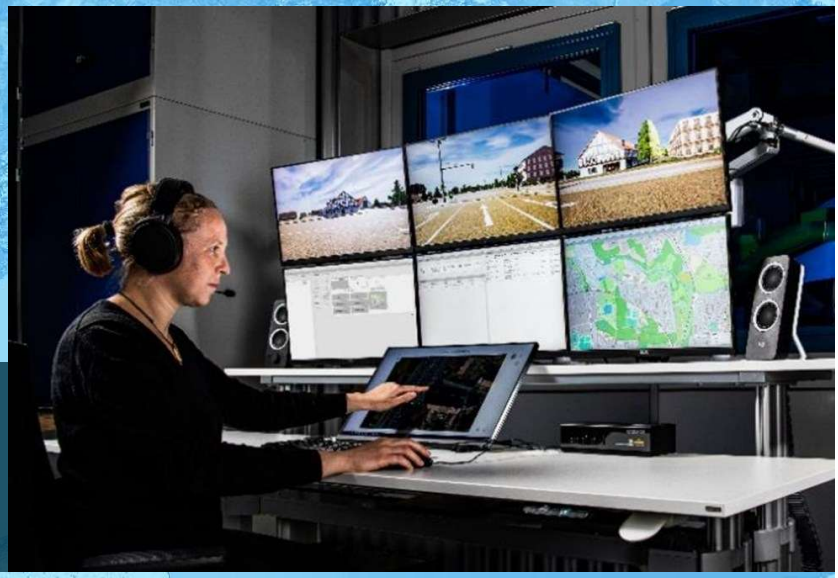
REMOTE OPERATION: THE HUMAN SUCCESS FACTOR FOR SCALING UP CCAM



ECTRI TG Safety Webinar

29 October 2026

Dr. Andreas Schrank & Dr. Michael Oehl

German Aerospace Center (DLR),
Institute of Transportation Systems

Credits: DLR (unless stated otherwise)

DLR

Remote Operation as an Enabler for Autonomous Mobility

Mobility of the future (passengers and goods)

Widespread use **of highly automated vehicles** (HAVs, SAE4) – with limitations

Supported by human **remote operator** to meet technical and legal requirements (AFGBV)

Scalability enabled by **AI** components

Need for safe and **smooth human-AI collaboration** arises



[DLR White Paper on Future Public Transport]

Automation across rail and road can improve public transport and cut costs



[DLR and DB Regio Autonomous Driving Study]

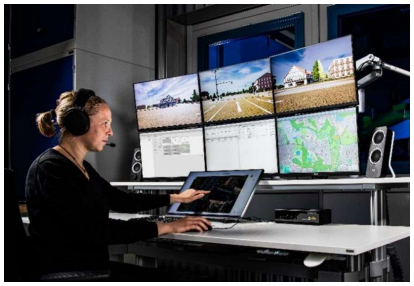
50% less waiting time and 11% less road capacity used if autonomous shuttles are incorporated into public transport

Taxonomy for Remote Operation (ROn)

Source	Term	Definition
SAE	**Remote Driving** (~ Direct ROn; *D:* StVFernLV)	**Performance** of part or all of the **dynamic driving task (DDT)** and/or DDT fallback (including real-time braking, steering, acceleration, and transmission shifting), by a remote driver
BASt	**Event-based Remote Driving**	Remote driving on demand *(requires higher level of automation)*
SAE	**(Remote) ADS Assistance** (~ Indirect ROn; *D:* AFGBV – "Technical Supervision")	**Event-driven provision of information or advice** by a designated human agent at the **request of an ADS** that is performing the DDT in order to facilitate trip continuation *(requires higher level of automation)* ADS assistance **does not include** the performance of the entire **DDT** or fallback. Rather, the ADS performs the entire DDT and/or fallback, even when assisted by an ADS assistant. It may include providing an ADS with revised **tactical goals** and/or tasks, **interpreting** human traffic control guidance, and **exchanging messages** with first responders. It **does not include** providing **strategic instruction** regarding selection of destinations or trip initiation timing (i.e., dispatch functions), […]
SAE	**Monitoring**	- of user, driving environment, vehicle performance, or DAS performance: […] functions involving real-time human or machine sensing and processing of data used to operate a vehicle […].

DLR exempl.Workplace





BASt WG Teleoperation (2024). Technical report of the working group „Research Needs in Teleoperation". Federal Highway Research Institute Germany (BASt). www.bast.de/teleoperation-en
SAE (2026). Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles. J3016. https://www.sae.org/standards/content/j3016/
DLR: https://www.dlr.de/en/ts/research-transfer/projects/remote-operation

Application of Remote Operation in HAVs: Already a Reality



Senator-led investigation on the **use** of human **remote operators** by corporations that entertain highly automated vehicles (HAVs, SAE 4) in the US revealed **widespread reliance of HAVs on remote operator support**

US Senator Ed Markey, Autonomous Vehicle Companies' Use of Remote Assistance, Report

- HAVs operating in the US rely on remote operators to intervene in situations or conditions that exceed the HAVs' operational design domain providing Remote Guidance (Remote Assistance)
- Remote operators provide guidance, approval, or clarifications (remote assistance) but do not take over the driving task completely (remote driving) – only Waymo and Tesla in low speed conditions
- E.g., Waymo uses remote operators abroad (in the Philippines) without a valid US driver's license

TESLA WAYMO Motional ZOOX MAYmobility nuro Aurora

The Human Success Factor:
Need for Calibrated Trust in Human-AI Collaboration

"[…] the **system did not detect common roadway conditions** that **impaired** camera **visibility** and/or provide alerts when camera performance had deteriorated until immediately before the crash occurred."

