Final in-vehicle prototypes

Deliverable D2.10 – WP2 – PU

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List of Abbreviations and acronyms

ACC	Adaptive Cruise Control
ADAS	Advanced Driver Assistance System
ADS	Automated Driving System
API	Application Programming Interface
AS	Automation State
BBI	Beat-to-Beat Interval
CAN	Controller Area Network
CD	Central Display
CM	Continuous Mediation (automation level)
DC	Driving Context
DL	Decision Logic
DS	Driver State
DSF	Driver State filter SW module
ECG	ElectroCardioGram
ECU	Electronic Control Unit
EPS	Electric Power Steering
HCD	Human Centred Design
HF	Human Factors
HMI	Human Machine Interface
HUD	Head Up Display
KSS	Karolinska Sleepiness Scale
LAN	Local Area Network
LED	Light Emitting Diode
LKA	Lane Keep Assist
LIV	Learning Intelligent Vehicle
ODD	Operational Design Domain
SAS	Simulated Automation State
SB	Standby (automation level)
SDL	Simplified Decision Logic
TI	Technical Integration
ToC	Transition of Control
TtS	Time To Sleep (automation level)
UART	Universal Asynchronous Receiver-Transmitter
UC	Use Case
USB	Universal Serial Bus
WoOz	Wizard of Oz

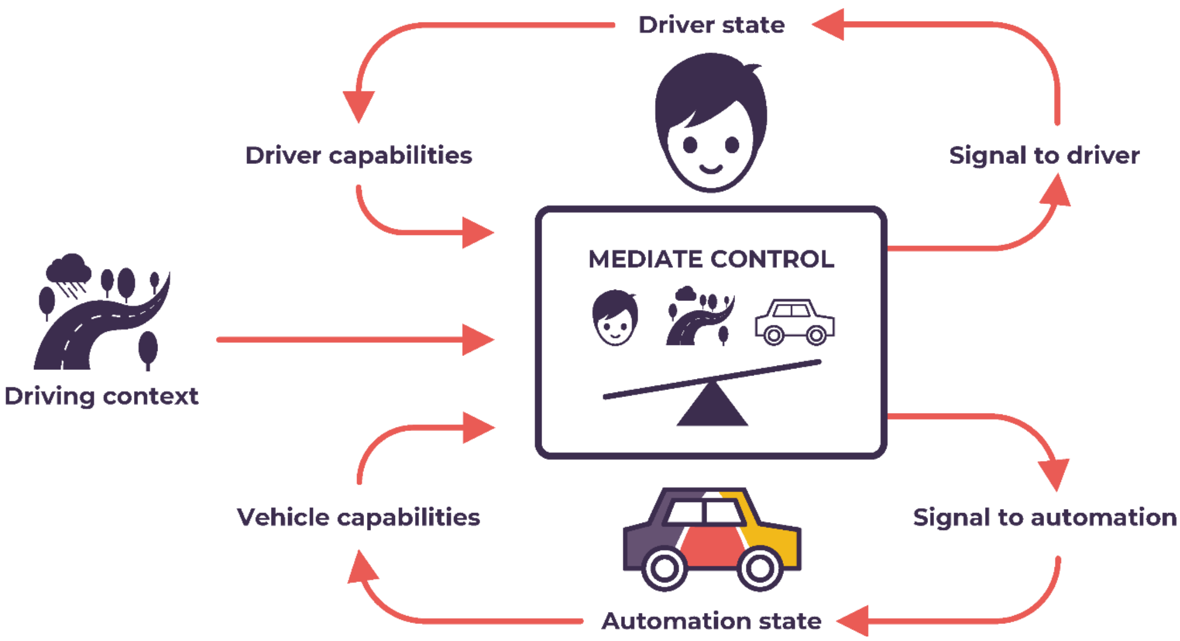
About MEDIATOR

MEDIATOR, a 4-year project coordinated by SWOV Institute for Road Safety Research, has come to an end after four years of hard work. The project has been carried out by a consortium of highly qualified research and industry experts, representing a balanced mix of top universities and research organisations as well as several OEMs and suppliers.

The consortium, supported by an international Industrial Advisory Board and a Scientific Advisory Board, represented all transport modes, maximising input from, and transferring results to aviation, maritime and rail (with mode-specific adaptations).

Vision

Automated transport technology is developing rapidly for all transport modes, with huge safety potential. The transition to full automation, however, brings new risks, such as mode confusion, overreliance, reduced situational awareness and misuse. The driving task changes to a more supervisory role, reducing the task load and potentially leading to degraded human performance. Similarly, the automated system may not (yet) function in all situations.



The Mediator system will constantly weigh driving context, driver state and vehicle automation status, while personalising its technology to the drivers' general competence, characteristics, and preferences.

The MEDIATOR project aimed to develop an in-vehicle system, the Mediator system, that intelligently assesses the strengths and weaknesses of both the driver and the automation and mediates between them, while also taking into account the driving context. It assists the timely take-over between driver and automation and vice versa, based on who is fittest to drive. This Mediator system optimises the safety potential of vehicle automation during the transition to full (level 5) automation. It would reduce risks, such as those caused by driver fatigue or inattention, or on the automation side by imperfect automated driving technology. MEDIATOR has facilitated market exploitation by actively involving the automotive industry during the development process.

To accomplish the development of this support system MEDIATOR integrated and enhanced existing knowledge of human factors and HMI, taking advantage of the expertise in other transport modes (aviation, rail and maritime). It further developed and adapted available technologies for real-time data collection, storage and analysis and incorporated the latest artificial intelligence techniques. MEDIATOR has developed working prototypes, and validated the system in a number of studies, including computer simulation, virtual reality, driving simulator and on-road studies.

With MEDIATOR we further paved the way towards safe and reliable future vehicle automation that takes into account who is most fit to drive: the human or the system.

https://mediatorproject.eu/

Executive summary

This public Deliverable describes the two in-in-vehicle prototypes that have been developed and used for evaluation of the Mediator systems regarding performances and user acceptability during real on-road studies. The report describes main components and sub-components and its intended functionality.

Chapter 1 describes the overall Mediator development strategy; this is related to the choice to have different Mediator in-vehicle prototypes, according to the specific needs of each evaluation platform. Chapter 2 reports the main choices related to the development of the first Mediator in-in-vehicle prototype to test the most complete and sophisticated HMI with evaluation on real roads in Italy and Sweden. Chapter 3 describes the second in-vehicle prototype for the test of the central Mediator concept, using real & real-time automation state, driver state, driving context and decision logic. Finally, Chapter 4 reports the main conclusions, summarising the main difference between the two in-vehicle prototypes and their usage in on-road in testing activities, for the evaluation of the Mediator integrated system.

Platform approach: During the development of each prototype dedicated "platform sub-teams" were formed including all interested stakeholders in the vehicle development, including subcomponents developers and final users of the vehicle in the selected use cases. This has allowed to best align technical developments with experimental evaluation designs for each study using the prototypes. The close connection with the stakeholders involved in on-road tests has allowed to reach the maximum synergy between the development phase and the validation activities. The complementary approach is also reflected in the main chapter structure of this deliverable, presenting each prototype by the respective study team.

In Annex 1 we present a benchmarking analysis on Wizard of Oz vehicles with small on-road laboratory tests used to define the main functionalities of the first Mediator in-vehicle prototype within the project.

1. Introduction and general considerations

In the MEDIATOR project a relevant activity has been the design and development of several prototypes, of the Mediator system, each specific for the platform in which it has been implemented, based on the knowledge, taxonomies, requirements, and selected use cases. This activity includes:

- the overall design of the Mediator system in terms of well-specified components and interfaces
- the design and development of the individual components (consisting of algorithms, software, and integration with hardware) of the Mediator system and perform component-level testing and optimization
- the integration of the individual components into one integrated lab prototype system and perform overall testing and optimization
- the integration of the prototypal Mediator system in different platforms (at simulator level or at vehicle level) suitable for demonstration and evaluation
- the updating of the different lab prototypes based on the evaluation results and definition of recommendations for further development.

This deliverable describes the two in-vehicle platforms, that have been developed and used to evaluate in-vehicle and on-road two different prototypes of the Mediator system, one more focused on human factors and the other more focused on technical integration of Mediator components. According to this in the next the two in vehicle platforms will be also called in-vehicle prototypes.

1.1. SAE Levels of Automation and Mediator terminology

Before to describe in detail the two vehicle prototypes and the related development choices, it is useful to briefly address the well-known SAE Levels of Automation and their relationship to MEDIATOR project and to Mediator terminology. The aim of MEDIATOR has been to develop and evaluate Mediator technology, through multiple components and multiple prototypes, to handle multiple SAE automation levels in innovative and better ways.

The relevant SAE levels are, in particular, L0 through L4. SAE Level 5 is fully automated driving in all situations and driving conditions and is completely theoretical at the time of writing of this document. L5 would make MEDIATOR obsolete, because MEDIATOR project focuses on mediating between automation and the human driver who is still assumed to be involved in the driving task in one way or the other, at least sometimes. In details:

- **L0**, on the completely opposite end of the spectrum, is completely manual driving; in Mediator HMI terminology we call it "*MANUAL*" mode.
- **L1** is driving with either a longitudinal ADAS control system (like Adaptive Cruise Control, ACC) or lateral ADAS control system (like a Lane Keep Assist system, LKA).
- **L2** is driving with both automated ADAS longitudinal and lateral control on at the same time (e.g. ACC + LKA), while still requiring constant supervision by the human driver in the car, who should be ready at any moment to take over control of the car if he/she observes that the ADAS system does not behave properly and safely, or if the ADAS system stops functioning by itself. Common commercial names for this type of system are "Pilot Assist", "Traffic Assist",

"Super Cruise", or even, according to some people somewhat misleadingly, "Autopilot" (Tesla). Importantly, it remains an "assistive" (=ADAS) feature; in Mediator HMI terminology we call it "*ASSISTED*" mode.

Because L0 through L2 require continuous supervision by the driver, in Mediator project terminology those levels are also called all together "*Continuous Mediation*" levels.

And again:

- **L3** driving is the first level to have (sometimes) unsupervised automated driving; in certain conditions the driver may leave full control to the vehicle automation and not supervise continuously. However, in L3, depending on the dynamically changing conditions (which might be related to traffic, or weather, etc.) the vehicle may have to return control to the driver at relatively short notice; but it is required to do safe in a safe manner, allowing sufficient handover time. For this reason, the MEDIATOR project describes L3 also as "*Standby*" mode; the driver must always be standby to take over control within a reasonable timeframe.
- **L4** driving goes one step further: there the Operational Design Domain (ODD) where full automation can be used must be clearly known and defined in advance in such a way that there are no such relatively short notice necessary handovers which are dependent on dynamically changing conditions. That is, the distances and time in which automation can be used are highly predictable, and can be large, allowing for the driver to be farther out of the loop. For this reason, the MEDIATOR project describes L4 also as "*Time to Sleep*" mode, assuming that the time available in automation mode is long enough to make it worthwhile for the driver to take a nap, and there is time enough to gradually wake up the driver and bring him/her back into the loop when approaching the end of the ODD. Another context for L4 automation is the so-called "Robotaxis" of Waymo already somewhat operational in a few US cities; there no human driver at all is required anymore (there are just "passengers"), but like all L4 contexts the ODD is strictly limited to certain zones in which the vehicle can operate. (This robotaxi use case is not a use case Mediator has concerned itself with.)

In MEDIATOR HMI terminology, both L3 and L4 are called "*PILOTED*" modes; but they are each associated with different HMI configurations to avoid mode confusions and to optimise for the specific driver roles and expectations.

Table 1 summarizes the SAE automation levels and the terminology used in MEDIATOR project.

Table 1: SAE automation levels and MEDIATOR terminology

SAE Automation levels	Description	MEDIATOR general terminology	MEDIATOR HMI terminology
0	No automation	Continuous Mediation (CM)	MANUAL
1	Longitudinal OR Lateral assisting automation		
2	Longitudinal AND Lateral assisting automation		ASSISTED
3	Conditional unsupervised automation	Driver Standby (SB)	PILOTED
4	High level unsupervised automation	Time to Sleep (TtS)	
5	Full automation		

1.2. Overall evaluation strategy and principles

The deliverable describes the development activities of two Mediator in-vehicle prototypes (the first focused on Human Factors (HF) and the second focused on Technical Integration (TI) of the Mediator software components) and the implementation of them in two vehicles from different car manufacturers, with different levels of automation. A central idea has been to reduce the overall complexity of development by allocating components of different complexity to each of those two vehicles, such that more manageable prototypes result, each with their own focus suitable for the research questions evaluated in on-road studies. In this way, it has been possible to break down the complexity into two more manageable subtasks and speed up the development by letting two (smaller) vehicle integration teams work in parallel on separate vehicles with a separate focus.

The Mediator Human Factors (HF) in-vehicle prototype focuses on the 'upper loop' of the Mediator conceptual diagram, as shown in Figure 1.1. It realises and explores the most sophisticated driver state technology and the most sophisticated HMI version(s). This vehicle has no actual vehicle automation and instead relies on a Wizard of Oz-like set-up to simulate vehicle automation. The focus of the HF in-vehicle prototype is on presenting to the participants the full concept HMI experience and recording their behaviour, response and experiences while driving on a real-world realistic route, with simulated high levels of vehicle automation. The simulated high level of vehicle automation is realized by having a wizard sitting in the actual driving position of a UK-oriented right hand steering position vehicle; whereas the naive participant sits in the front passenger seat (on the left side), equipped with a steering wheel and the most complete and sophisticated HMI.

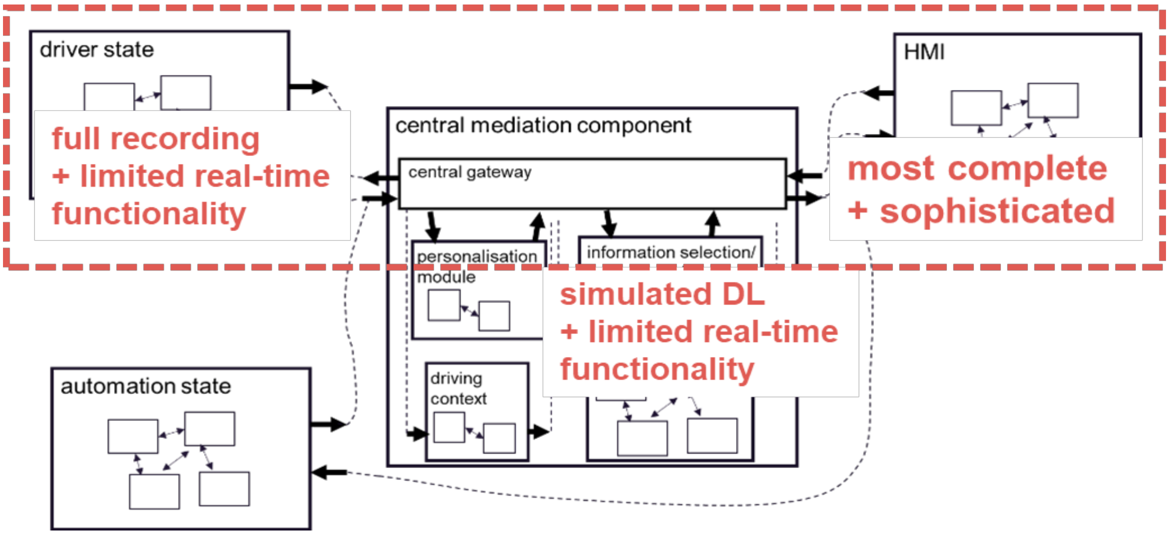


Figure 1.1: The first Mediator in-vehicle prototype focused on Human Factors

In the Mediator HF in-vehicle prototype the HMI is, in terms of various multimodal actuators, the fullest and most sophisticated HMI, compared to all HMIs used in the other platforms developed to assess the Mediator system. For driver state, the full sensor suite of cameras and physiological sensors are used, and data from that are recorded for post-hoc analysis. Next to recording, some real-time driver state functionality is also realised, by using a commercial eye tracker system for distraction detection. Decision Logic is largely simulated, focusing on going through pre-programmed scenarios (like what happens in some driving simulators); but there is some real-time functionality for driver corrective actions based on real-time distraction and fatigue detection.

The Mediator HF in-vehicle prototype is a Wizard of Oz (WoOz) vehicle, specifically designed and developed in MEDIATOR project; it consists of a second set of driving controls on the left side, consisting of functioning but not functional steering wheel and pedals (Bangler et al., 2020); in this vehicle the actual control of the vehicle is performed by the wizard, a professional driver sitting in the right hand driving position in the vehicle, and the naïve participant driver faces the Mediator HMI on the left hand side (Figure 1.2).

Figure 1.2: The Mediator Human Factors prototype vehicle.

The Mediator TI in-vehicle prototype focuses on the left side of the Mediator conceptual diagram, as shown in Figure 1.3; and it necessarily limits the automation level to what is feasible on a current vehicle driving on the road, in particular Level 2 ("Continuous Mediation", "Pilot Assist") automation. It focuses on the automation and automation state side of the Mediator system in conjunction with the driver state side and driving context side, allowing demonstration and evaluation of the real complete Mediator Decision Logic component. This prototype has a basic HMI, allowing for more technical Mediator logic evaluation and not the full envisioned user experience.

