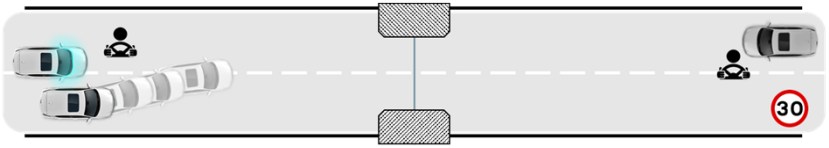
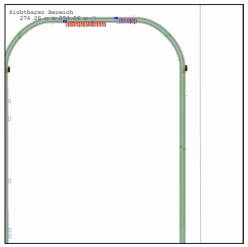
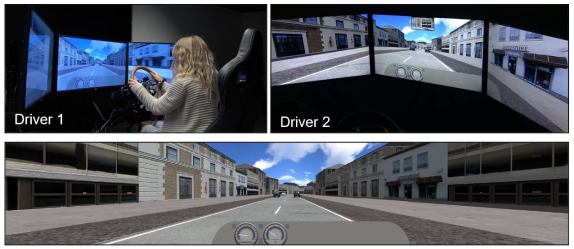
Multi-Agent Driving Simulator Experiment





Birds-eye view simulation map



Simulation view: Driver 1

- Drivers **expected AVs to yield** the right-of-way in narrow passages and **manual vehicles (MVs) to insist** on their priority
- Behavior of AVs that **conformed** to those expectations (yielding) lead to **faster passing times** than the same behavior of MVs
- **Yielding** was subjectively evaluated **more positively** than insisting in terms of, e.g., comfort, trust, and cooperativeness

Miller, L., Koniakowsky, I., Kraus, J., & Baumann, M. (in press). The Impact of Expectations about Automated and Manual Vehicles on Drivers' Behavior: Insights from a Mixed Traffic
Driving Simulator Study. In *Proceedings of the 14th International Conference on Automotive User Interfaces and Interactive Vehicular Applications.*