US Office of Defects **Investigation on Tesla's "Full Self Driving"** (FSD), NHTSA ID: EA26002 / Philip Koopman (18 March 2026)



https://www.teslarati.com/wp-content/uploads/2023/08/tesla-fsd-beta-v11-scaled.jpg

Problem

- **Lack of transparency** in driving-related automated systems (here: ADAS, SAE 2+)
  - **"Silent Failure":** System did not disclose to driver that limit of Operational Design Domain (ODD) regarding visibility was transgressed
- **Diffusion of responsibility:** *Who* is responsible *for what* and *when*?
  - Driver were not made aware they were responsible to take over at ODD limit → fatal crash occurred

Solution

- **Human-centered design** of human-AI collaboration and its **human-machine interfaces** (HMI)
- **Calibrated trust** trough **XAI** and **transparent** communication of **system capabilities and limits**

Remote Operation of HAVs (SAE 4) and the Potential of AI



Highly automated shuttle vehicle U-Shift (DLR)





Remote Operation

- Contribution to **flexible and innovative mobility solutions**, e.g. on-demand shuttle services on the “last mile” between mobility hub and destination
- New **legal frameworks** that require remote assistance for autonomous driving on public roads
- Suitable for different **vehicle types** (shuttle buses, passenger vehicles, trucks, …) and **operation concepts**

Potential of AI

- **Allocation** of remote operation tasks across remote operators (roles, etc.)
- Helping **gain situation awareness by HMI adaptation** to task demands, e.g., by enrichment of poor video quality with visualized sensor data
- **Maneuver suggestions** for scenarios exceeding the ODD (in the future)

DLR‘s Research Projects on HAV Remote Operation – 1/3

RealLabHH



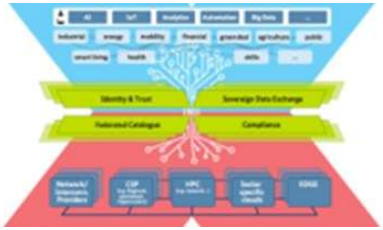
- *33 Mio. € - national - 2020-2021*
- On-demand shuttle service integrated in Hamburg‘s public transport
- Design and evaluation of a workplace for remote operation

U-Shift 33



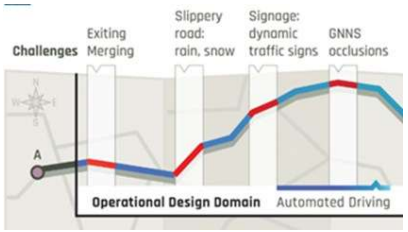
- *3,6 Mio. € - national - 2020-2022*
- DLR's modular vehicle concept: Automated driveboard & capsules
- Design of workplace for remote operation of driveboard

GAIA-X 4 ROMS



- *> 20 Mio. € - national - 2021-2024*
- Application of the GAIA-X ecosystem to integrate AVs into public transport
- Design of a workplace for remote operation of a smart managed public transport fleet

Hi-Drive



- *60 Mio. € - EU H2020 - 2021-2025*
- Large-scale tests for CAD → remote op to expand ODDs
- Interaction strategies for remote operation and workplace design

KIS‘M



- *9.5 Mio. € - national - 2022-2025*
- User-centered AI-based system for connected mobility → AV shuttle service in Berlin
- Design of the workplace and interaction between passengers & RO

DLR‘s Research Projects on HAV Remote Operation – 2/3

MAD Urban



- *3.3 Mio. € - national - 2022-2025*
- Managed Automated Driving for urban mobility → based on infrastructure
- Advice on the implementation of remote operations workplaces

STADT:up



- *63 Mio. € - national - 2023-2026*
- Seamless solutions for automated driving in urban space
- Concepts for interaction at the workplace of the Technical Supervisor

KIRA



- *4 Mio. € - national - 2023-2026*
- On-demand shuttle fleets in public transport (urban/rural)
- Supporting implementation of remote operation workplaces

IMoGer



- *39 Mio. € - national - 2024-2027*
- Combination of public transport and cargo use case with modular DLR vehicle U-Shift
- Development of generic technical supervisor workplace

RemoteReadyMove



- *6 Mio. € - Horizon Europe - 2026-2029*
- Advancing Technical and Societal Readiness of Remote Operation in Connected, Cooperative, and Automated Mobility Services for People and Goods
- 14 Partners, 7 countries; consortium leader: DLR

Project key facts

RemoteReady Move

Project duration

3 years

June 2026 till May 2029

Funding

EU Horizon

Research and Innovation (RIA)

5.99 Mio Euro

Consortium

14 partners

from eight European countries

DLR | Coordinated by German Aerospace Center (DLR)



RemoteReadyMove – Our Objectives

1. Develop a holistic system-of-systems model and technical components for Remote Operation.
2. Advance Societal Readiness through inclusive stakeholder engagement in design and evaluation.
3. Develop a comprehensive safety validation and assurance framework for Remote Operation.
4. Evaluate operational, societal, and regulatory impacts across six European Pilots.
5. Explore the economic viability and scalability of Remote Operation and unlock new business models.
6. Create guidelines and inform policy recommendations to ensure interoperability and regulatory consistency.