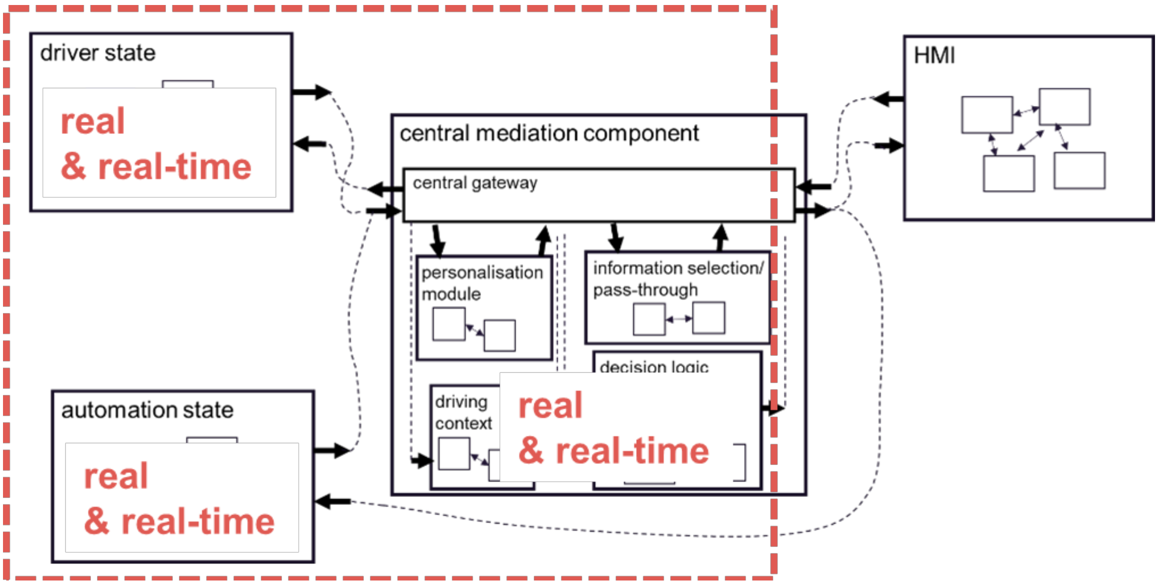


Figure 1.3 : The second Mediator in-vehicle prototype focused on Technical Integration of the Mediator Components

The Mediator TI in-vehicle prototype has L2 and continuous mediation automation and corresponding focus on real automation and automation state and decision logic; but it has a basic Mediator HMI focused on the large central console screen (see Figure 1.4).

Figure 1.4: The Mediator TI in-vehicle prototype

1.3. Main development choices

In the Mediator HF in-vehicle prototype, there is no real vehicle automation and consequently there is a simplified Automation State and a Simplified Decision Logic based on the information derived from the navigation system (point of interest, traffic, and road information). The Simulated/Simplified Decision Logic component plays out pre-programmed scenarios based on passing fixed positions in the driven evaluation route(s) and some limited real-time functionality based on detection of degraded participant driver performance by the driver state systems. The Driver State component operate only in part real-time (to feed real-time distraction detection information to the Simulated/Simplified Decision Logic component). Other than limited real-time functionality, the main purpose is recording for post-hoc analysis of the multi-modal (visual and physiological) driver state information (with focus on distraction and fatigue, and to some extent comfort). The highest level of sophistication in the Mediator HF in -vehicle prototype lies in the HMI (Grondelle et al., 2021), with sophisticated methods to invoke participants' mode awareness of the (simulated) automation levels in the most sophisticated way, which also include time budget awareness associated with current and upcoming automation levels. Sophisticated and interactive 3-step transition of control procedures (also called "rituals") were developed for transitioning between different (simulated) automation levels, as well as likewise 3-step Degraded-Driver "Corrective" actions aimed at mitigating detected fatigue (sleepiness) and distraction.

In the Mediator TI in-vehicle prototype, the focus is on technical evaluation of the software components Driver State, Automation State, Driving Context and Decision Logic, compromising instead in terms of HMI sophistication. Thus, this in-vehicle prototype includes a full stack real-time Mediator concept system that can be evaluated on-road in real-world circumstances with a real Level 2 (Continuous Mediation) automation in the vehicle, and the driver experiencing and driving the vehicle and real-time Mediator functionality. This prototype, however, obviously does not have Level 3 and/or Level 4 automation and, therefore, cannot evaluate those aspects of the full Mediator concept (which the Mediator HF in-vehicle prototype can, albeit only by simulating such higher levels of automation). The Mediator TI in-vehicle prototype has simultaneous, real and real-time driver state and automation state assessment, in combination with a real and real-time driving context. The vehicle's driving context allows to the real-time central Mediator Decision Logic to operate for real in realistic settings and allows to the evaluation of how sensible and intuitive decision logic's actions and suggestions are in real-world situations.

Table 2 summarizes the Mediator main components related to the two in-vehicle prototypes, showing what type and level of sophistication of features each of the two in-vehicle prototypes contains, i.e., what design choices were made for each of the in-vehicle prototypes in terms of specific Mediator feature variations. A detailed description of the development of two Mediator prototypes platforms are reported in the chapters 2 and 3.

Table 2: Mediator main software components and Mediator in-vehicle prototypes: "Match" table

Mediator main sw components	HF in-vehicle prototype	TI in-vehicle prototype
Driver state – distraction & fatigue	Real-time distraction & fatigue Recording for post-hoc full system;	Real-time, but only camera-based system (no physiological sensing)
Driver state – comfort	Recording, interviews	Simple, table/ situation-based, use case focus
Driving context	Simplified: Some real & real-time functionality fed by vehicle/route	Real and real-time, fed by vehicle/automation systems, map, other data.
Automation State	Limited simulation, using pre-programmed route / triggers based on the start and end of each use case included in the automated sequence of the predefined trip in Italy and Sweden	Real and real-time, use case focus, development focus
Decision Logic	High-level decisions simulated/triggered; with real and real-time low-level decision logic for specific use cases	Real and real-time; but focused on simple, robust version
HMI	Real and real-time, fullest version of HMI Mediator development The HMI integrates several commercial and prototypes HMI components in line with the HMI holistic design concepts	Basic, in terms of limited multi-modality (visual and auditory only, one screen instead of two) but in line with Mediator HMI holistic design concepts

1.4. The two in-vehicle prototypes and the MEDIATOR evaluation activities

The MEDIATOR evaluation activities focus on the two main evaluation areas: technical and user evaluation.

- Technical evaluation aims at assessing the performance, reliability, functionality, and effects on driving safety of the Mediator system.
- User evaluation aims at assessing acceptance, trustworthiness, perceived safety, and user-friendliness of the Mediator system for different users. User groups consist of naïve and professional users, different age groups as well as gender-balanced samples.

The two Mediator in-vehicle prototypes are used on-road in testing activities, for the evaluation of the Mediator integrated system. On-road tests are very challenging and cover a varying extent of these two areas, because it includes users (naïve / professional). Depending on the study type (e.g., involving naïve participants or professional test driver) and vehicle availability, driving time can be high. Thus, large amounts of real data can be collected under varying conditions. On-road studies potentially allow for various options regarding user and technical evaluation. On the other hand, real vehicles pose constraints on integrating additional new devices due to safety aspects, space, and electrical power limitations as well as potentially restricted access to vehicle data. The flexibility, variety and reproducibility of scenarios is limited due to the technical, safety, ethical and environmental constraints. Ethical and legal issues play a more important role than in simulated environments due to real driving risks and regulations of road authorities. The Mediator HF in-vehicle prototype uses a Wizard-of-Oz (WoOz) approach to overcome some of these issues, including testing potentially critical scenarios with users (e.g., distraction, fatigue).

Within the testing activities the two in-vehicle prototypes are used on-road in Italy and Sweden in different use cases (UC), related to different automation levels. The UCs provide a description of the functional range and the desired behaviour of the Mediator system, whereas “scenarios” provide the concrete implementation of the UCs. As reported in the deliverable D1.4 (Cleij et al., 2020) a total of ten UCs were designed to verify the scope of the MEDIATOR project in each evaluation study (e.g., road type, parameters, manoeuvres, etc.). In the following a summary of the ten UCs is given:

1. Mediator system initiates takeover (human to automation): Degraded human fitness, caused by either drowsiness (a) or distraction (b), is detected by the Mediator system. The system reacts by initiating a takeover to automation.
2. Driver takes back control: The driver uses the HMI to indicate a desire to take back. The Mediator system reacts by confirming that the driver is fit enough to drive and guiding the takeover.
3. Comfort takeover (human to automation): Either the driver (a) or the Mediator system (b) initiates a takeover from human to automation.
    a) The driver indicates via the HMI that he/she is not motivated to drive. The Mediator system reacts by confirming the automation fitness and guiding the takeover.
    b) The Mediator system detects an event, such as receiving a text message or an upcoming traffic jam, from which it concludes that the driver comfort could be improved. The system reacts by suggesting a takeover to automation.
4. Corrective Action: While driving in StandBy (SB) the human driver becomes drowsy, the Mediator system reacts by initiating an action to improve the driver fitness and monitors the effect.
5. Mediator initiated takeover (automation to human): A planned (a) or an unplanned (b) takeover from automation to human is initiated by the Mediator system.
    a) The automation indicates that the current route leads to automation unfitness as it will leave its Operational Design Domain (ODD). The Mediator system reacts by preparing the driver for and guiding the driver through a non-urgent takeover.
    b) The automation indicates that its fitness is rapidly degrading and can soon no longer perform the driving task. The Mediator system reacts by informing the human driver and guiding the urgent takeover.
6. Comfort switches on: Either the driver (a) or the Mediator system (b) switches on driving in Continuous Mediation (CM).
    a) The driver indicates via the HMI that he/she is not motivated to drive. The Mediator system reacts by confirming the automation fitness and switches on CM.
    b) The Mediator system detects sufficient fitness for driving in CM from which it concludes that the driver comfort could be improved and reacts by suggesting switching on CM.
7. Preventive Action: While driving in CM, the driver is supported by the Mediator system in performing the monitoring task. The system does this by trying to prevent underload and keeping the driver in the loop.

8. Corrective Action: While driving in CM, degraded driver fitness is detected by the Mediator system. The system reacts by initiating a corrective action to improve driver fitness.
9. CM shuts off instantly: While driving in CM, the automation fitness degrades, and automation can no longer perform its driving task. The Mediator system reacts by communicating to the driver that CM is switching off.
10. Smooth transition from Time To Sleep (TtS) to SB: while driving in TtS the driver is fully disengaged from the driving task when the automation indicates that the current route will leave the ODD. The Mediator system detects adequate automation fitness for driving in SB and reacts by informing the driver that SB will be switched on and subsequently monitors the required driver fitness.

1.5. The on-road tests and the different stakeholders' needs

The Mediator HF in-vehicle prototype, a WoOz vehicle with basic automated driving levels, is used for the on-road studies in Italy and Sweden. This solution, even if limited, because the participant does not have any control of the vehicle, has the advantage that it is possible to run experiments simulating with higher levels of automation that aren't yet available.

The **on-road study in Italy** aims to evaluate naive users' experience on the following aspects:

- the acceptance and trust of the three Mediator levels CM, SB and TtS of the "automated driving" with and without the Mediator HMI, in an ecological way on a public road
- the Mediator HMI solutions in the different driving conditions, to select the most appropriate one to be used in the second on-road study in Sweden.

The Italy MEDIATOR study is conducted: on public roads around Orbassano (TO), with the following characteristics: around 46 km of length, urban and rural (10 km), highway (36 km). During the on-road test the participants experienced the following use cases[1]:

- UC 1a: Mediator system initiates takeover (human to automation)
- UC 1b: Mediator system initiates takeover (human to automation) caused by distraction
- UC 2: The driver desires to take back the control
- UC 3a: The driver indicates via the HMI that he/she is not motivated to drive
- UC 3b: The Mediator system detects an event (message)
- UC 4: The Mediator system reacts by initiating an action to improve the driver fitness (while driving in SB)
- UC 5a: The Mediator system initiates a planned takeover (automation to human).

The **on-road study in Sweden** aims to evaluate the functionality, potential safety effects and user acceptance of the Mediator system under different degraded driver performance conditions, including conditions of degraded automation. The route and the scenarios have been chosen to cover as many automation levels, UCs and Mediator functionalities as possible. This includes lower levels of automation, despite the limitations with the platform.

The route is about 83 km and takes just over 1h to drive. The route is essentially divided into three main stretches where the first is an urban road which affords SAE level 2 automated driving in the experiments, the second stretch is a rural road which affords SAE level 3 automated driving, and the third stretch is a motorway which affords SAE level 4 automation. The experimental protocol is designed to include several transfers of control between human and automation and between

[1] Sometimes the use case has been split in 2 parts: part a and part b; UCxa is related to fatigue and UCxb is related to distraction.

various automation levels. Distraction and fatigue detection, and associated corrective actions, are active throughout the experiment.
The route consists of 11 scenarios, which have been designed to evaluate the following Mediator functionalities and UCs:

- Corrective actions to counter distraction in CM and SB (UC 8).
- Corrective actions to counter fatigue in SB and TtS (UC 4, UC 10).
- Automation failure, SAE level 2 shuts off immediately (UC 9).
- Mediator system initiates the transfer of control CM → SB due to distraction (UC 1).
- Mediator system initiates the transfer of control CM → SB when entering a CM capable road.
- Mediator system initiates the transfer of control SB → TtS when entering a TtS capable road.
- Mediator system initiates the transfer of control before leaving ODD, SB/TtS → CM (UC 5a).
- Mediator system initiates the transfer of control before leaving ODD, TtS → SB (UC 10).

The Mediator TI in-vehicle prototype is used for **on-road in Sweden** to evaluate the functionality and user acceptance of the Automation State component system under different driving contexts, including the assessment of how well the system can predict bad automation performance, but also more generally the complete Mediator system including central Decision Logic, Driving Context, Driver State, Automation State, and HMI. All drivers were professional test drivers and drove the route several times.
The route consists of five main scenarios; but other scenarios including degraded driver state scenarios are also possible when they occur naturally. The main scenarios have been designed to evaluate the following use cases:

- Driver initiated CM on (UC6, scenario 1)
- Mediator initiated CM on (UC6, scenario 2)
- Low automation performance, CM shuts off immediately (UC9, scenario 3)
- Shorter-term planned Mediator initiated takeover from CM (adapted UC 5, scenario 4)
- Longer-term planned Mediator initiated takeover from CM (adapted UC 5, scenario 5).

2. Mediator Human Factor in-vehicle prototype

The Mediator Human Factor (HF) in-vehicle prototype realizes and explore the most sophisticated driver state technologies and the most sophisticated HMI version(s). This vehicle has basic level of Automated Driving System (ADS) sophistication and relies on a not functional Wizard of Oz (WoOz) vehicle set-up.

To define the functional requirements of the WoOz platform, a detailed state of the art of WoOz vehicles used in research studies and small laboratory tests involving experts were conducted. Literature research on WoOz vehicles and small laboratory tests on-road are reported in Annex 1. As a result of the benchmarking analysis and related tests the following solutions emerged for the Mediator HF in-vehicle prototype:

- Right hand drive vehicle with some ADAS Level 1 (e.g., lane departure warning, emergency braking system, cruise control)
- Second set of driving controls on the left side, consisting of functioning but not functional steering wheel and pedals, (e.g., steering wheel rotating in accordance with the driving wizard steering wheel…)[2]
- HMI display with Mediator HMI in front of the left seat.

D.1.5 (Grondelle et al., 2021) reports the design of a holistic HMI (visual, audio, haptic), based on the development of new devices (properly developed within MEDIATOR project) and several on-market devices (like LED strips, displays for cluster and head unit to be used by the naive participants for feedback, infotainment, navigation purposes, for the sound system and the ambient lighting) that have been used in an integrated way with reference to the specific use case.
In Figure 2.1 an initial sketch of all Mediator HMI devices is reported.

[2] The second set of controls for the naïve participants (left seat) is not either by wire or mechanically connected to the vehicle control. To cope with the aim of testing in real life conditions, ensuring at same time safety performances and homologation requirements, the Mediator HF in-vehicle prototype has dual controls, without adding real or automotive proof functionalities.

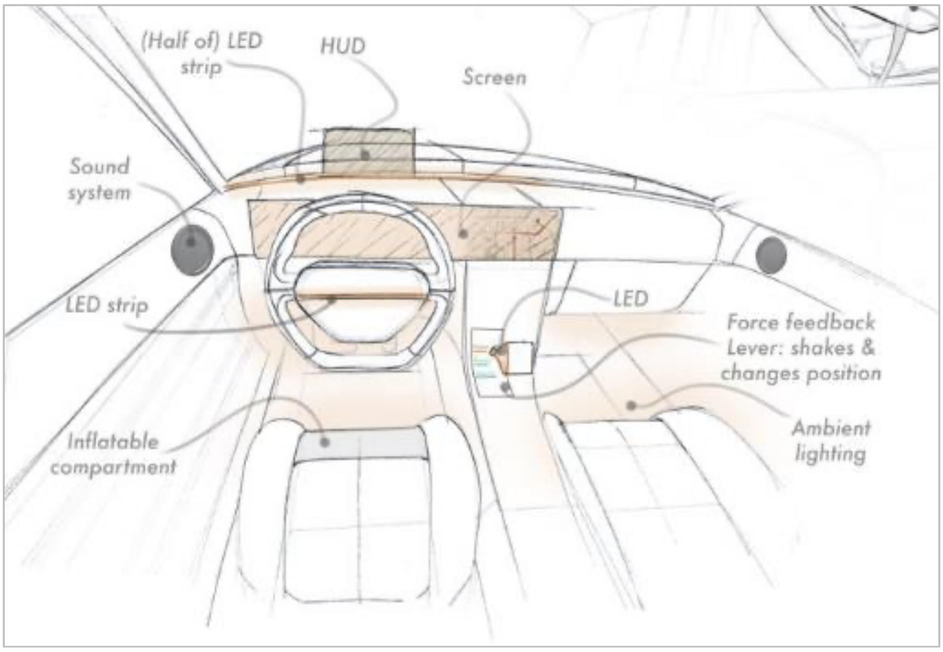


Figure 2.1 Mediator HMI components

2.1. Vehicle set-up

The Mediator HF in-vehicle prototype is used to evaluate in Italy and in Sweden functionality, safety effects and user acceptance of the Mediator system under different degraded driver performance conditions, including conditions of degraded automation.

