Communication and Interaction between Automated Vehicles and other Road Users

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with contributions of J.Schmidtler, J.Reinhart, C.Gold, D.Damböck, M.Kienle, D.Bortot
What is the **driver’s state and role?**
Integration and Validation of non-driving related activities
Concept and design of transitions

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.”
Definition of take-over situations

Identification of six possible and reasonable take-over situations for the workpackage 3 experiments.
We are able to do this – Why change
33:40 Sinfonie der Großstadt
Explicit Communication
Implicit Communication
Current OEM Concepts

- Add. Display
- Projections

-> 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**?”
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

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
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

$R_{XY}(\tau)$
Research on Interactions between Vehicles and VRUs

Field Data

Pedestrian Simulator TU München

Testbed Aachen
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?
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 manoeuvres
- Animations of various external HMI concepts
- Evaluation of outward appearance of automated vehicles
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:**
5th Enabler
Methodology for assessing the quality of interaction

4th Enabler
Novel HMI elements

3rd Enabler
CCPU & safety layer

1st Enabler
Psychological models

2nd Enabler
Intention recognition & behavioural predictions

The challenge

Achieve a safe, highly accepted and efficient integration of Automated Vehicles in mixed traffic environment

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

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

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
Impaired Vision and Individual Mobility

- Increase of average age
- Increase of impaired vision at ages > 55+
- Correlation between age and vision
- Vision as basis for driving task

→ Impaired mobility with increasing age

Cooperation between TUM Chair of Ergonomics and 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 – $\text{TTC}_{\text{min}}$

\begin{figure}
\centering
\includegraphics[width=\textwidth]{plot.png}
\caption{Comparison of TTC values under different conditions (Eyewear: no Goggles vs. with Goggles) across different pedestrian scenarios (Crossing, zebra, freelance).}
\end{figure}
Simulated Impairment Study

Cross correlations

No Goggles - BOT - Freelane

No Goggles - PED - Freelane

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.

<table>
<thead>
<tr>
<th>Level</th>
<th>Name</th>
<th>Narrative definition</th>
<th>Execution of steering and acceleration/deceleration</th>
<th>Monitoring of driving environment</th>
<th>Fallback performance of dynamic driving task</th>
<th>System capability (driving modes)</th>
<th>BAdT level</th>
<th>NHTSA level</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No Automation</td>
<td>the full-time performance by the human driver of all aspects of the dynamic driving task, even when enhanced by warning or intervention systems</td>
<td>Human driver</td>
<td>Human driver</td>
<td>Human driver</td>
<td>n/a</td>
<td>Driver assist</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>Driver Assistance</td>
<td>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</td>
<td>Human driver and system</td>
<td>Human driver</td>
<td>Human driver</td>
<td>Some driving modes</td>
<td>Assisted</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>Partial Automation</td>
<td>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</td>
<td>System</td>
<td>Human driver</td>
<td>Human driver</td>
<td>Some driving modes</td>
<td>Partially automated</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Automated driving system (“system”) monitors the driving environment</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Conditional Automation</td>
<td>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</td>
<td>System</td>
<td>System</td>
<td>Human driver</td>
<td>Some driving modes</td>
<td>Fully automated</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>High Automation</td>
<td>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</td>
<td>System</td>
<td>System</td>
<td>System</td>
<td>Some driving modes</td>
<td>Fully automated</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>Full Automation</td>
<td>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</td>
<td>System</td>
<td>System</td>
<td>System</td>
<td>All driving modes</td>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>

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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