3 Use Cases

6 European Pilot Sites















Societal Readiness Pilot



Advance Societal Readiness of Remote Operation in CCAM systems by **developing, implementing (i.e., piloting), and evaluating** a tailored approach.

To increase the societal uptake and successful deployment of Remote Operation as integral part of the CCAM systems, a **full understanding and integration of Societal Readiness aspects** in the research and development processes is needed.

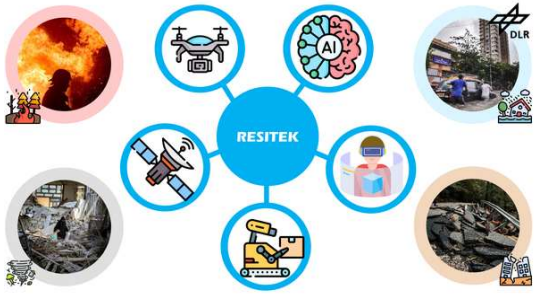
DLR‘s Research Projects on Remote Operation – 3/3: Civil Protection and Disaster Prevention

AHEAD Response



- *< 1 Mio. € - with WFP - 2026-2028*
- Transport of relief supplies in crisis regions with amphibious vehicles
- Design of an HMI for remote operation of the amphibious vehicle "Sherp"

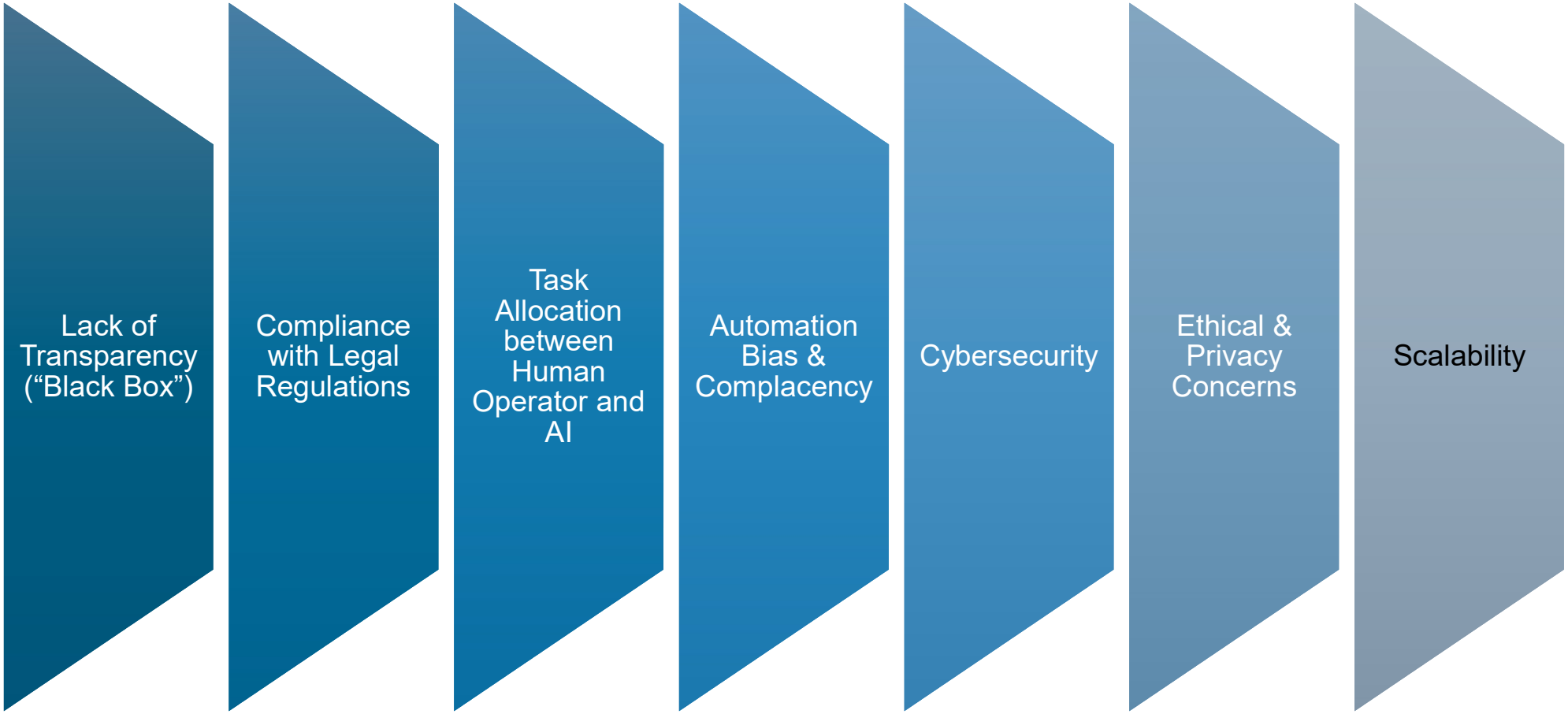
RESITEK



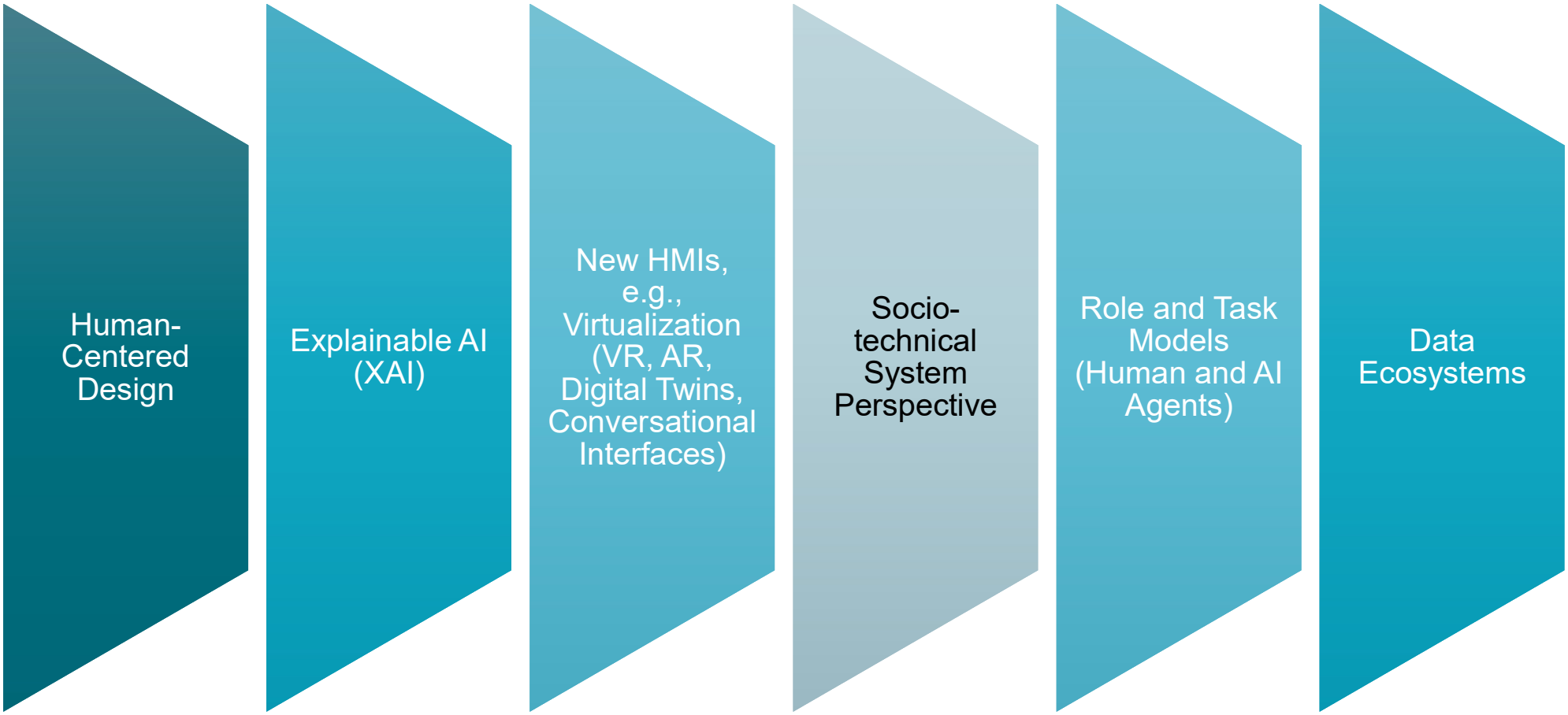
- *11 Mio. € - 2024-2026*
- Innovative technology network to strengthen effective and resilient disaster prevention and crisis management
- Using robust and resilient remote operation for automated and connected vehicles in disaster scenarios



Human Factors Challenges in Human-AI Collaboration



Pathways to Enable Human-AI Collaboration



The Sociotechnical System Remote Operation at the DLR Institute of Transportation Systems

DLR‘s Institute of Transportation Systems looks at AV (SAE 4) remote operation **holistically** across a wide range of research areas, i.e., **system and service design of a socio-technical system**.