The HF in-vehicle prototype preparation used an on-market Jeep Renegade with the following features:

- Right hand drive
- ADAS SAE Level 1 (e.g., lane departure warning, emergency braking system, cruise control).

Due to safety reasons the main vehicle constraint for having on-road tests with naïve participants was related to don't modify the homologation requirements**.** According to this, the main development choices were the followings:

- Wizard of Oz prototype vehicle with of a second set of driving controls on the left side, consisting of functioning but not functional steering wheel and pedals (Bangler et al., 2020), to allow the users to have an "automated" vehicle experience even if it doesn't have real automated functionality
- Each naive user (in the left seat) is always accompanied by an experienced driver (the wizard) in the right seat, who always controls the vehicle, and supervised by an experimenter (on the back seat)
- Data from naive users driving (the left side steering wheel and pedals data) are recorded, to collect data from "manual driving" of the naïve participant.

The design and development of the Mediator HF in-in-vehicle prototype is based on a driven design process which, in a structured manner, identifies the full scope of future developments and how they impact human behaviour, i.e., human – product interaction (Hekkert & van Dijk, 2011).

The chosen research-by-design method, which foresees in a sequence of rapid iterative design projects, aligns with this:

- Search among the commercial devices those that could satisfy the behaviour requirements defined in D1.5 (Grondelle et al., 2021) and could satisfy the safety requirements of the first Mediator in-vehicle prototype.
- Specify the HW architecture to manage the very different and miscellaneous devices chosen from HMI devices defined in D1.5 and the vehicle requirements, related to the constrain to adapt a on market vehicle. According this one hand constraint minor modifications respect to the HMI design have been done; on the other hand, the Mediator infotainment has required to remove the on-market infotainment system (replacing it with a dedicated and open-source development).
- The main HMI devices chosen for the realization of the Mediator system are automotive standard compliant and others were appositely developed within MEDIATOR project (i.e. shifter, the haptic seat belt).

In Figure 2.2 the architecture of Mediator HF in-vehicle prototype, with the full integration of the HMI components and related hardware for data acquisition and HMI triggering, is shown. The Mediator HF in-vehicle prototype is equipped with the following HMI components:

1. Dashboard led bar
2. Second steering wheel (WoOz related) with led bar
3. Ambient lighting bar
4. Pedals naïve participant (WoOz related)
5. HMI front monitor
6. Central display with infotainment system, driving context and sound system
7. Shifter
8. Haptic retractable seatbelt
9. Inflatable seat-compartment.

In addition, the vehicle is equipped with the following hardware devices:

11. Mediator embedded module for HMI, for Simulated Automation State and Simulated Decision Logic components
12. Data logger system acquisition
13. Smartphone/tablet for the experimenter (for the cameras system)
14. Sound system speakers
15. Ethernet Lan switch (according to the common messages-based communication on ZeroMQ (https://zeromq.org/) protocol)
16. Driver state sensors (camera and thoracic chest band)
17. HMI automation controller, gateway controller.

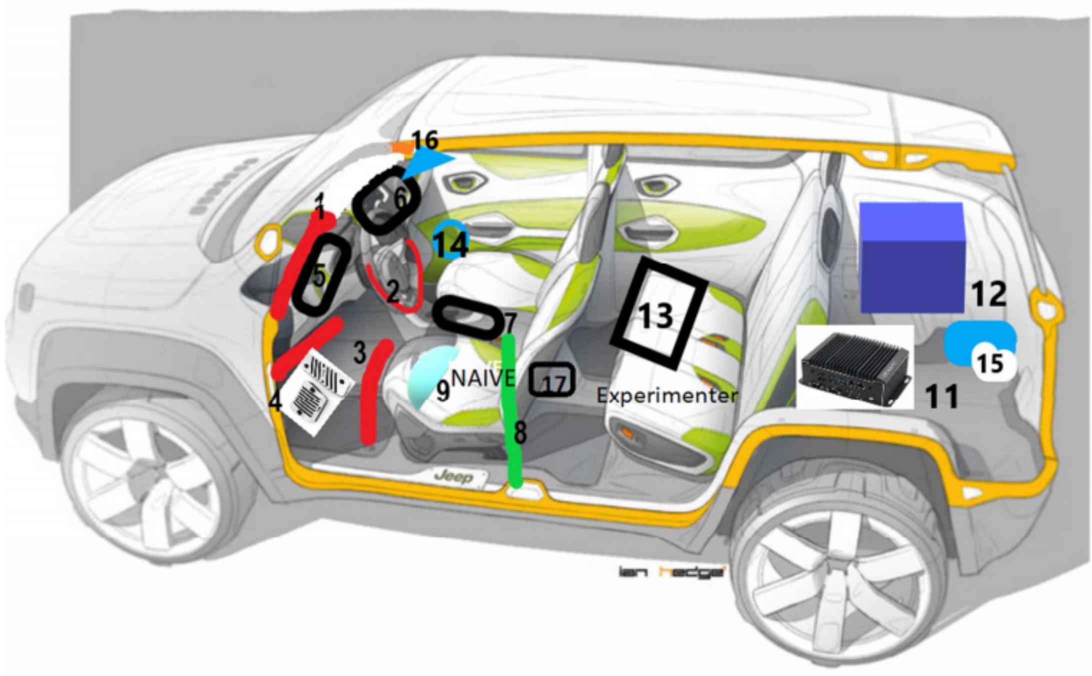


Figure 2.2 The Mediator HF in-vehicle prototype architecture

Minor changes on the in-vehicle prototype are related to specialize the in-vehicle prototype for the Sweden on-road tests:

- Updated the Jeep Renegade steering wheel, with biomedical sensors and integrated led bars
- Added new cameras for Driver State components.

2.1.1. Prototypal devices

In this paragraph the main devices installed on the Mediator HF in-in-vehicle prototype are described, with reference to the main scope: WoOz devices, HMI devices (Figure 2.3).

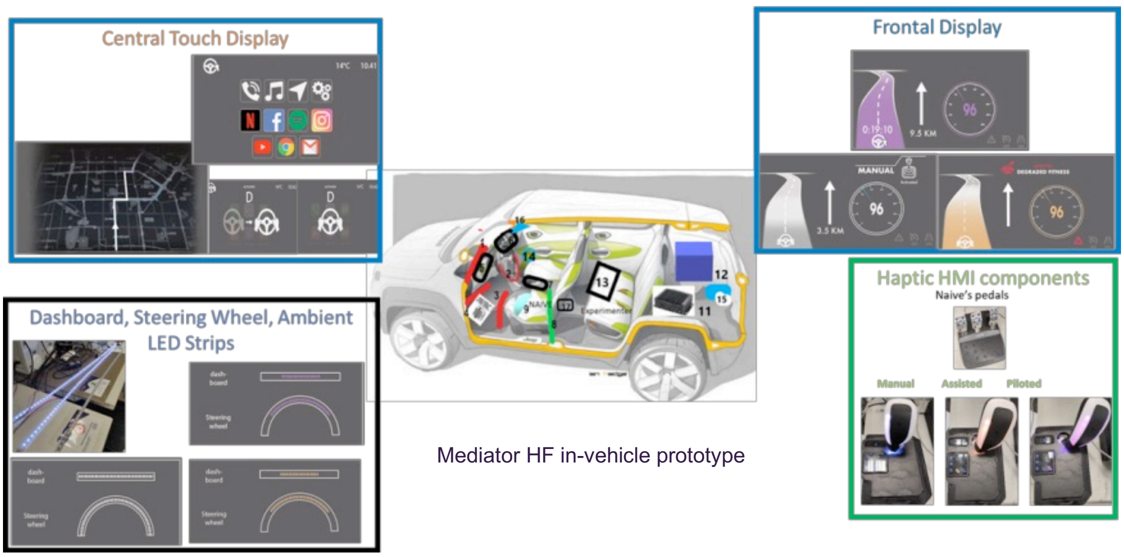


Figure 2.3 Mediator HF in-vehicle prototype: some HMI devices

WoOz devices

- Second Steering wheel, located in front of the passenger seat, is managed by the gateway controller. To install this device several packaging studies were done, also in addition to specific virtual validation analysis on the safety performances.
- Naive pedal board was installed to give to the naïve participant the impression to drive effectively. The pressure of the two pedals by the naïve participant is acquired and stored in the output data files and can be evaluated as a reaction of the naïve to HMI proposed in the Italian and Sweden use cases.
- Private Controller Area Network (CAN) for MEDIATOR project was installed to manage the vehicle information and the integrated software components and to preserve the safety of the standard vehicle, was defined. Vehicle information is an input for the Mediator system, but other vehicle data are needed to analyse the outputs of the Mediator trip during the test relating of the vehicle behaviour.

HMI devices

- Haptic retractable seatbelt. The device produces the behaviour of pretension and vibration as a tactile warning. It is connected at the private Mediator CAN bus and it is managed by the specific CAN message to:
  - Activate the pretension of the passenger seat belt
  - Activate the vibration (when the ritual of the use case is included).

Figure 2.4 Integrated seat belt passenger side and electric retractor for haptic functions

- Second steering wheel. For the Sweden tests the Jeep Renegade steering wheel was modified with the following innovative features:
  - integrated a LED-bar on the upper part of the rim; this LED-bar is part of the HMI developed within the MEDIATOR project.
  - Electrocardiogram electrodes. These electrodes give information about the occupants' heart rate for subsequent use in the fatigue monitoring module. For stability and redundancy reasons, an additional source of heart rate data comes from a consumer grade chest band heart rate monitor, communicating via Bluetooth.

The integrated LED-bar can be controlled to provide colours and patterns to communicate driving modes according to the HMI-specifications.

Figure 2.6 visualizes the new and innovative steering wheel used for preliminary laboratory tests.

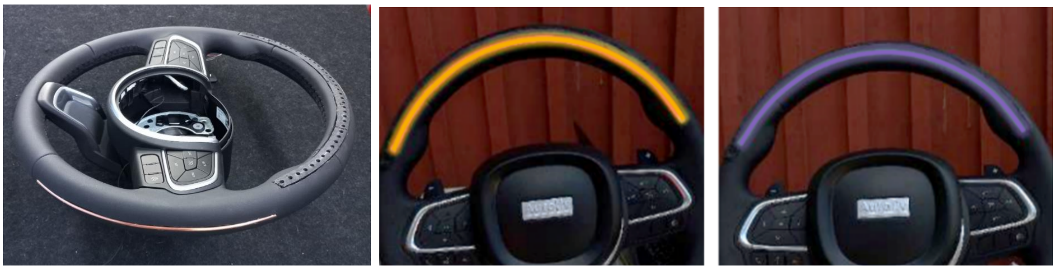


Figure 2.5 Innovative steering wheel for laboratory tests

After the laboratory tests the new features of new and innovative steering wheel have been installed on the Jeep Renegade steering wheel for on road tests in Sweden. Figure 2.6 visualizes the Jeep Renegade steering wheel with the new and innovative features for on road Sweden tests.

Figure 2.6 Innovative steering wheel installed on the Jeep Renegade for the Sweden tests

- LED Strips. Inside the HF in-vehicle prototype three LED strips are installed on the steering wheel, on the dashboard (passenger side), and inside to the cabin. The LED strips are managed according to the use case logic (Grondelle et al., 2021) developed inside the HMI component. The management regards the colour (linked to the driving level), the flashing frequency and the number of the activated LEDs inside each bar. Figure 2.7 visualizes the ambient lighting.

Figure 2.7 LED strips and ambient lighting

- Inflatable seat-compartment. The prototypal device, developed in MEDIATOR project, inflates and deflates to support an active seating position when the (naïve) driver needs to prepare for involvement in the driving task. These phases are managed by the HMI automation controller according to the logic for each use case.

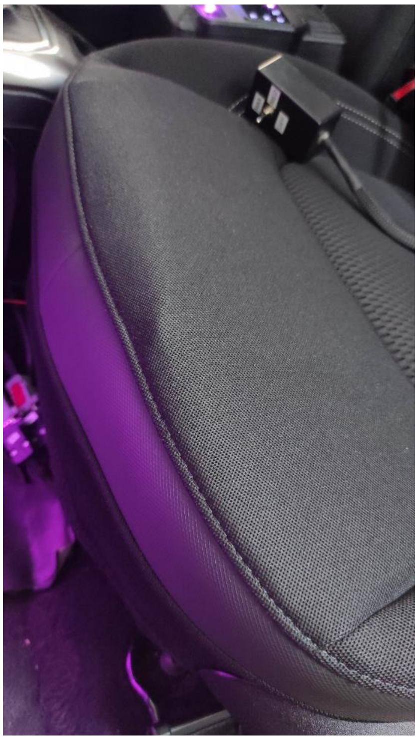


Figure 2.8 Inflatable seat-compartment

- Shifter. This device, designed and developed in MEDIATOR project, is the main HMI device. It allows the handover communication between the user and the automation. The naïve participant could move the lever to choose the Mediator driving modes are referred to as DA (Assisted driving), DP (Piloted driving) and D (manual driving). The driving position has been sent at the HMI Module and shared to the SDL module to decide the acceptance of driver's choice.

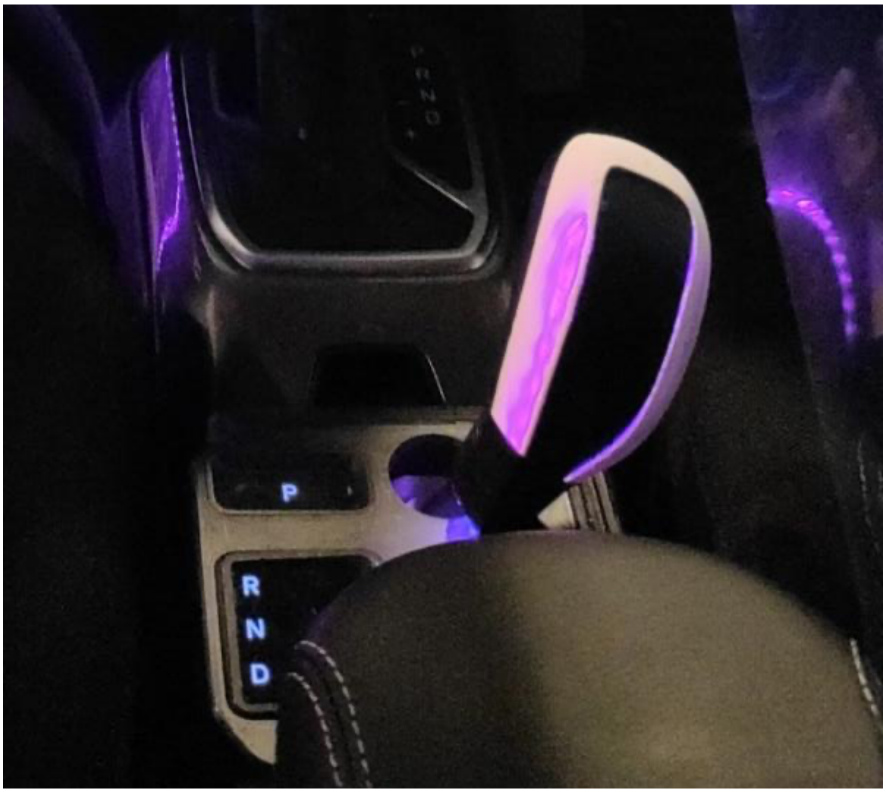


Figure 2.9: Shifter

- Display. The new display in Mediator HF in-vehicle prototype is composed by two devices:
  - In front of the naïve passenger seat an industrial monitor is installed to simulate the front display.
  - The infotainment cluster has been replaced by a central display.

  Figure 2.10 shows the frontal display linked by the HMI SW module.
  Figure 2.11shows the central display infotainment and navigation module.

Figure 2.10 Frontal display linked by the HMI SW module

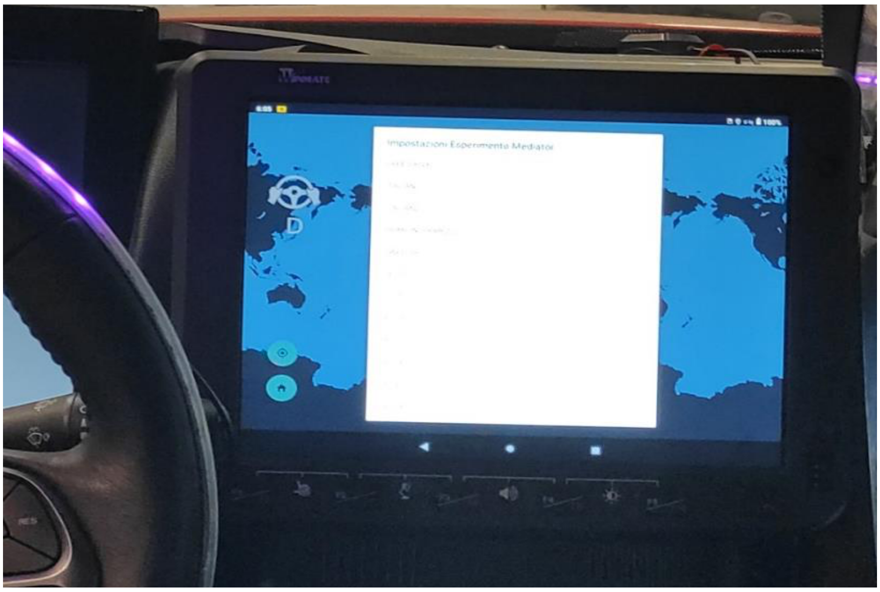


Figure 2.11 Central display infotainment and navigation module

Driver state devices

Within MEDIATOR project two different driver state devices have been developed and installed on the Mediator HF in-vehicle prototype.

The first driver state device was used for Italy and Sweden tests. It is composed by a camera-based real-time driver visual distraction detection algorithm and a real-time physiology-based fatigue detection algorithm. Both algorithms are hosted on a Raspberry Pi 4.

- The distraction detection relies on a commercial eye-tracker camera and is based on the VTI AttenD- algorithm (Ahlstrom et al., 2013).

- The fatigue detection device relies on heart rate variability. This algorithm is developed from data collected in the trials on sleepiness and automation (collected during the first MEDIATOR project's activities). For further details see section 2.2.2 Driver State.

The second driver state device is a multi-cameras system, that has been used only for Sweden tests. In this in-vehicle prototype the system is configured only for recording, with the objective of full but post-hoc analysis of the recorded video data (combining it also with the physiological data). This analysis is done both for distraction and for fatigue. Figure 2.12 visualizes the prototypal cameras and computer set-up for the driver state devices, installed on HF in-vehicle prototype. Two computers are used and connected by USB3[3] cables and connectors to four cameras installed in the (simulated or real) vehicle cabin:

1. Monochrome (Near Infrared or NIR sensitive) driver face view camera. For the multiple goals of facial feature extraction for emotion/discomfort and fatigue estimation; gaze estimation of where the driver is looking; outside and inside the cabin, and Eyes-Off-Road /Non-Driving Related Tasks (NDRT) gaze analysis
2. Upper body view of driver camera (important for driver activity recognition, for post-hoc distraction analysis
3. Outward-looking (forward view) camera (for real-world vehicle outside driving context).
4. Over the shoulder (dashboard/cabin view) camera mounted on the internal roof: seeing the whole dashboard/HMI that the driver sees (Used for post-hoc analysis and visualization of how the driver interacted with the HMI and where his gaze was).

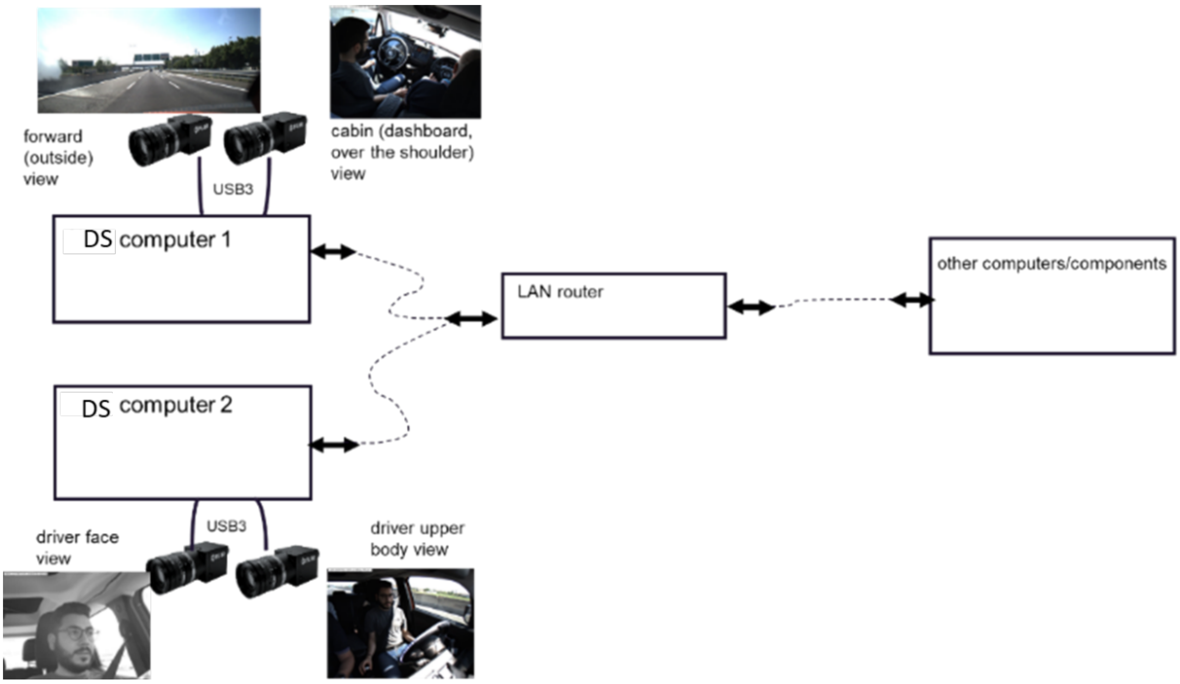


Figure 2.12 Driver State device's cameras and computers set-up, installed in the first Mediator in-vehicle prototype

Figure 2.13 shows the camera positions of these face view, body view, forward view, and cabin (over the shoulder, dashboard) view cameras in the Mediator HF vehicle prototype. Figure 2.14

[3] USB 3.0 is the third major version of the Universal Serial Bus (USB) standard for interfacing computers and electronic devices.

shows example images (from the test drives in May 2022) from these face view, body view, forward view, and cabin (over the shoulder, dashboard) view cameras.

Figure 2.13 Camera positions of the face view, body view, forward view, and cabin (over the shoulder, dashboard) view cameras in the Mediator HF in-vehicle prototype.

Figure 2.14 Example images from the Driver State view cameras.

2.1.2. Communication Interface

The Mediator HF in-vehicle prototype uses a real-time messages-based communication between all other main components and logging technical framework based on ZeroMQ (https://zeromq.org/), according to the definition occurred in the previous development activities.

According to this a standard, fast, and robust standard *proto buffer* is used. This allows for inclusion of all kinds of types of information, numerical, text, byte-level encoded information of images, etc. in a simple message format in which various fields are defined and shared between the partners between nodes within a standard computer Local Area Network (LAN) inside the Mediator system.
All the Mediator sw components 'live' primarily on the ZeroMQ communication based on the defined framework. The general Mediator ZeroMQ framework uses message definition based on the Google Protocol Buffer message format and message.

2.2. Main Mediator software components

The main software components of the Mediator HF vehicle platform are reported in Figure 2.15, in terms of main software and data information flow between them, with the following details:

- Yellow blocks are referred to the HMI devices
- Green blocks are the vehicle standard devices and the gateway controller between the vehicle and the Mediator system
- Cyan blocks are the main components of the Mediator system
- The links represent the type of the communication protocol used to pass through the data between each main component:
    - Universal Asynchronous Receiver-Transmitter (UART)/serial protocol
    - Ethernet communication based on Mediator LAN network
    - CAN, is a robust vehicle bus standard designed to allow to microcontrollers and devices to communicate with each other's applications without a host computer.

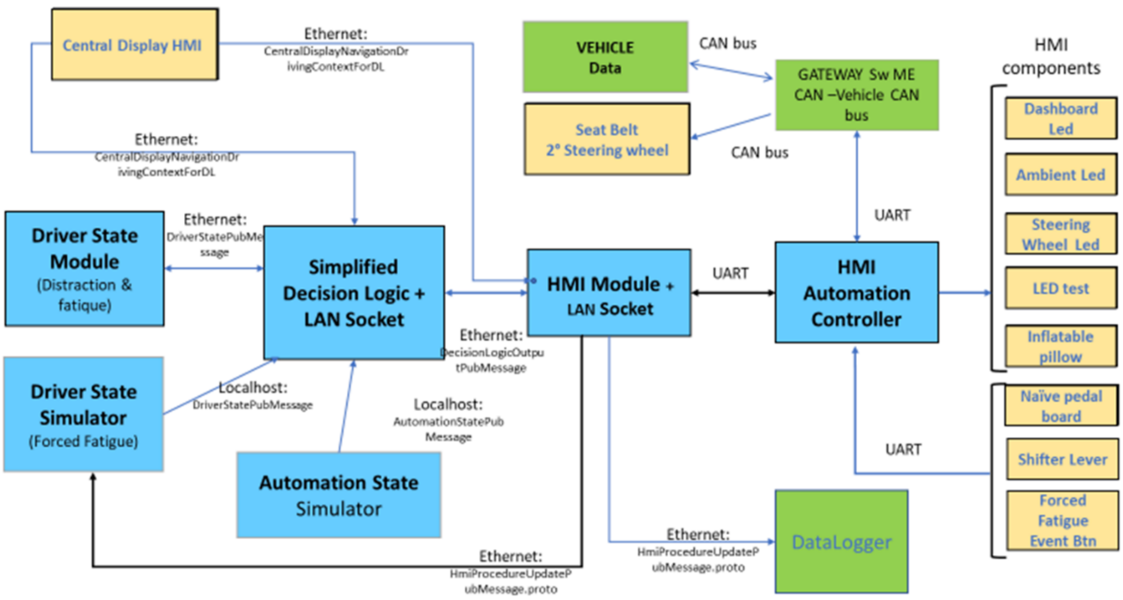


Figure 2.15 SW architecture of Mediator HF in-vehicle prototype

2.2.1. Communication modules

All data and information from the main components included in the Mediator system, corresponds to input and output of the Simplified Decision Logic (SDL). As explained, there are two main ways of communicating such messages.

- The first is through a publish message. This means that messages, once produced by a component, are simply pushed out or "published", with a certain "content description" associated to it describing what the message is about.
- The second type of protocol that has been realized is the request/reply message. This means that a component may produce and send a request message to another component, which essentially asks for specific information based on supplied parameters. The 'responding' component then produces and sends back a reply message containing the answer to that question, and/or performs some action that is required of it. An example of this may be the Decision Logic requesting a specific action from the HMI component, to which the HMI component replies with details on the precise HMI procedure that is being performed.

On a technical level, the Zero MQ framework is the main communication protocol for sending and receiving the messages from the main software modules (Simplified Decision Logic, Decision Logic, Driver State, Context Driving and HMI). The messages sent around using the Zero MQ framework use the standard, fast, and robust protocol buffers message serialization standard.

To implement the HMI ritual, the flow of the behaviour of HMI components in each use case, it was necessary to design the activity diagrams to define the logic and data flows between the main components of the Mediator system; in Figure 2.16 an example of activity diagram, related to the UC 2 is reported.

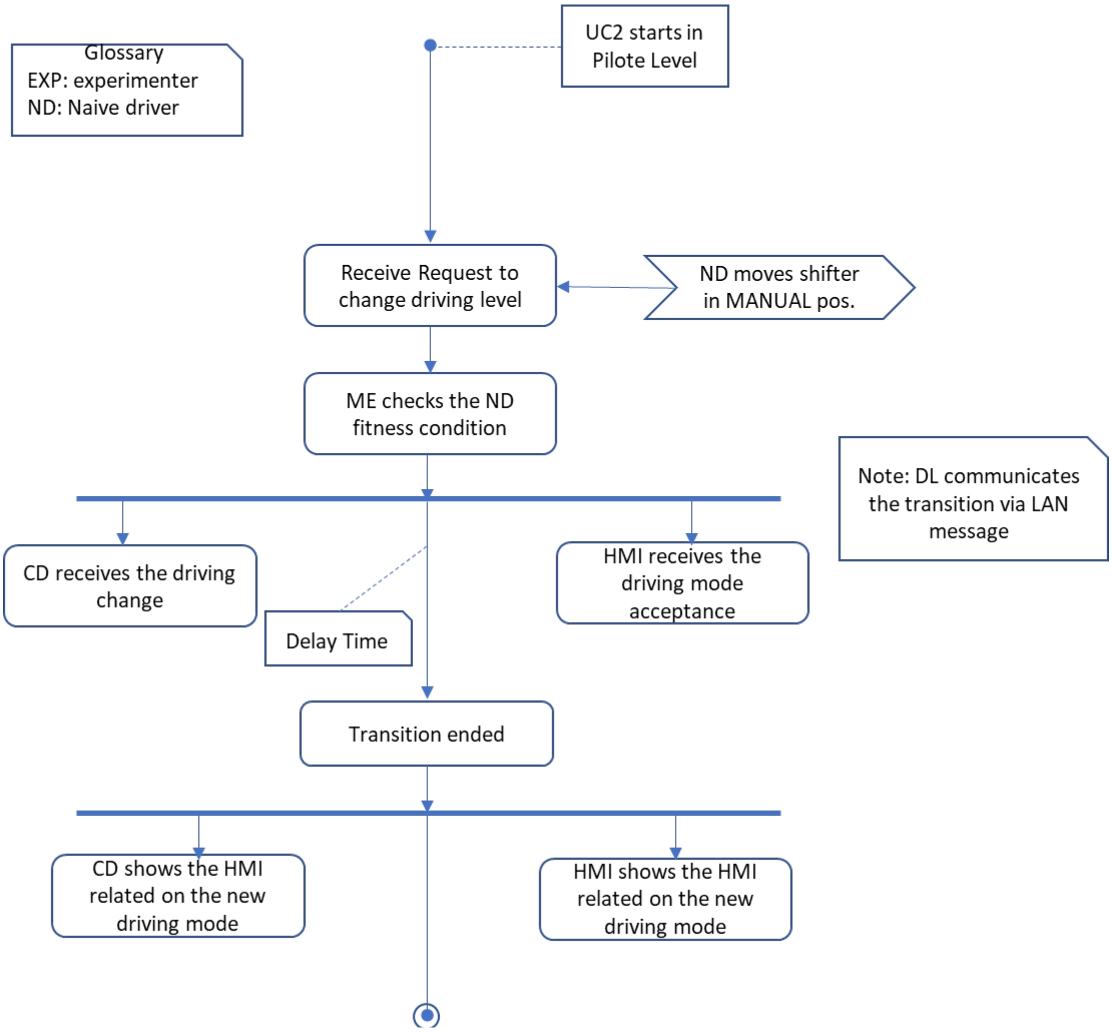


Figure 2.16 Activity diagram of the use case 2

2.2.2. Driver State

Physiology-based fatigue detection

The fatigue detection is based on physiology, specifically it is calculated by heartbeat variability. Wearable device (Polar H10) is used in this study, which measures the ElectroCardioGram (ECG) signal of the participants and transmits to the data process device (Raspberry Pi). To reduce data traffic instead of transfer raw ECG data the Beat-to-Beat Interval (BBI) is sent. Each collected BBI of 5 minutes is processed by a group of feature extraction functions. The features extracted are of different types include time domain feature, frequent domain feature, geometrical feature and so on. A pre-trained decision tree model predicts drivers Karolinska Sleepiness Scale (KSS) score from those features of every 5 minutes. Once the predicted KSS and its credibility are obtained, the data process device packs information according to a defined Protobuf message and publishes the message in the test vehicle network, such that other component, for example the Decision Logic, can use it.

Real-time distraction detection

To create a more realistic behaviour for the corrective warnings for distraction as compared to have the wizard estimate the participant distraction-state, a real-time distraction detection algorithm was added into the Drive State module. The algorithm uses commercial eye tracker camera and VTI-AttenD-algorithm, based on three levels of detection for the escalation of the distraction use cases. The distraction algorithm behaves as a time integrator. The integrand is the eye gaze target types: eyes on the road, eyes on display or mirror, eyes off the road. When the driver looking at the road (windshield) the integrand value is positive. Once the driver looks at screen or mirrors the integrand value is zero for 2s then becomes negative if the driver's eye still not back to the road. If the driver's eye gaze is not on either windshield nor display or mirrors, the integrand value becomes negative. When the eye gaze is not detected, the algorithm will check if driver's head is facing to the strictly front. In this case the algorithm considers the situation same as eyes on the road, otherwise the integrand value becomes negative. The integration starts from value equals to 2, and the value is clamped between 0 and 2. The integration value is published as soon as new eye tracking data is received by the data process device. While the driver being distracted for more than two seconds, that is the integration value equals to zero, a warning action should be taken. The VTI-AttenD- algorithm was later modified to output three levels of distraction unless the driver responds to the corrective actions from the HMI, and thus also effectively constitutes part of the Simplified Decision Logic for HMI triggers (see also 2.2.3 Simplified Decision Logic).

Driver State detection is unchanged in the Sweden tests, but capabilities are added for data collection for post-drive analysis of driver states distraction and fatigue.

2.2.3. Simplified Decision Logic

The inputs of the Simplified Decision Logic (SDL) component come from the Driver State (DS) component, the Automation State (AS) component (emulated from navigation data), and the central Driving Context (DC) component (emulated from some navigation data) like the real module to maintain the same structure of the Mediator system.

This component is simplified because it is not directly connected to the real current scenario but is connected to the trip using the predefined point of interest. The main activities of the software module are the followings:

- simulate the logic of the automation state and driver state to run the sequence of the current use case in automatic mode starting from information derived from Navigator module outputs; according to this a software use case simulator has been developed to automatically run the use case sequences and communicate with the Decision Logic component.
- Transmit via LAN communication (ZeroMQ), the GPS coordinates of the Italian or Sweden road trip to manage the start and the end of the use case and manage the ritual in terms of timing to be done react the HMI, the CD and HMI components
- Manage the data from the input modules (DS, CD) to the HMI module using the LAN message (ZeroMQ).
- Simulates the observer pattern module to control that all modules are running in LAN and to check if the data is congruent during the automatic sequence of use cases in the road trip
- Develop a graphical interface to test in laboratory the progress of the automatic sequence and the related logic for each use case.

Store the received data and output LAN messages (ZeroMQ),

2.2.4. HMI

The HMI component is based on the HMI Functional requirements, and it has been translated into design requirements defined at beginning of the MEDIATOR project. The HMI component is developed using modular approach: e.g., specific task and interactions are designed as individual routines that develop the escalation ritual for each UCs.