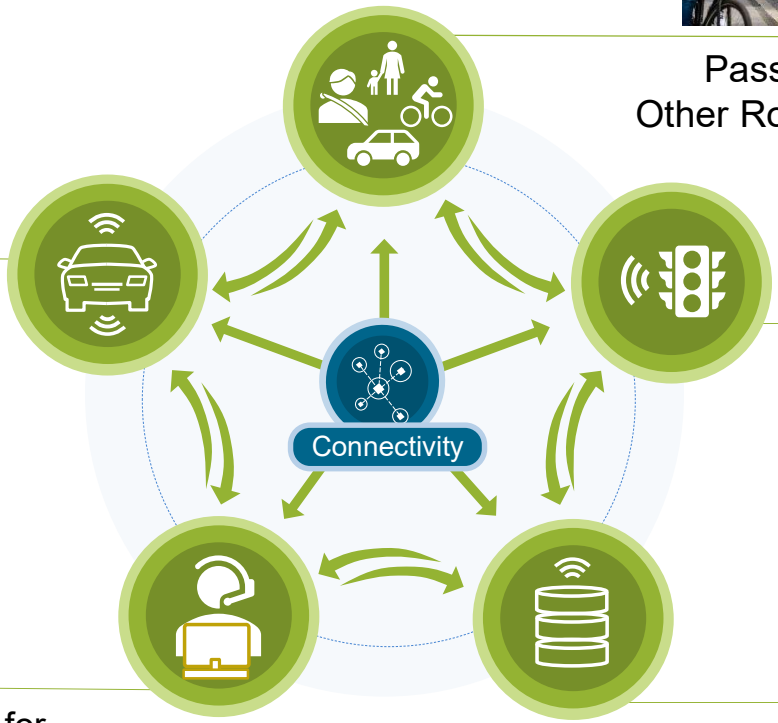
Passengers & Other Road Users



Connected & Automated Vehicles
(different automation levels)



Road & C-ITS Infrastructure





Remote Operators for Remote Assistance & Remote Driving



AI Layers / Backend Infrastructure

All Photo Credits:
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The Sociotechnical System Remote Operation and the Role of AI Components



Interaction w/ passengers

Interaction w/ other road users

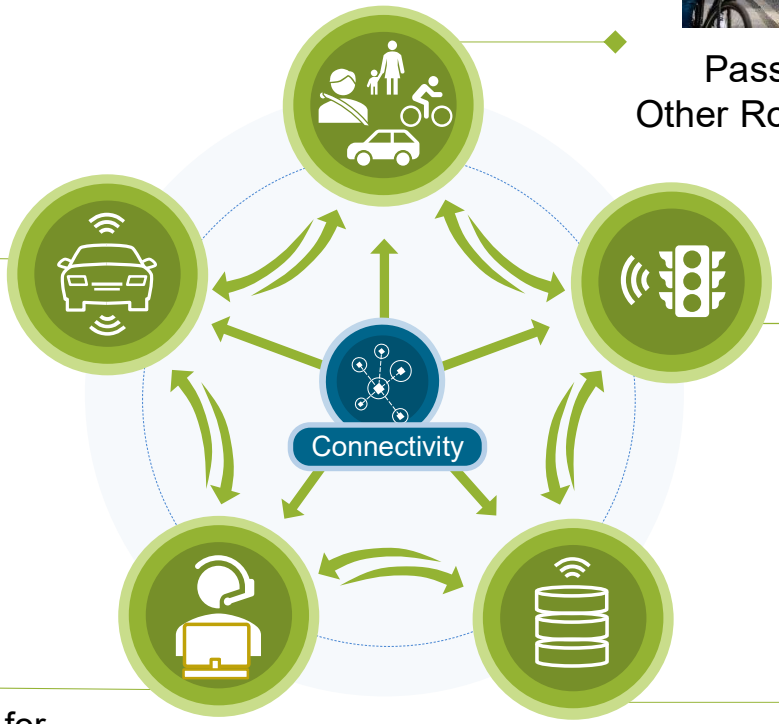
Passengers & Other Road Users

Perception

Decision-making



Connected & Automated Vehicles
(different automation levels)