The HMI component is spitted into three main sub-components:

- The global routine and the internal central gateway, frontal display routine in HMI embedded module. It manages all input data and the HMI states related to the different use cases
- The HMI automation controller to drive the behaviours of the various HMI components. It communicates by a protocol appositely customized for MEDIATOR project, to receive the output vehicle data (e.g., vehicle speed, active Autonomous Emergency Breaking, active Lane Departure Warning, etc.).
- The central display sub-components with navigation tool. It manages the following information:
  - geospatial data,
  - pre-defined Italian and Sweden routes,
  - experiment start and progress
  - Interaction with other commercial apps like digital radio, Spotify, Netflix.

The main activities of the HMI component are summarized below:

- Initial processing routine is the communication interface for the Simplified Decision Logic processing parameters on enforced or preferred actions, like level transfers of increasing driver fitness, conditions, and the scope of options the human has, like available autonomous levels.
- Enforced take-over routines, manage either driver or automation enforced take-over, and may evoke a controlled emergency stop.
- Negotiation routine informs the driver on available autonomous levels, negotiates with the driver on the level to be selected, and handles conflict.
- Driver fitness routine to increase current or future estimated driver fitness.
- Human preferences routine that processes both the outcome of the negotiation routine and all human inputs into the HMI, into primary and secondary feedback to simplified Decision Logic.
- Information management routine controls primary information to the driver, as well as secondary information (entertainment) and is crucial in managing information load with respect to autonomy, trust, and comfort.
- Manage the set of commands at the automation HMI controller to react in the defined mode during the escalation routine each HMI components.

2.2.5. Data logging for Italy and Sweden tests

All Mediator main components send information in output based on the P*roto Buffe*r definition via LAN communication with the defined rate frame. The dedicated software has been written to sniff LAN packages using a higher frequency than the modules for the Italian trip, and this is in the data logger PC. The Data Logger logs all information for each Mediator main components.
For example, the main information logged from the Simulated Automation State module are:

- Number of use case, message frame
- Current driving level, recommendation transition, next driving level
- Next transition
- Degradation automation level
- Criticality of fitness

From Driver State there are the following type of information:

- Number of use case, message frame
- Distraction status
- Fatigue status

- Fatigue KSS
- Input sensors connected (chest band, camera, external switch to force the KSS of the Med, Max score)

From HMI module there are the following type of information:

- the LAN input data
- the Vehicle CAN bus data
- Participant ID, Number of use case, message frame
- HMI state in which it has been included the behavior of the set of HMI components.

From the CD module logs the following type of information:

- Number of UC, message frame
- the latitude, longitude data
- trip distance [m] and in time [s]
- Distance, and time to the next point of interest.
- Manoeuvre type, road type
- Area and next manoeuvre plot in Navigator (*OpenstreetMap* app).

Next to these data sniffers, for the Sweden tests the central gateway software component was also added. This component was used here both for software component health and status monitoring and for data logging of some components not logged by the data sniffers described above. These components include the four camera streams of the camera-based driver state system, the self-reported KSS values reported by the drivers, and several types of data related to the distraction tasks for the drivers.

3. Mediator Technical Integration in-vehicle prototype

The Mediator Technical Integration (TI) in-vehicle prototype is meant to combine all Mediator components to demonstrate the full Mediator system. All components have been deployed on the vehicle with real and real time functionality. The only component that is considerably basic compared to the other Mediator prototypes, is the HMI – which is used to an end to demonstrate the functionality of the Decision Logic, which in turn is based on the input of the Driver State, Automation State, and Driving Context component.

The development of the Mediator TI vehicle prototype is based first and foremost on the development of the different components. This prototype was developed in parallel to the lab prototype (Bakker, et al., 2022). The lab prototype was always used as a first step to test the functioning and interactions of the separate components, before final implementation into the vehicle.

3.1. Vehicle Setup

The Mediator TI in-vehicle prototype is implemented using the Learning Intelligent Vehicle (LIV) research vehicle from Veoneer side. LIV is a Volvo XC90 production vehicle (depicted in Figure 1.4), extended with different algorithms which have been developed in different research projects over time.

This prototype explores all major concepts of the Mediator system (as depicted in Figure 1.3). The Mediator technology is divided into, and allocated to, several main components, which communicate to each other using a clearly defined Application Programming Interface (API). The Automation State component has a major focus in this prototype. This is the only prototype that has an actual Automation State component running real-time, in real driving conditions, in a vehicle with real (SAE Level 2) automation. Since the central mediation component including Decision Logic plays a central integration, decision, and communication role, and that interacts with each of the other main components, that is also an important component here. All major information flows go through this central component, and all main Mediator decisions are made within this central component.

The overall system uses the central mediation system, and in particular the central decision logic, to monitor the vehicle automation, the driver, and the driving context simultaneously. This is used to decide and make suggestions in real time on who is currently and in the near future fittest or needed for driving – the driver or automation – correcting the driver's degraded performance when necessary and possible, handing over from and to the driver when necessary, and providing the driver with relevant information such as available time budgets for the vehicle automation (see again Figure 1.3 for a visualisation of the main concepts). In the Mediator TI in-vehicle prototype all components are running for real, in real time, demonstrating the functionality of the Mediator system. The Driver State system in this vehicle ignores driver fatigue and instead focuses only on distraction detection, using multiple implemented cameras, providing the necessary information for the central Decision Logic's comparison of driver fitness and automation fitness. The HMI is basic and set up in a way that it provides sufficient concepts to communicate with the driver, but nevertheless incorporates multiple visual and auditory signals, going beyond standard automotive state of the art HMIs.

Figure 3.1 shows a view inside the vehicle with the hardware setup that is used by the HMI to communicate with the driver. The central display cluster represents the main display where information from the HMI is displayed, but which is also used to receive input from the driver.

Figure 3.1 View inside the vehicle, with a central display cluster and LEDs.

Furthermore, LED strips are used to communicate different driving modes; and they also communicate decreasing time budgets (the top LED strip becoming smaller and eventually red) as well as urgent handover to the driver or corrective actions (LED strips becoming red). LED strips are placed above and below the main console display on the driver side, but also in the lower part of the passenger side, to create the ambient atmosphere in line with the holistic HMI design.

Other main hardware components (apart from the driver state cameras), consisting of several computers running the different components of the Mediator system as well as power supply and vehicle computer network equipment are placed in the trunk. This trunk setup can be seen in Figure 3.2.

Figure 3.2 View on the computers in the trunk of the vehicle.

3.1.1. Communication Interface

The Mediator TI in-vehicle prototype has been equipped with an existing extensive real-time messages-based communication and logging technical framework based on MQTT (see https://mqtt.org/). MEDIATOR project in general, however, had already decided on, and been working with, another real-time messages-based communication and logging technical framework, based on ZeroMQ (https://zeromq.org/).

Rather than forcing one or the other set of systems and components to 'switch' to the other framework, it was decided to use both in parallel. Some components 'live' primarily on the MQTT side; others primarily on the ZeroMQ side. A custom *MQTT-ZMQ Interface application* was developed within MEDIATOR which provides real-time interfacing between the two sides; such that components on one side can communicate freely with any component on the other side. This has been made relatively easy by the fact that both vehicle MQTT framework and the general Mediator ZeroMQ framework had been using similar message definition based on the Google Protocol Buffer message format and message serialisation.

Figure 3.3 visualises once again the different components of the Mediator system used in the Mediator TI in-vehicle prototype where some components live mainly on the MQTT side (i.e., automation state, vehicle sensors and system, HMI), and others on the ZeroMQ side (i.e., driver state and central mediation component). The figure also visualizes by the blue dashed line the communication between the two sides, which is realized by the custom-built MQTT-ZMQ Interface application.

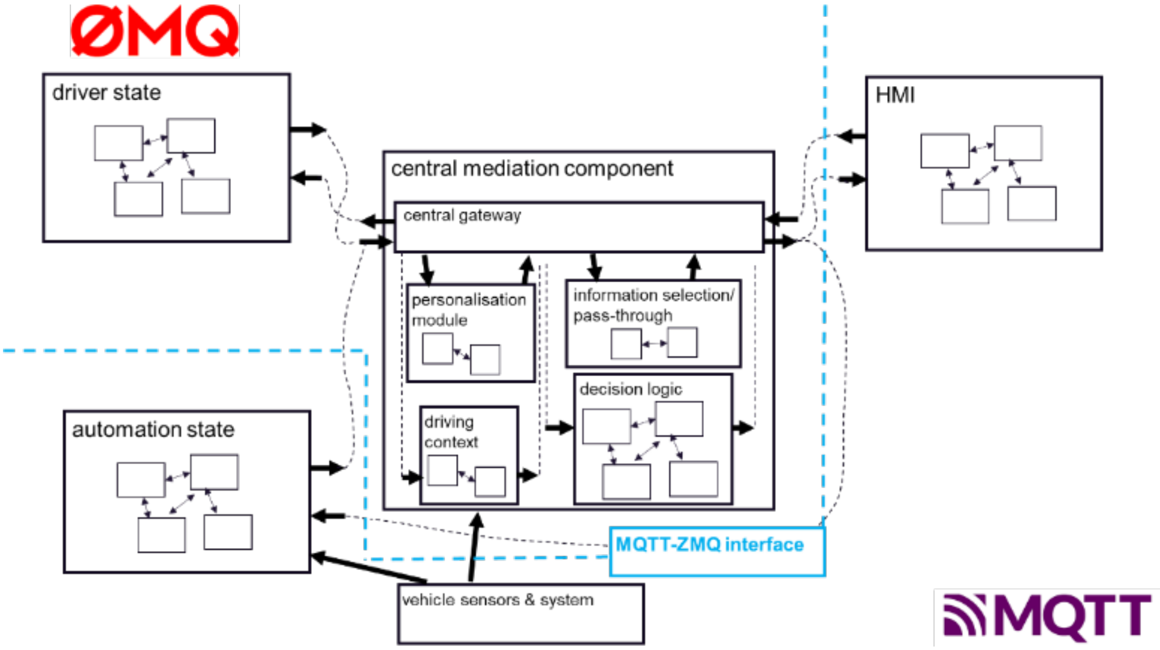


Figure 3.3: The Mediator system in the TI in-vehicle prototype using both MQTT and ZMQ as communication and logging framework.

3.1.2. Step by Step Developmental Approach

The Mediator TI in-vehicle prototype has been developed with a close connection to the lab prototype (Bakker et al., 2022), in which each of the components in 'computer desktop' setups were firstly tested. This is to guarantee that the components work as intended, but also that the integration of the different components into one system is still fulfilling the requirements as expected and that the components work and interact together well.

Since the components also depend on the input/output of each other, they needed to be developed/integrated sequentially to be able to test the functionality. For example, testing the Decision Logic without having the Automation State component is not possible, since the Decision Logic reacts on the input of the Automation State component to calculate time budgets, but also make sense of a given situation. The Automation State component in turn could not work without the input of the Driving Context component – because the automation fitness/unfitness is calculated based on the context of any given point in time and future upcoming context. Therefore, a step-by-step developmental approach for this prototype, was chosen:

- Driving context and Automation State component were developed conceptually (and later also technically) in parallel – where the input of the Driving Context was driven by the needs of the Automation State component – and later the Automation State component development was dependent on a functioning Driving Context component to provide inputs. First, the Driving Context module was developed and tested (together with the Automation State component) in the lab prototype and when those two components performed as they were supposed to, then it was uploaded and tested in the TI in-vehicle prototype.
- Next, the Decision Logic could use the input from the Automation State component and the Driving Context component to be able to output the automation time budgets and could be tested in the lab prototype first again to make sure that it is working as expected
- For the integration and the testing in the TI in-vehicle prototype, the Decision Logic was dependent on the functionality of the HMI to output the decision of the Decision Logic. Hence,

a first version of the HMI was developed next to be able to test the functionalities and be able to judge whether the outputs from the Decision Logic make sense.
- As a last add-on of the different components was the Driver State component, which would allow the Decision Logic to compare the fitness of the driver and the vehicle automation.

Following this timeline of adding more and more components to the full set of Mediator system in the TI in-vehicle prototype, each of the component's developments again went through several implementation iterations, where each of the components was first integrated in a very simple version with the goal to connect the component to neighbouring components and make sure that the interfaces are properly set up and the communication between the components takes place. Only then were increasing levels of functionality of the components added – usually with basic functionality development in one iteration, followed by further improvements and trimmed functionality in later iterations (if time and needs allowed).

To clarify this process on one of the components developments, let us take a closer look into the development of the automation state component:

1. The first iteration was focused on connecting this (Automation State) component to other components that it communicates with. More specifically, the Automation State component takes input from the Driving Context component and direct input from the vehicle itself. It outputs values back to the Driving Context component, which in turn communicates this information further to the Decision Logic. The first iteration included very basic outputs on the automation state's fitness outputs operationalised as Time to Automation Fitness and Unfitness (TTAF/U).
2. In a second iteration, the focus was to improve the calculations of the TTAF/U values based on the driving context information. In parallel, the Driving Context module was developed to include improved information for static driving context (e.g., road type, lane marker information). The TTAF/U values have been derived in a data driven way of working, where driving data on the driving context was collected with information on the vehicle automation is available. Based on this information, correlations between vehicle automation and driving context were derived, which then was used to develop the algorithms to integrate the proper TTAF/U values.
3. As preparation for the third iteration, again plenty of driving data was collected with the Automation State component running on the vehicle. The performance of the Automation State module was studied, and true positives/true negatives and false positives/false negatives were determined. Furthermore, the dynamic context information (e.g., weather, traffic) has been integrated into the Driving Context component. Based on this, the third iteration included the tuning of performance for the static driving context and including the dynamic driving context information in the calculation of the TTAF/U values, followed by testing.

3.1.3. Route

The TI in-vehicle prototype is used in the evaluation activities on the route visualised in Figure 3.4. It contains a mix of highway and rural and city roads. This allows for different situations in terms of vehicle automation availability.

The route starts in Vårgårda (uppermost point of the route in the map in Figure 3.4). After getting out of Vårgårda, the route is a highway where automation is available for a longer period. When reaching Alingsås and entering a city, automation availability is limited and the driver is asked to drive manually, where we have several intersections etc. Then the route continues with a highway.

Then it takes a turn to the left to drive on rural road – with a mixed availability of the automation again. After getting back to Alingsås, there is a stretch of automation availability again on the highway (same as at start of the route).

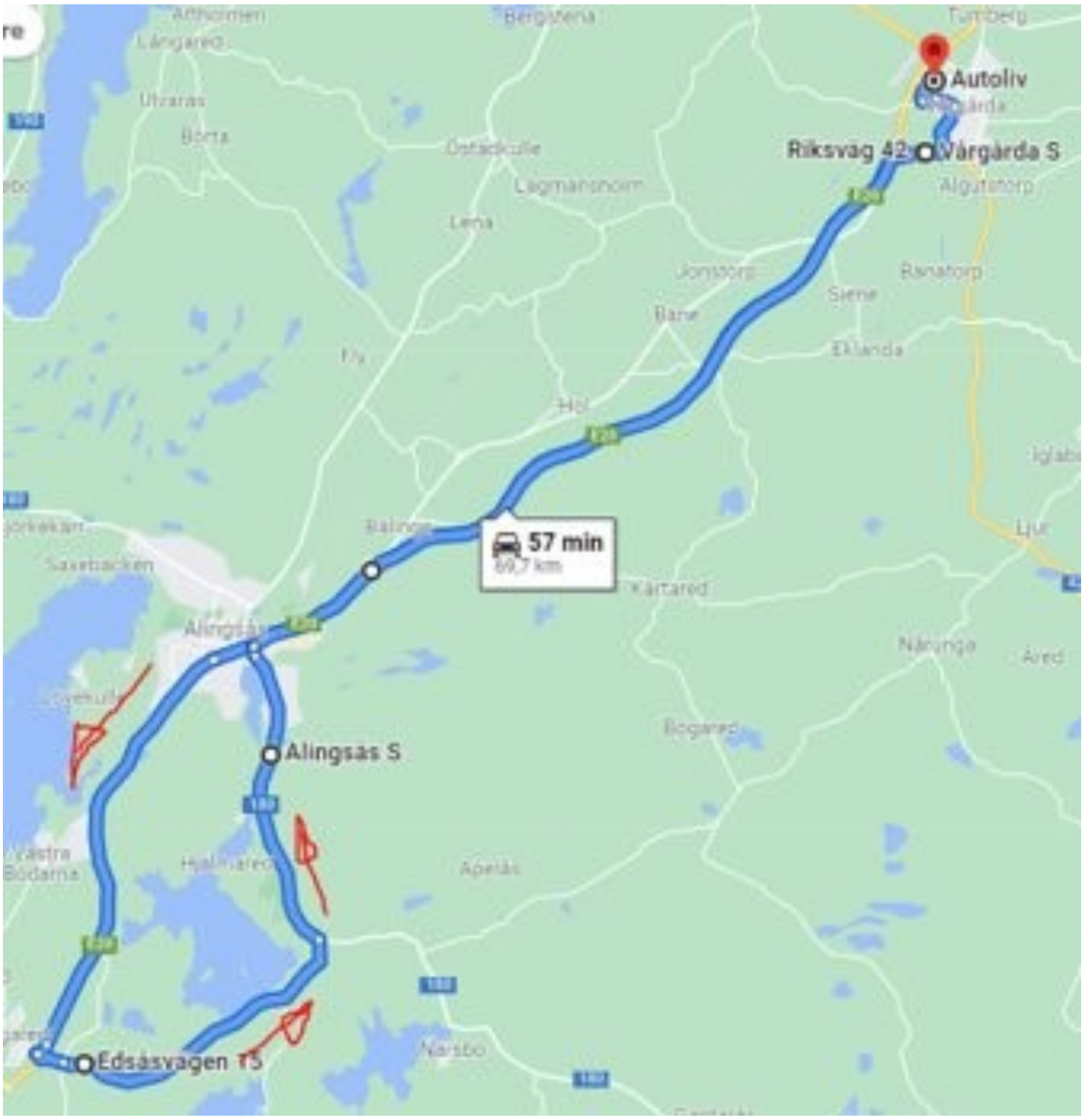


Figure 3.4 The route used for the evaluation of the Mediator TI in-vehicle prototype.

3.2. Main Mediator Software Components

3.2.1. Automation State

The Automation State (AS) component has the goal to estimate the current and near future performance of the driving automation system (e.g., auto pilot and autonomous driving). As input, as depicted in Figure 3.5, it requires information from the central driving context to be able to judge the current and upcoming context, like road information, weather, and traffic. Furthermore, it requires information from the vehicle itself for example on the driving automation system (e.g., current automation level). In the TI in-vehicle prototype, this information is provided directly from the vehicle communication system to the Automation State component, while the driving context information is processed by the central driving context before it is put into the Automation State component. As output, the Automation State component is providing fitness assessment values operationalised in terms of *Time to Automation Unfitness* (TTAU) and *Time to Automation Fitness* (TTAF) values, which capture current and near-future “time to readiness”, as well as the reason for change in fitness/unfitness (e.g., for the upcoming change from fitness to unfitness from one automation level to another one). It also provides information on the current level of automation and a list of available levels (right now and in the near future).

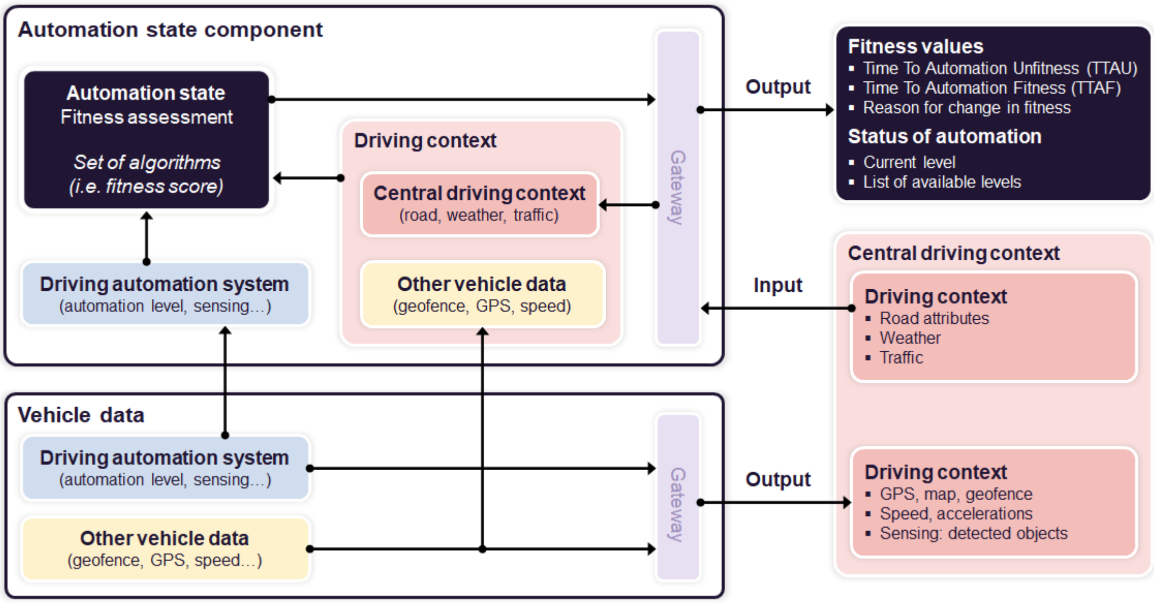


Figure 3.5 Automation State component design including its inputs, output and project partners contributions.

Technically, the Automation State component is operationalised by a set of algorithms (that process the input, estimate fitness score, and derive the outputs) which are classified into three different areas in Figure 3.6 Set of algorithms of the Automation State component

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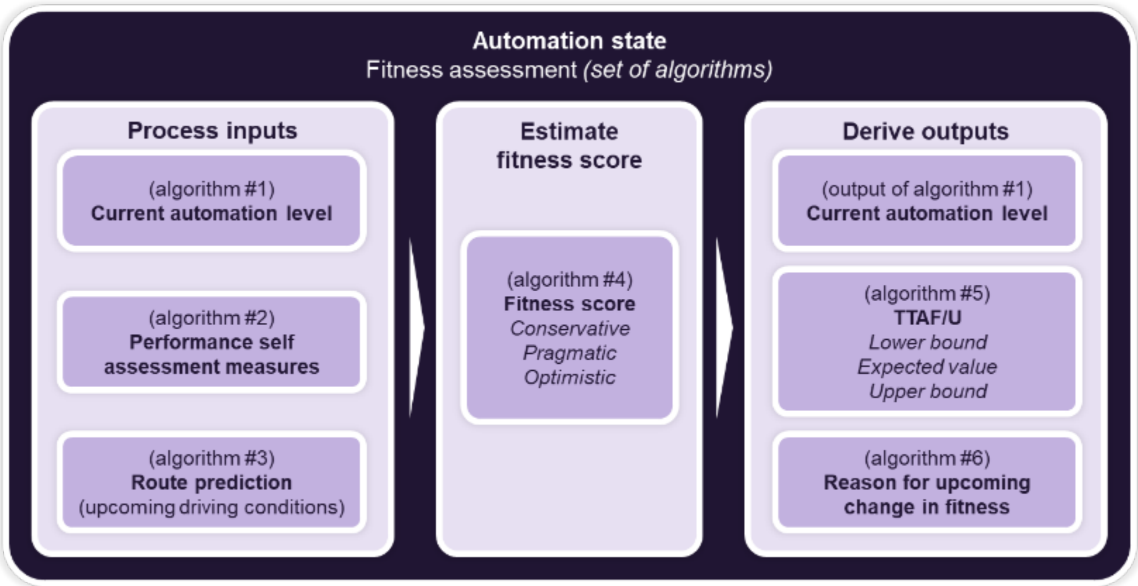

Figure 3.6 Set of algorithms of the Automation State component

The main part (*algorithm #4*) represents the estimation of the current and near future automation fitness score, a score that predicts how good the automation performance is. This is a first step in the direction of calculating the TTAF/U, which is done by an algorithm in the "derive the outputs" category. Due to uncertainty and the possibility that different outcomes are possible for a current road and traffic situation and to encode the uncertainty about this in a practical manner, three values are used for the prediction. For the fitness score, three different estimates are calculated by the Automation State component - a "conservative", "pragmatic" and "optimistic" value respectively, that consider varying assumptions and uncertainties in the fitness assessment of the driving automation system and the driving context. These estimated fitness scores are further processed by the Automation State component with the help of cut-off threshold values to determine the fitness/unfitness of the driving automation system. It results in three measures respectively which represent the lower bound, expected value and upper bound estimates (also known as worst, likely and best cases). Figure 3.7 shows this process on how the three TTAF/U values are derived from the fitness scores. The estimated fitness scores (values from 1 to 5) are represented on the x-axes and the TTAU values are derived from the timings of the future fitness scores for the predicted variation in fitness scores. Dotted lines indicate what TTAU or TTAF would have been in case of automation being in the other level than the one currently selected.

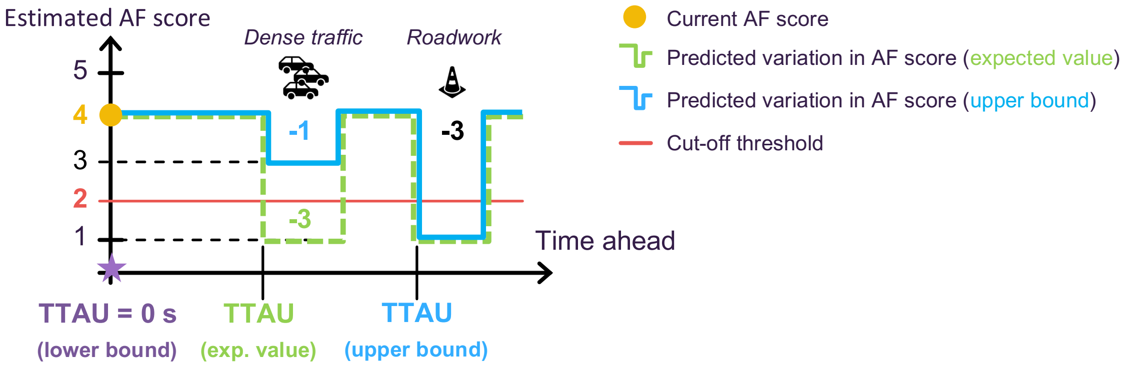

Figure 3.7 TTAU estimations for continuous mediation level (CM).(Adapted figure from MEDIATOR deliverable D1.3)

The different values of TTAF/U are calculated for the current stretch of road (i.e., the stretch of the route that can be driven in the current driving mode) and the next stretch (i.e., the different parts of the route for a different level of automation). For example, if the current driving mode is manual, because the vehicle is unfit for automated driving, the next stretch will be L2 driving in this prototype, since we only have two levels in this vehicle: manual driving (L0/L1), or L2/CM automation. This information from the automation state can be plotted over time – as visualized in the example reported in Figure 3.8.It shows the fitness status of the driving automation system, the automation level that has been activated, and the TTAF/U that are decreasing over time for a certain stretch of the route. Dotted lines indicate what TTAU or TTAF would have been in case of automation being in the other level than the one currently selected.
Note that the automation state module, due to the inputs it has access to, is only able to output information on two stretches – the current and next one; however, this is enough to realise sufficient predictive information, to allow Decision Logic to make suitable decisions and suitable recommendations to the driver, and to allow useful proactive information for the HMI.

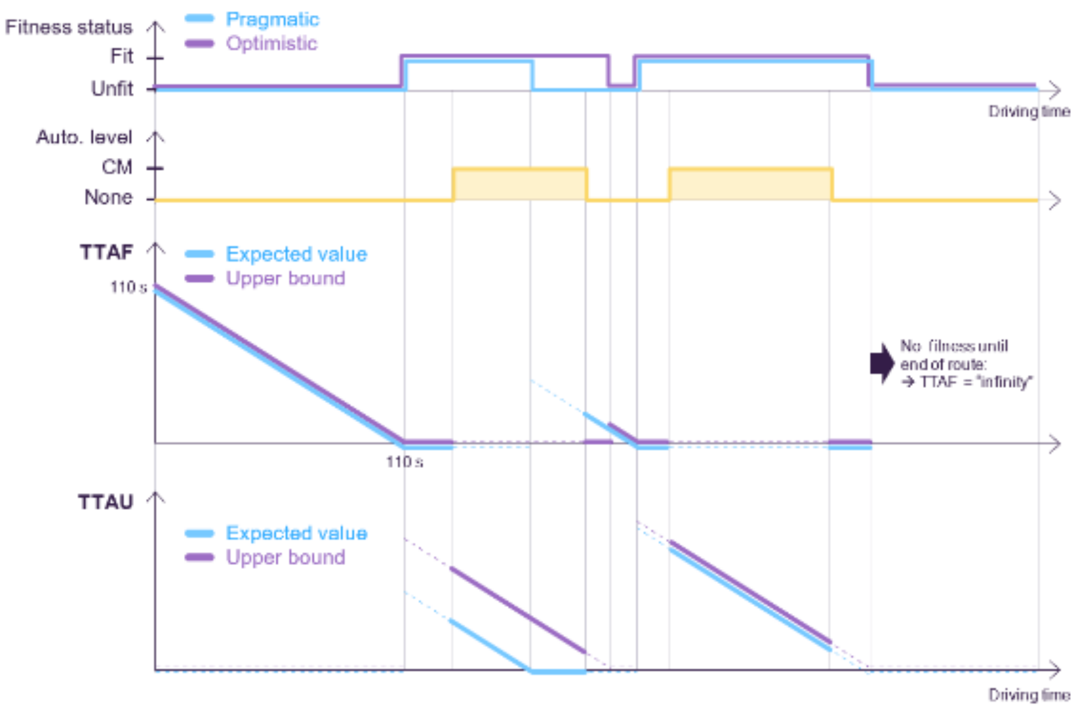

Figure 3.8 Example TTAF and TTAU values over time (horizontal axis), as produced real-time by the Automation State component.

The information on the two road stretches ("current" and "next") is received by the Decision Logic and further processed and filtered. After processing the information from the Automation State component, the Decision Logic triggers the HMI to show the lengths of the two stretches in terms of "time budgets" on the screen of the prototype – as can be seen in Figure 3.9. TTAF/U after it has been processed by the Decision Logic will be presented as "time budget" in the HMI for the current stretch (i.e., time left in the current driving mode and represented in orange for current automation level) and the next stretch (i.e., time in the next driving mode represented in grey for manual driving).

Figure 3.9 TTAF/U after processing by DL is presented as "time budget" in the HMI for the current stretch

3.2.2. Driver state

The Driver State component in the Mediator TI in-vehicle prototype uses a multi-camera system but does not use the physiological sensors that are used in the HF in-vehicle prototype. Respect to the other in-vehicle prototype, in this vehicle the multi-camera system is configured for real-time use, but limited to distraction (i.e. ignoring possible driver fatigue). The focus is on detecting driver distraction in multiple ways, using both eye gaze patterns to detect eyes off road gaze behaviour, and object/hand detection to detect phone use. In terms of hardware (computers and cameras), this system uses two computers and multiple cameras, which were installed on this vehicle in Sweden in September 2021. Since then, many test drives were done with the Driver State system in recording mode to collect calibration and testing data, before deploying the real-time Driver State detection and warning system for the driver experiments in the spring of 2022.

Figure 3.10 visualizes the cameras and computers set-up. Two computers are used and connected by USB3 cables and connectors to four cameras installed in the (simulated or real) vehicle cabin:

1. Monochrome (Near Infrared or NIR sensitive) driver face view camera. For the multiple goals of facial feature extraction; gaze estimation of where the driver is looking (outside and inside the cabin, Eyes-Off-Road/NDRT gaze analysis).
2. Upper body view of driver camera (important for driver activity recognition, for distraction analysis, in particular phone in hand detection);
3. Outward-looking (forward view) camera (to capture real-world driving context data);
4. Over the shoulder (dashboard/cabin view) camera mounted on the internal roof: seeing the whole dashboard/HMI that the driver sees including mirrors (Used for post-hoc analysis and visualization of how the driver interacted with the HMI and where his gaze was).

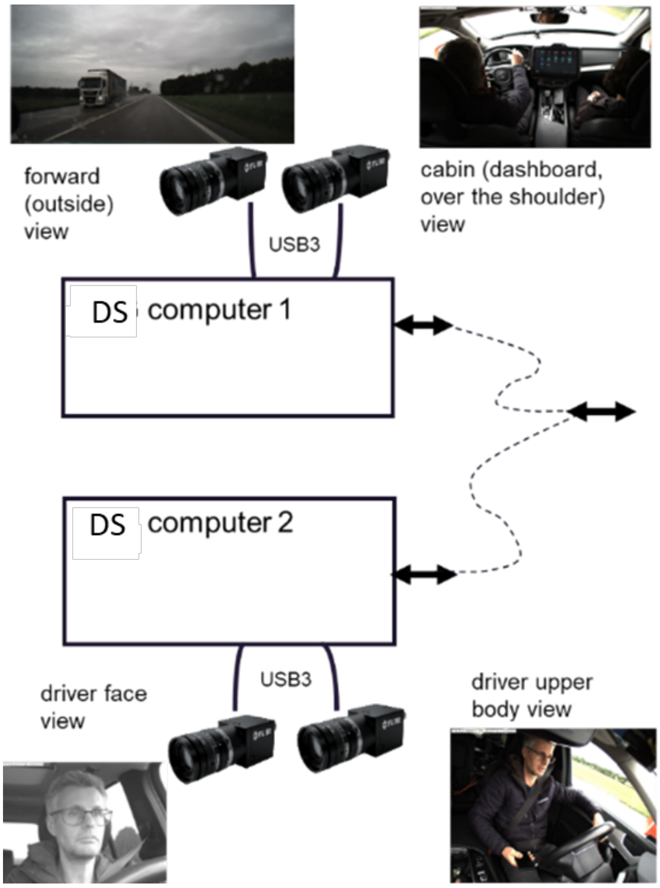

Figure 3.10 The D2.8 Driver State component's cameras and computers set-up.

Figure 3.11 shows the camera positions of these face view, body view, forward view, and cabin (over the shoulder, dashboard) in the vehicle (highlighted by orange boxes).

Figure 3.11 Camera positions in the Mediator TI in-vehicle prototype

In this prototype, the focus of the Driver State component is on distraction – assuming that this is the major use case for this vehicle when driving with L2 (Continuous Mediation, CM) functionality activated. While driving in L2 mode, the driver might be, even more than during normal manual driving, become distracted (e.g., taking out the phone to look at it). Focusing on distraction, Figure

3.12 shows the main submodules and information flows for the Driver State component, including the eventual outputs, which (analogously to the Automation State component) are mainly operationalized by means of *Time to Driver Fitness* and *Time to Driver Unfitness* (TTDF and TTDU) values, which capture current and near-future "time to readiness". The face/eyes data is used to first estimate Eyes Off Road (EOR) and based on that a simplified variation of the AttenD distraction algorithm, which estimates decreasing and increasing driver situation awareness based on EOR temporal patterns. The body view data is used to detect cell phones (or other objects) in the hand and do basic activity recognition based on that (which is beyond the current state of the art for virtually all Driver Monitoring systems currently available in cars). All this information is integrated in overall distraction and driver state estimates and as a final step transformed into TTDF and TTDU estimates, passed on, next to the underlying distraction values, to Decision Logic.