Providing sensor data

Integration into traffic management

Road & C-ITS Infrastructure

Decision support / proposing maneuvers

Supporting perception



Remote Operators for Remote Assistance & Remote Driving



Enabling scalable fleet operations

Computing power for MAD / DA²D

AI Layers / Backend Infrastructure

All Photo Credits:
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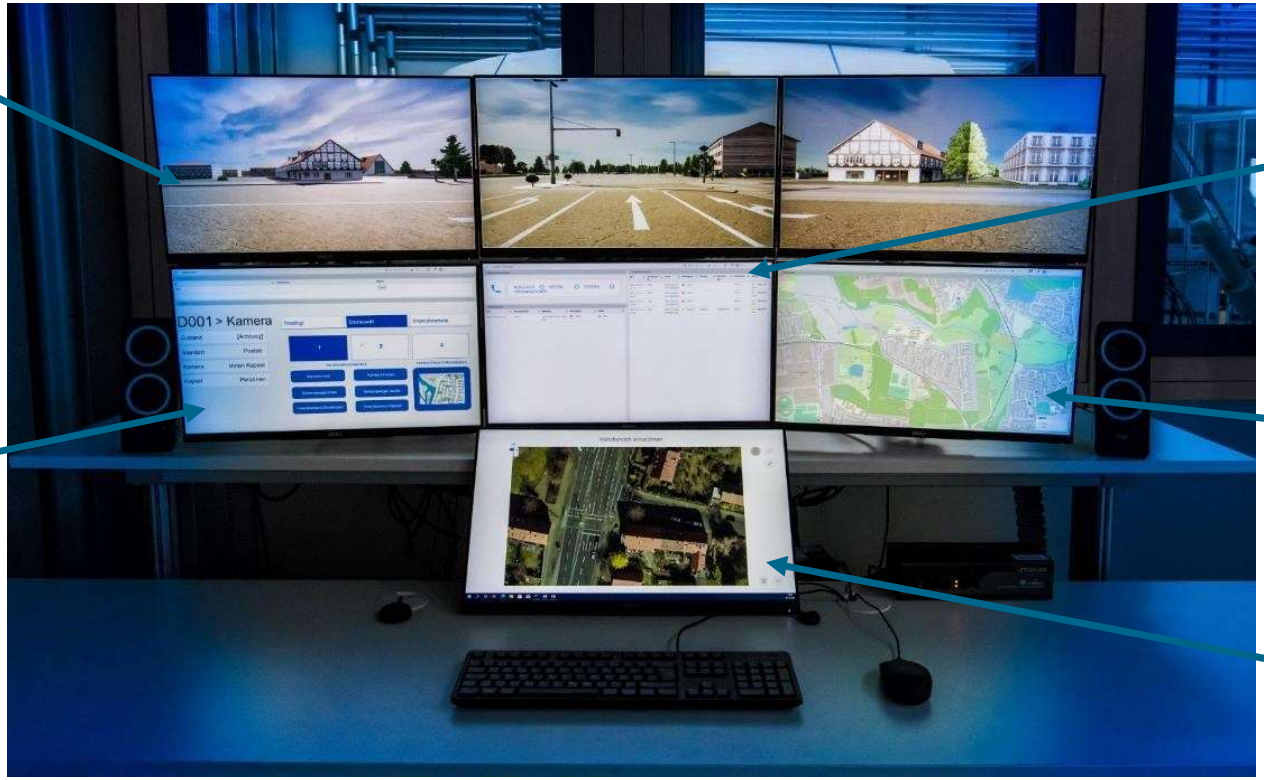
Artificial Intelligence (AI) for Remote Operation

- **AI layers** as an additional component of the sociotechnical system remote operation
- **Purpose**: Supporting the remote operator in task completion
- **Advantages**:
  - Enabling **scaling** of remote operation systems for AV fleets
  - Increasing the **robustness** of remote operation
- **Potential application of AI components**:
  - Processing of sensor data (objection recognition, semantic segmentation, augmentation, fusion, …)
  - Task rendering and allocation
  - Operator-AI collaboration (situation analysis, decision support, LLM-based communication with operator)



HMI of the Workplace for Remote Assistance

Video Screens



Notification Screen
- Incoming Notifications
- Task Manager
- Communication Bar

Map Screen

Details Screen
- Technical State
- Position and Schedule
- Camera Configuration

Touchscreen
- Setting Waypoints
- Setting Trajectories

Schrank, A., Walocha, F., Brandenburg, S., & Oehl, M. (2024). Human-centered design and evaluation of a workplace for the remote assistance of highly automated vehicles. *Cognition, Technology & Work*. https://doi.org/10.1007/s10111-024-00753-x

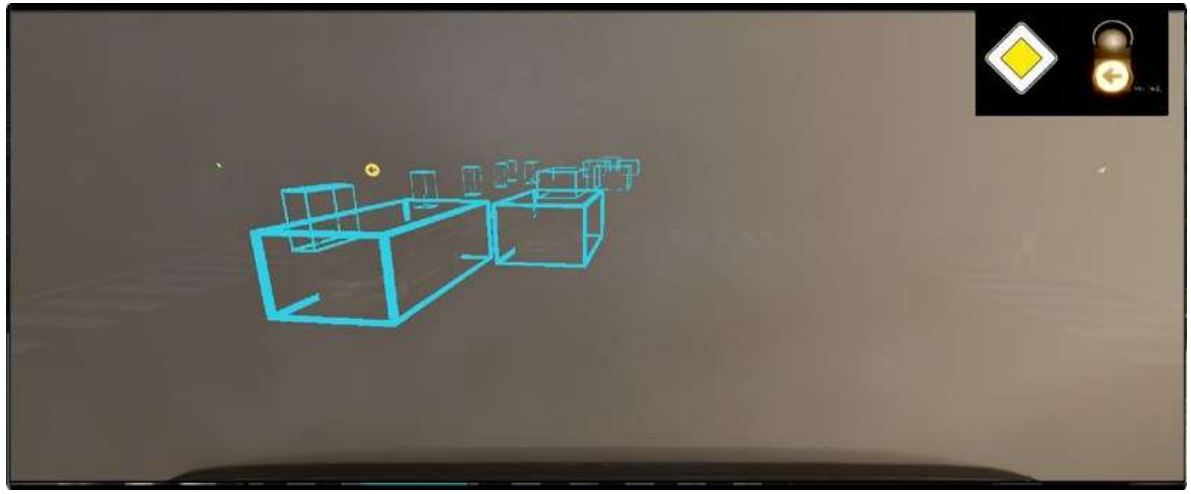
Augmented HMI for Remote Assistance

Main Idea

- **Sensor data** from the supervised AV or the infrastructure are **visualized** to resemble an **augmented** video stream of the traffic environment
- The **perception-based augmentation** supports the remote operator in detecting road users by bounding boxes
- The **adaptive** variant of the perception-based augmentation only shows **relevant** road users