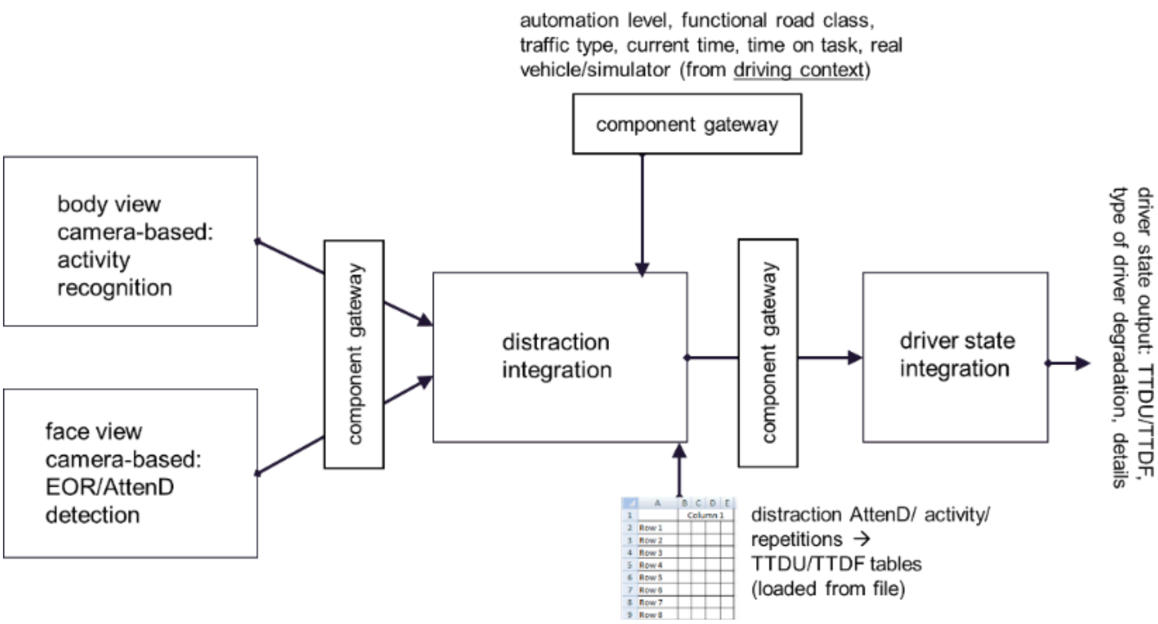

Figure 3.12 Main submodules and information flows for the Driver State System

3.2.3. Driving Context

The Driving Context (DC) component is an important component for the Automation State component, since it is providing important information input on the future route and the context along the route: providing relevant information on the current route, road, and driving conditions. This information is also used by the Driver State and Decision Logic.

In the on-road experiments, the route is known in advance and therefore pre-programmed, but this could also use information from other sources based on navigation system or historical drive pattern information, combined with (high-definition, HD) map data typically employed in modern vehicle automation systems. The tabular route splits the route to be driven in small segments and assigns them a unique ID (i.e., edge_id). It stores the start and end latitude and longitude information of the segment to know exactly where it is located. It fills important information that are needed for the Mediator system to function: speed limit, and context information like road information, lane information, weather, but also intersections, turns and roundabouts, centre and right lane marker availability, etc. are covered in the tabular route.

Figure 3.13 visualizes the Driving Context component's functioning during driving including its main inputs and outputs. The core tabular route information is loaded at start-up and forms the basis for real-time processing. During driving, basic vehicle data comes from the vehicle systems, incl. GPS position, speed, steering wheel, gear, and pedals behavior, etc. In addition, advanced sensor data comes from the vehicle systems: detected objects around the vehicle, weather data & traffic data (sourced externally, detected road geometry, etc.). This dynamic data is used to update DC's internal tabular route data structure; and when a significant enough update is done, this update is also sent outwards to other components for which this is relevant.

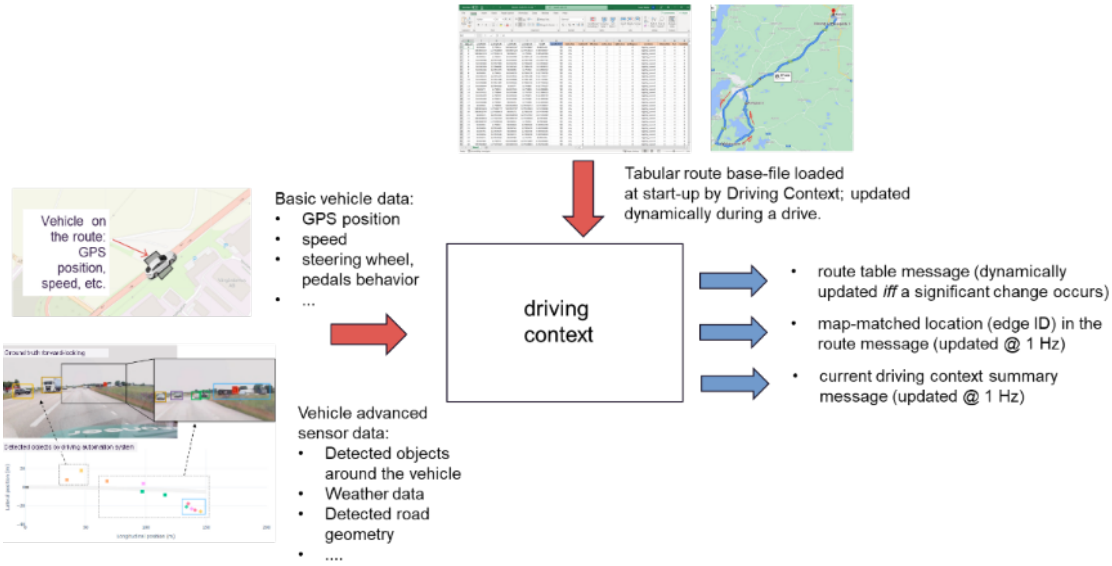

Figure 3.13 Driving Context Module main inputs (red) and outputs (blue).

Thus, the dynamic vehicle and external source information is integrated with the tabular route data to produce three main Driving Context output messages:

- A route table message (dynamically updated if and only if a significant change occurs, including start-up). This message contains information on the entire route, including the upcoming parts, and static and dynamic information expected on those remaining parts. This message is used in particular by Automation State. Because this information contains information on the upcoming parts, this allows Automation State to look ahead to see what is (likely) coming and base its predictions of the near future on this.
- A map-matched location (edge ID) in the route message (updated at 1 Hz), in particular aimed at informing Automation State and Decision Logic where we are exactly in the planned or estimated route.
- A message summarizing the current driving context (updated at 1 Hz), i.e., summary of current road type, automation availability and selected automation state, speed and speed limit, current traffic and weather and roadworks situation, etc. This message is aimed at informing Driver State and Decision Logic about the (summarized) current driving context.

3.2.4. Decision Logic

The Decision Logic (DL) component running in this prototype is a real and real-time functioning component based on the foundations of the decision logic concepts developed earlier in simulation, making use of decision trees usable for many different driver, automation, and driving context situations. The decision trees were adjusted in multiple ways to account for the specific setting in the Mediator TI in-vehicle prototype– for example to account for the fact that this vehicle only covers two levels of automation in this vehicle L0/L1 and L2, excluding emergency actions because emergency actions are not relevant and not available in this in-vehicle prototype, but also because trials will be done with professional drivers who will not exhibit the type of degraded behaviour that could trigger emergency actions. Figure 3.14 shows the overall Mediator component diagram, with Decision Logic and its partner-subcomponent Information Selection/Pass-through highlighted (in red). The figure shows how the Decision Logic component is integrated with the rest of the system and which inputs and outputs it is using and providing.

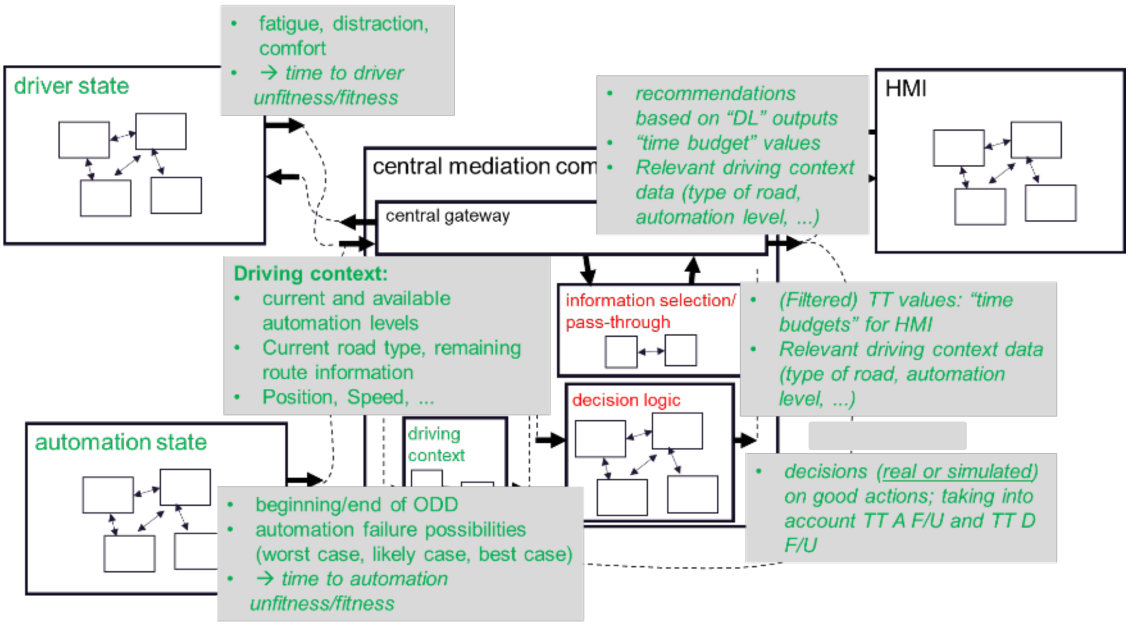

Figure 3.14 Main information flows from Decision Logic and subcomponent Information Selection/Pass-through

As main inputs, Decision Logic receives information from the Automation State component and the Driver State component – which are designed in a way that the two inputs can be compared to each other. Driver, but also automation degradation is operationalized by means of Time To Driver/Automation Fitness and Time To Driver/Automation Unfitness. Both have lower bound, expected value (likely case), and upper bound estimates, to account for uncertainty. This operationalization is bringing the "fitness" levels of the two driving resources (driver or driving automation system) into the same "space", such that they can be compared and "balanced" by decision logic, which is then able to determine who is fittest to drive in any given context. Furthermore, by including estimates on the uncertainty of the values, more robust decisions can be derived from them. The driver state class input provides additional information on the underlying reason (if any) for driver unfitness. For instance, this can correspond to the information that the driver is distracted, and if phone use was detected, adding that specific bit of information as well. Analogously, the Automation State component provides underlying contextual reasons for automation unfitness (if any) i.e. smaller Time to Automation Unfitness during for example full automation; perhaps corresponding to lane marking visibility and tracking problems by automation, or unusual incident or roadworks situations. The Decision Logic component uses this information then for awareness and reasoning of what should be done in any given situation and to be able to inform the driver about automation unavailability for example.

Another important input to the Decision Logic component is provided by the Driving Context component on the current and near future route information – like current position, road, lane, intersection, roadworks, weather, etc. This is used by the Decision Logic component to make a holistic understanding, for example, about the future route, upcoming road stretches, but also using this information to get an understanding of when it is appropriate to communicate with the driver ("window of opportunity") to account for safety in the vehicle and not communicate with the driver in safety critical situations like at intersections.

The "Information Selection/Pass-through" subcomponent of the Central Mediation component, which is technically (in the software) a separate subcomponent but can be viewed as part of the Decision Logic, supports Decision Logic by providing additional, frequently updated information, especially related to "time budget" and driving context information to the HMI. (The HMI component is the final component that interacts with the driver to provide information to the driver, but also to collect input from the driver.)

During pre-processing and at regular intervals during the drive, and taking as input, from the Driving Context and Automation State components, future likely upcoming automation availability, the Decision Logic pre-processes the information to calculate some appropriate automation stretches of consideration for recommendations. Figure 3.15 visualizes an example of this functionality on the trimming of automation availability to remove short periods of automation availability (as can be seen by the orange stretches at the start of the route in the middle of Figure 3.15). After the trimming, the understanding of the Decision Logic about an appropriate availability of the automation is visualized (on the right in Figure 3.15), where the small stretches are removed and will not been shown to the driver.

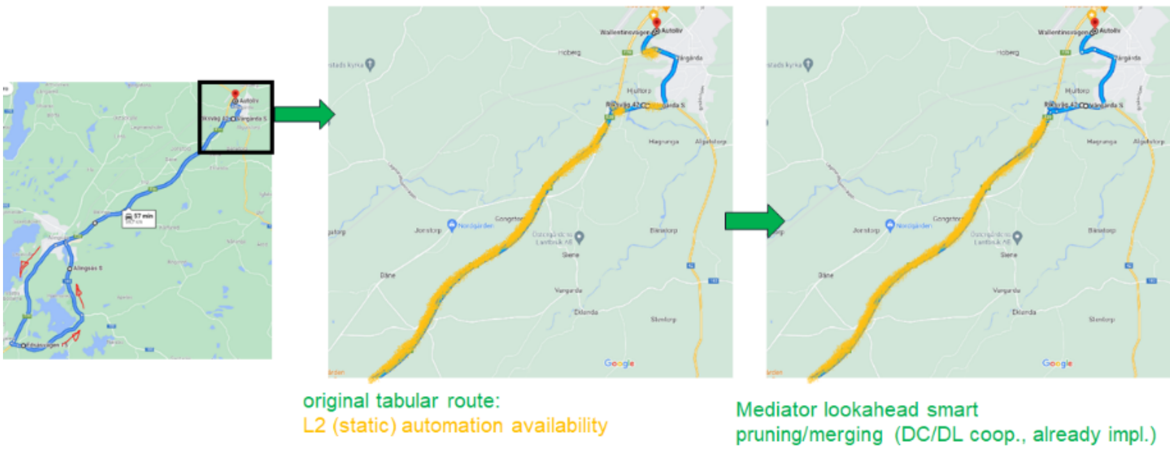

Figure 3.15 Smart trimming of short automation availability stretches by the Decision Logic component

During driving, continuously (at a 1 Hz frequency), Decision Logic takes all inputs and decides on what action need to be taken at the current point in time, taking into account the current and predicted future state of the driver and automation components as well as the overall driving context, and sends out its outputs. Its outputs go both to the HMI and back to Driving Context, Automation State, and Driver State (informing them on the current overall decisions and general state of the system).

As a secondary but also innovative feature implemented by the Decision Logic for safety reasons, to avoid as much as possible distracting the driver at the wrong time, is the feature of *estimating* *the best time to communicate the Decision Logic's actions and recommendations to the drive.* This was done by first estimating an appropriate "*window of opportunity*", i.e., the time window within with the action or recommendation must have been completed. Within that window of opportunity, this feature estimates when the driver is currently or soon facing a relative demanding driving activity and attempts to select a moment at which the driver is probably *not* busy. In other words, at certain times, in "demanding driving situations" or when the "driver is likely busy", which can be determined based on the input from driving context and driver state respectively, it is not advisable to communicate with the driver - e.g., when the driver is in a curve or just accelerating or braking relatively strongly or about to merge into the highway. Hence, the Decision Logic component estimates the moments that are likely not demanding and where the driver is not busy with the driving task and uses those not-busy moments to communicate its actions and recommendation to the driver, through the HMI (except for the time budgets, which always remain visible and updated).

3.2.5. Basic HMI

As described above, the HMI component has not been the focus of the TI in-vehicle prototype and has only been used to communicate the information from the other component to the driver in relatively simple ways, compared to HF Mediator prototype. Nevertheless, the main Mediator HMI concepts were followed, and a carefully adapted customized HMI design for this in-vehicle prototype was developed and implemented in hardware and software. As depicted before the HMI in this prototype consisted of information displayed on the central stack display, auditory signals, and LED strips to communicate the driving mode, time budget, and urgent actions.

Five design guidelines, determined in Deliverable D1.5 (Grondelle et al., 2021), have been followed throughout the design process:

- Design with a holistic design approach i.e., involving the whole of the vehicle interior to involve all components to contribute to an unambiguous interaction and understanding, instead of individual components disturbing or competing with primary tasks.
- All interactions with the human driver are designed from a single ritual for intuitive and quick learning.
- Design from learned affordances to ensure intuitive and quick learning.
- Design for user acceptance which amongst other things, implies that user autonomy is essential.
- Design for industry acceptance which implies that exploitation is being considered in all design decisions as is automotive branding i.e., OEMs design space in the adaptation of HMI components.

Figure 3.16 shows conceptually how time budget information and automation availability information is provided by one such message, and how the time budget is visualized through the HMI on the central display cluster. Time budget information and automation availability information is provided by a protobuf message, which feeds into the HMI's time budget visualisations. This information is provided continuously by Decision Logic's information selection/pass-through subcomponent.

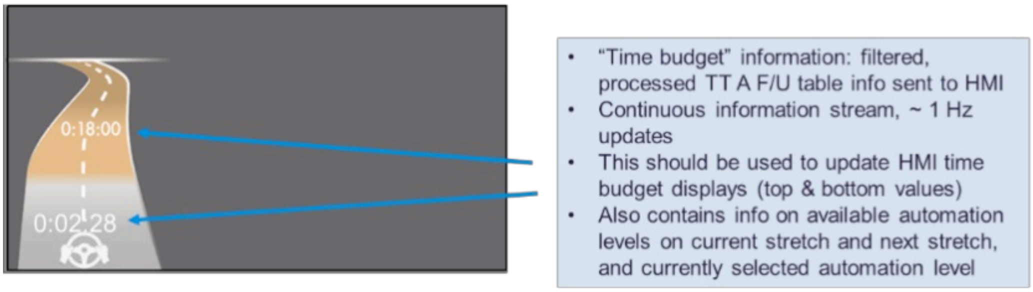

Figure 3.16 Time budget information and automation availability information.