Key Results

- **Higher detection performance** of relevant road users including VRUs → improved **situation awareness** and enhanced **safety**, especially in phases of higher cognitive load (Schrank et al., 2025)
- Particularly effective for **degraded video streams** and/or **impaired viewing conditions** (e.g., fog, night)



Schrank, A., Wilbrink, M., Brandenburg, S., & Oehl, M. (2025). Improving road user perception in adverse weather: An augmented human–machine interface for remote assistants of automated vehicles. *Transportation Research Part F: Traffic Psychology and Behaviour*, *113*, 500–516. https://doi.org/10.1016/j.trf.2025.05.017

Visualizing Sensor Data for Remote Assistance

Main Idea

- **Sensor data** from the supervised AV or the intelligent infrastructure (LiDAR / RADAR / ultrasonic sensors etc.) are **visualized** to resemble an (augmented) video stream of the traffic environment
- Objective: supporting the remote operator's situation awareness by providing information in addition to / in lieu of actual video stream (Schrank et al., 2024)



Key Results

- Providing **visualized sensor data improves situation awareness** at perception level
- **Complementing** the (degraded) video stream can help react dynamically to **latencies** and **low bandwidth** of data link

Schrank, A., Wendorff, N., & Oehl, M. (2024). Assisting the Remote Assistant: Augmenting Degraded Video Streams with Additional Sensor Data to Improve Situation Awareness in Complex Urban Traffic. In C. Stephanidis, M. Antona, S. Ntoa, & G. Salvendy (Eds.), *Communications in Computer and Information Science. HCI International 2024 Posters* (Vol. 2118, pp. 283–294). Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-61963-2_28

Adjusting Camera Perspectives in Remote Assistance

Main Idea

- First-person view not ideal for assessing distances and recognizing hidden objects
- Alternative **camera perspective (**bird‘s-eye view, third-person view) may be better suited to support a remote assistant

Research Design

- Experimental lab study with **complex left-turn task** (paradigm adopted from Schrank et al., 2025)
- Metrics: operator performance, situation awareness, mental workload, usability, UX

Key Results

- No positive effect of other camera perspectives in this task
- Augmentation helped offset negative effect of perspectives



Simulation environment – participant‘s view (**bird‘s-eye view**); oncoming traffic (circled) needs to be yielded to when turning left at intersection



Simulation environment – participant‘s view (**third-person view**)

Schrank, A., Kaas, A.-S., Brandenburg, S., & Oehl, M. (2026). The Effects of Camera Perspective and Augmentation on Performance, Situation Awareness and Mental Workload of Remote Assistants of Highly Automated Vehicles. *Transportation Research Part F: Traffic Psychology and Behaviour*. https://doi.org/10.1016/j.trf.2026.103632

Adjusting Lead Time in Event-Based Remote Driving

Main Idea

- **Providing video stream** with **extended lead time** to support remote drivers in highly complex traffic situations during remote take overs, by giving them time to identify and track relevant traffic elements in the traffic situation

Research Design

- 3×2×2 within-subject experimental design in **complex urban environment**:
  - **Lead Time** (7sec vs. 10 sec vs. 13sec)
  - **Augmentation** (on vs. off),
  - **Situation Complexity** (high vs. low)

Key Result

- **Extended Lead Time supports RDs** during remote take-overs in highly complex traffic situations



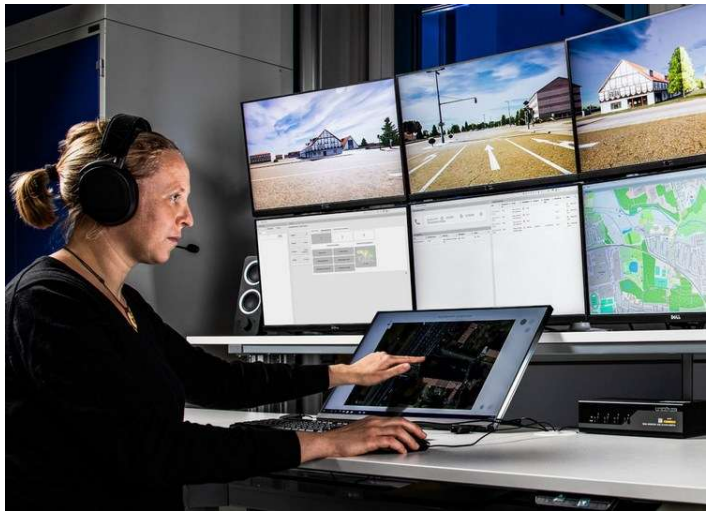
Exemplary Remote Driving Workplace



Simulation environment during a high complexity traffic situation – participant‘s view

Reisinger, A., Wilbrink, M., Baumann, M., & Oehl, M. (2026, March 16–18). Investigating the time required by remote drivers to get into the loop during event-based remote takeovers (Conference presentation). Tagung experimentell arbeitender Psychologen (TeaP) 2026, Tübingen, Germany. https://coms.app/teap26/documents/TeapP_2026_Booklet_Upload260314.pdf

Explainable AI (XAI) for Remote Operation



Workplace for HAV remote operation (DLR)



Remote assistant wrongly prompted the ADS to pass a school bus with extended stop arm.

National Transportation Safety Board (NTSB) Investigation on Waymo's automated driving system (ADS), ID: HWY26FH007

Problem

- Human-AI collaboration created a safety critical traffic incident
  - **Remote operators** need to **calibrate their action** based on the **AI-supported driving automation**

Solution

- **Human-centered design of human-AI collaboration**
  - Context-dependent adaptive HMI
  - Visualized sensor data
  - Extended lead times

Intelligent Infrastructure





Main Idea

- Sensor data from **intelligent infrastructure units** (cameras, LiDAR sensors, traffic lights, roadside units, etc.) support the remote operator by providing information in addition to / in lieu of on-board sensors

Use Cases

- **Complex traffic environments** (intersections, obstructed view, high traffic density, etc.)
- **Obstacles** that block view from on-board sensors onto road section ahead
- Detecting road users that are hard to spot, particularly **VRUs**
- Substitute for **impaired on-board cameras** and other sensors -> **collective perception**

Transparent iHMI for Communication of an MRM to Passengers of an Automated Shuttle (SAE 4)

Main Idea

- **Improving passengers' understanding** and **predictability** of HAVs' **driving behavior**
- Using different **media** to provide information about the automation system and the remote operation process to passengers





Screenshots from the interface design

Research Design

- Repeated Measurement single within-factor design
  - Transparency (no, low, medium, high, max)

Key Results

- **Text-based interface** (see figure) works best in improving passengers' understanding and predictability of HAVs' driving behavior (no avatars are necessary)



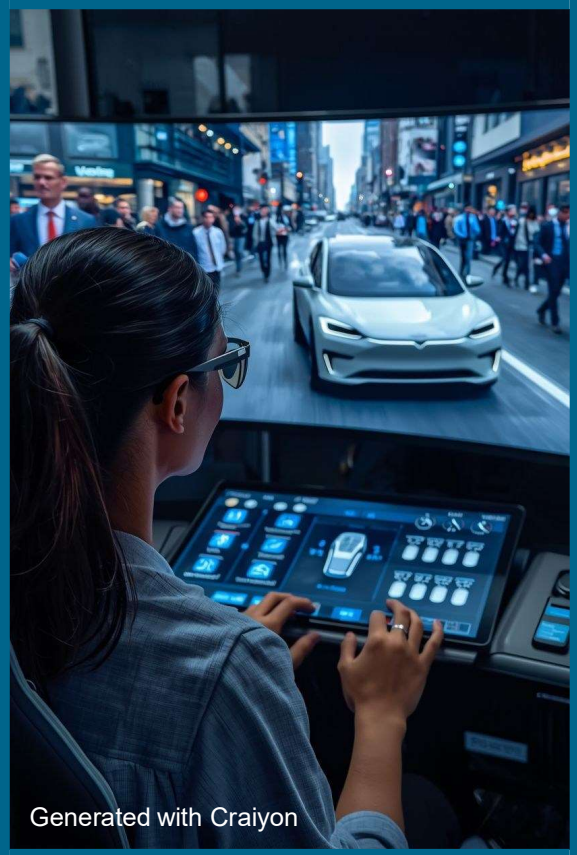
Example of a passenger HMI in a simulated shuttle

Brandt, T., Wilbrink, M., & Oehl, M. (2024). Transparent internal human-machine interfaces in highly automated shuttles to support the communication of minimal risk maneuvers to the passengers. *Transportation Research Part F: Traffic Psychology and Behaviour, 107*, 275-287. DOI: 10.1016/j.trf.2024.09.006

Chances and Risks of AI for Remote Operation

Chances

- Enhancing safety for passengers and other road users
- Helping remote operators make faster decisions (situation awareness)
- Optimization and better coordination of fleets
- Bridging latency issues in challenging situations by using sensor fusion and collective perception
- Increasing system scalability and robustness of remote operation



Risks

- Probabilistic nature of AI systems (particularly LLMs) – Challenging for safety-relevant application based on rules
- Vulnerable cybersecurity, especially relevant for remote operation
- Overreliance on AI-driven suggestions → automation bias and complacency
- Intransparent decision-making of AI systems – need for explainable AI (XAI) for efficient human-AI partnership and decision support

Key Messages

- We need **human-centered design of human-AI collaboration** – particularly when scaling up the remote operation of HAVs
  - AI components need to be integrated into human-machine interfaces (HMIs) for the remote operator to ensure scalability
  - Designing for context of use is essential for tackling challenges (ISO 9241-210, 2019, Ergonomics of human-system interaction Part 210: Human-centred design for interactive systems)

- AI-based systems are **fallible**
  - Risk of **complacency** and **automation bias**
  - Explainable AI (**XAI**) is needed to ensure **calibrated trust**

- **AI-powered decision support** and **task allocation** is vital for safe and **scalable** remote operation
  - Highest potential of human-AI collaboration in remote assistance
  - Sole use of remote driving insufficient (lower scaling potential) – potential bridging technology: event-based remote driving



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Thank you very much for your attention

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