Figure 3.17 shows how Decision Logic's actions trigger (by another type of protobuf message) recommendations in the HMI, such as a recommended automation level change. In contrast to the time budget information, this information is not provided continuously, but instead is *event-based* (incidental).

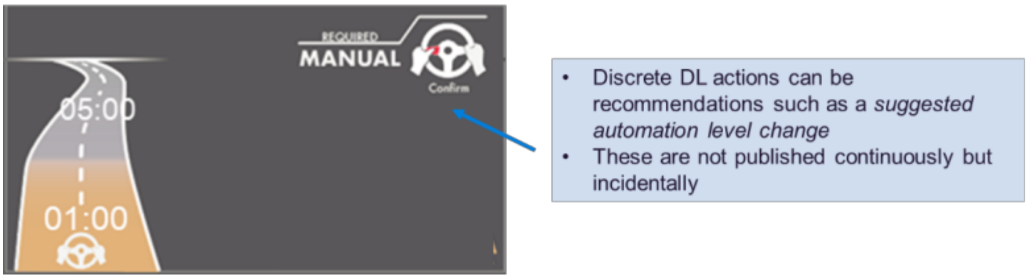

Figure 3.17 Discrete, event-based (incidental) DL actions can trigger recommendations in the HMI

One important aspect of the HMI is that it is designed in a way to inform the driver also about critical and urgent situations in a more obtrusive way. Critical take over manoeuvres, where automation availability will no longer be existing in a very short period, are one example. In that case, the colour *red* is used for visualizations, where the actions to be taken are highlighted in red (e.g., hands on steering wheel icon) and the sound is repeated – as visualized in Figure 3.18 in the central display cluster. Additionally, as can be seen in Figure 3.19, LED strips are also then showing the red colour.

Figure 3.18 Visualization of an urgent take over procedure, where the HMI indicates visualized in red and using repeated auditory cues to indicate that manual driving is required.

Figure 3.19 LED lights are used as HMI and highlighted in red in critical/urgent take over manoeuvres.

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4. Conclusions

The deliverable summarizes the main design and development activities of the two in-vehicle platforms, that have been developed and used to evaluate two different prototypes of the Mediator system, one more focused on human factor and the other more focused on technical integration of Mediator components, regarding performances and user acceptability during real road studies.

A central idea has been to reduce the overall complexity of development by allocating components of different complexity to each of those two vehicles, such that more manageable prototypes result, each with their own focus suitable for the research questions evaluated in on-road studies. In this way, it has been possible to break down the complexity into two more manageable subtasks and speed up the development by letting two (smaller) vehicle integration teams work in parallel on separate vehicles with a separate focus.

The two in-vehicle prototypes have been implemented in two vehicles from different car manufacturers, with different levels of automation and different research focal points.

- Mediator Human Factors in-vehicle prototype realises and explores the most sophisticated driver state technology and the most sophisticated HM version(s). This vehicle has no actual vehicle automation and instead relies on a Wizard of Oz-like set-up to simulate vehicle automation (Bengler et al., 2020). The focus of HF in-vehicle prototype is on presenting to the naïve participants the full concept HMI experience and recording their behaviour, response and experiences while driving on a real-world realistic route, with simulated high levels of vehicle automation.
- Mediator Technical Integration in-vehicle prototype focuses on the automation and automation state side of the Mediator system in conjunction with the driver state side and driving context side, allowing demonstration and evaluation of the real complete Mediator Decision Logic component. This prototype has a basic HMI, allowing for more technical Mediator logic evaluation and not the full envisioned user experience. Driver State, Automation State, Driving Context, and Decision Logic are all real and real-time Mediator software main components, as envisioned in the concept, providing inputs on the fly to the HMI, thus demonstrating the Mediator concept(s) on real roads.

The platform approach for each in-vehicle prototype has allowed to best align technical developments with experimental evaluation designs for each study using the prototypes. The close connection with the stakeholders involved in on-road tests has allowed to reach the maximum synergy between the development phase and the validation activities.

The two Mediator in-vehicle prototypes are used on-road in testing activities, for the evaluation of the Mediator integrated system. On-road tests are very challenging and cover a varying extent of these two areas, because it includes users (naïve / professional). Depending on the study type (e.g., involving naïve participants or professional test driver) and vehicle availability, driving time can be high. On-road studies potentially allow for various options regarding user and technical evaluation. On the other hand, real vehicles pose constraints on integrating additional new devices due to safety aspects, space, and electrical power limitations as well as potentially restricted access to vehicle data.

5. References

Ahlstrom, C., Kircher, K., Kircher, A. (2013). "A Gaze-Based Driver Distraction Warning System and Its Effect on Visual Behavior". In *IEEE Transactions on Intelligent Transportation Systems*, 14 (2), 965-973, doi: 10.1109/TITS.2013.2247759.

Bakker, B., Knauss, A., Rodrigues de Campos, G., Tanov, N., Andersson, S., Mano, D., Athmer, C., Enhuber, S.M., Beggiato, M., Spaan, M. (2022). Development of integrated lab prototypes, *Deliverable D2.9 of the H2020 project MEDIATOR*.

Baltodano, S., Sibi, S., Martelaro, N., Gowda, N., Ju, W. (2015). The RRADS platform: a real road autonomous driving simulator. In Proceedings of the *7th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*, pp. 281-288

Bengler K., Omozik, K., Müller, A. I. (2020) The Renaissance of Wizard of Oz (WoOz) – Using the WoOz methodology to prototype automated vehicles. In Proceedings of the *Human Factors and Ergonomics Society Europe* Chapter 2019 Annual Conference. ISSN 2333-4959 (online). Available from http://hfes-europe.org

Berghöfer, F. L., Purucker, C., Naujoks, F., Wiedemann, K., Marberger, C. (2018). Prediction of take-over time demand in conditionally automated driving-results of a real world driving study. In Proceedings of the *Human Factors and Ergonomics Society Europe* Chapter 2018 Annual Conference, pp. 69-81.

Christoph, M., Cleij, D., Ahlström, C., Bakker, B., Beggiato, M., Borowsky, A., ..., Van Nes, C.N (2019). Mediating between human driver and automation: state-of-the art and knowledge gaps. *Deliverable 1.1 of the H2020 project MEDIATOR*.

Cleij, D., Bakker, B., Borowsky, A., Christoph, M., Fiorentino, A., van Grondelle, E., & van Nes, N. (2020). Mediator System and Functional Requirements, *Deliverable D1.4 of the H2020 project MEDIATOR.*

Detjen, H., Pfleging, B., Schneegaß, S. (2020). A Wizard of Oz Field Study to Understand Non-Driving-Related Activities, Trust, and Acceptance of Automated Vehicles. In *12th International Conference on Automotive User Interfaces and Interactive Vehicular Applications (Automotive UI '20)*, Virtual Event, DC, USA. DOI:10.1145/3409120.3410662

Grondelle, E.D. van, Zeumeren, I. van, Bjorneseth F., Borowsky, A., Chandran, T., Cleij, D., … Christoph, M. (2021). HMI Functional Requirements, *Deliverable D1.5 of the H2020 project MEDIATOR*

Mano, D., Berger, N., Larsson, A., Brännström, M., Knauss, A., Toffetti, A., … Christoph, M. (2021). Quantified Markers for Degraded Automation Performance, *Deliverable D1.3 of the H2020 project MEDIATOR.*

Omozik, K., Yang, Y., Kuntermann, I., Hergeth, S., Bengler, K. (2019). How long does it take to relax? Observation of driver behavior during real-world conditionally automated driving. In Proceedings of the *Tenth International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design*, Driving Assessment Conference 10, 245-251. doi: https://doi.org/10.17077/drivingassessment.1702

Osz, K., Rydström, A., Fors, V., Pink, S., Brostrom, R. (2018). Building Collaborative Test Practices: Design Ethnography and WoOz in Autonomous Driving Research. *IxD&A, 37,* 12-20.

Portillo, D., Paljic, A., Ojeda, L. (2019) On-road evaluation of autonomous driving training. In *14th ACM/IEEE International Conference on Human-Robot Interaction (HRI). IEEE*. p. 182-190..

Sena, P., d'Amore, M., Brandimonte, M. A., Squitieri, R., & Fiorentino, A. (2016). Experimental framework for simulators to study driver cognitive distraction: brake reaction time in different levels of arousal. *Transportation Research Procedia, 14*, 4410-4419.

Van der Laan, J.D., Heino, A., & De Waard, D. (1997). A simple procedure for the assessment of acceptance of advanced transport telematics. *Transportation Research - Part C: Emerging Technologies, 5*, 1-10

Wang, S., Sibi, B., Mok and W. Ju. (2017) Marionette: Enabling On-Road Wizard-of-Oz Autonomous Driving Studies. *12th ACM/IEEE International Conference on Human-Robot Interaction (HRI)*, pp. 234-243

Weinbeer, V., Muhr, T., Bengler, K., Baur, C., Radlmayr, J., Bill, J. (2017). Highly automated driving: How to get the driver drowsy and how does drowsiness influence various take-over-aspects? In 8. Tagung Fahrerassistenz

6. ANNEX 1: Wizard of Oz Literature research and small laboratory tests

6.1. Wizard of Oz Literature research

The Wizard od Oz (WoOz) is a research approach, born in Human Computer Interaction domain, in which the users interact with a system that they believe to be real, but which in reality is controlled, completely or partially, by a hidden human being (Bella & Hanington, 2012), the Wizard. According to a recent bibliographic collection (Bengler et al., 2020) the WoOz paradigm has allowed research on human-machine interaction in parallel with the technical development. Indeed, within the automotive research community, WoOz vehicles are started to be used as a method for analysing the effects of "intelligent" probabilistic systems, as automated vehicles are, even if not fully developed yet.
With the aim of finding the best solution for the design of the Mediator HF in-vehicle prototype and of its HMI, a benchmarking analysis was carried out to deepen and study the experiences and solutions already created by OEMs and universities (Figure A1 1).

Car Owner	Partecipant Driver	Profesional Driver	Experimenter	Functionant controller		Separation panel	Measuring System	Visual feedback	Audio feedback	Haptic feedback	On the road test
				Wizard	Partecipant						
FCA / Università degli Studi di Salerno	FRONT	FRONT	REAR	• Steering wheel • Pedal	• Steering wheel • Pedal	Left to Right	• Eye tracker • Car pc • Camera • APW • sensors	• Distraction device • LED • Cluster	• speakers	• Seat • Steering wheeel	Public roads (Italy)
CITROËN	FRONT	FRONT	REAR	• Steering wheel • Pedal	• Steering wheel • Pedal	Left to Right	• Ex pc • HMI pc	• Cluster • Distraction device	• Allert • Vocal message		Public freeway 2 carriageway with central barrier
Stanford University	FRONT	FRONT	REAR	• Steering wheel • Pedal	Not functionant steering wheel and pedal	Left to Right	• Car pc • Cameras		• Activation • Allert	• Steering wheel • Pedal	Stanford Campus road
Stanford University	FRONT	FRONT	REAR	• Steering wheel • Pedal	Not functionant steering wheel	Left to Right	• Cameras • HMI pc	• Distraction device	• Allert • Vocal message	• Seatback • Foot well	Public freeway (Germany)
VOLVO	FRONT	REAR	FRONT	• Joystick	• Steering wheel • Pedal	Front to Rear	N.A.	• Distraction device • Cluster	N.A.		Public highway (Sweden)
VW	FRONT	FRONT	REAR	• Steering wheel • Pedal	Not functionant steering wheel and pedal	Left to Right	• Camera-Monitoring system	• Distraction device • LED • Cluster	• Activation • Allert		Public highway (Germany)
BMW	FRONT	REAR	REAR	• Steering wheel • Pedal	• Steering wheel • Pedal	Front to Rear	• Cameras • Eyetracker • Car pc	• Distraction device • LED • Cluster	• Activation • Allert		Public freeway 2 carriageway (Germany)
BOSCH / BMW	FRONT	FRONT	REAR	• Joystick • Pedal	• Steering wheel • Pedal		• Cameras • HMI pc	• Distraction device • LED • Cluster • HUD	• Activation • Allert		Public freeway (Germany)

Figure A1 1 Overview of the benchmarking analysis on WoOz vehicles

In this benchmarking analysis, summarized in Figure A1 1, the attention is focused on nine elements, salient for the realization of the prototype, which are the following:

- The role of the subjects involved in the trial, which include:
  - the participant, who can be unaware of the presence of the driving wizard who operates the system
  - the driving wizard or professional driver who can operates the system in a hidden way from the participant

- the experimenter, who takes care of interaction with the participant, and the driving wizard and of the data recording. More than one experimenter can be on the vehicle, according to the research protocol.

- The position of the subjects taking part in the trial. In fact, this aspect is particularly important for the roles of the participant and the driving wizard into the study, because the position is connected to the purpose of the trial. The participants is always on the left front seat (for a right drive car), the wizard is on the right front seat or on the rear seat and the experimenter will be on the rear or on the right front seat.
- The driving controls used by the wizard driver and by the participant: the WoOz in the automotive research is characterized by the presence of the double driving controls, which allow the real or apparent control of the vehicle through different tools: steering wheel, pedals, joystick (only for the wizard driver)
- The separation panel, that is used to hide the wizard view from the participant; it can be positioned in two ways, depending on the chosen layout, separating the right side from the left side the front from the rear of the vehicle
- The measurement systems that are used to record the trial data; they can include for example the presentation of video and audio recording systems, eye monitoring, computers for HMI management and for recording routes and driving performance data
- The visual feedback: use of visual tools in the interaction between the subjects and the vehicle; visual feedback can be provided through the cluster screen, radio screen, additional screens such as tablets and phones and through the presence of LEDs lights
- The auditory feedback, that is to say the use of audio tools in the interaction between the subjects and the vehicle. The auditory feedback, such as sounds or voice messages, can be provided for system activation, alarm and request for attention
- The haptic feedback thanks to the use of haptic tools in the interaction between the subjects and the vehicle. They can be placed on the steering wheel, pedals, or seats of the vehicle
- The scenario in which the test with the WoOz vehicle is carried out. The experiments are carried out on different types of roads, public or private, double lane or motorways.

The WoOz vehicles analysed, through bibliographic research, are eight vehicles made by OEMs and by universities. In the following paragraph, these Wizard of Oz vehicles are described.

6.1.1.1. FCA Italy - SIM Panda (2013)

The Sim-Panda is a prototype vehicle, developed by FCA and University of Salerno in 2013, and is a real FIAT Panda car with right hand drive, equipped on the left side with a full interface for driving simulator.
This prototype keeps all its functional and safety vehicular features unaltered and compliant to the Italian regulatory specifications, so it has a regular homologation, and it is possible to drive the Sim-Panda on every road as a common car with right-hand drive.
On the left side, the glove open compartment and the dashboard panels was adapted to lodge a medium level commercial steering wheel for driving simulators. Analogously, off-the-shelf gear shifter and pedals, both commercialized as input devices for Sim-Racing or gaming, has been fixed respectively to the car’s console and on the floor to replicate gears, throttle, brake and clutch commands.

Figure A1 2 The Sim-Panda dual wheel setup

The Sim-Panda appears to be the first reported vehicle configured with a two-wheel setup and the first full-size travelling driving simulator, as it is equipped with a portable projector with WXGA resolution and a powerful gaming netbook to host the simulation software (Sena et al., 2016).
For special uses limited to virtual environment or for purposes related to the study of human perceptions, the left side seat is replaced with an active seat able to provide haptic feedback to the driver's body, through the motion of actuators in the seat base and backrest.

Figure A1 3 The Sim-Panda as a full-size driving simulator

The rationale in development of the SIM-Panda is to achieve an experimental tool placed in halfway between a simulator and a vehicle, which allows the experimentation of driver monitoring solutions in condition where the driver's specific variables (tiredness, alcohol level, etc.) could be dangerous to test directly on the road in an uncontrolled environment. The availability of right-hand drive and a professional driver, entrusted with continuous control of the vehicle, allows in fact to perform, in the simulated driving seat on the left, a series of functional tests on a real road, in absolute safety conditions, without this diminishes the effects related to vibrations, different road surfaces, etc.

6.1.1.2. PSA Group (2015)

The WoOz vehicle realized by the PSA Group, in collaboration with the MINES ParisTech robotics centre, was built in 2015 as part of a larger research study with the aim of making automotive users ready for the advent of automated driving. The study (Portillo et al., 2019) used various training

methods for educating the participants in the use of an automated driving vehicle; the WoOz was used as a final test of the study, measuring the transfer of knowledge acquired during the different types of training in the real road context. For the construction of the WoOz vehicle was used a right-hand drive Citroen Gran Picasso 4, to which a double driving control was added in the front passenger seat, consisting of a steering wheel, pedals and gear lever, fully working. The HMI interface consisted of a computer, two screens, an audio system and a button for the activation of the autonomous driving; the screens, positioned behind the driver's steering wheel, were used to give information about the vehicle and to carry out secondary tasks during the activation of the automated driving (e.g.: watching a movie).
During the test, the automated driving was entirely performed by the driving Wizard, sat in the front passenger seat, who was informed of the current state of the car and whether the participant was touching the steering wheel or the pedals via a screen behind his steering wheel.
In Figure A1 4, the Citroen Gran Picasso 4 WoOz layout is shown.

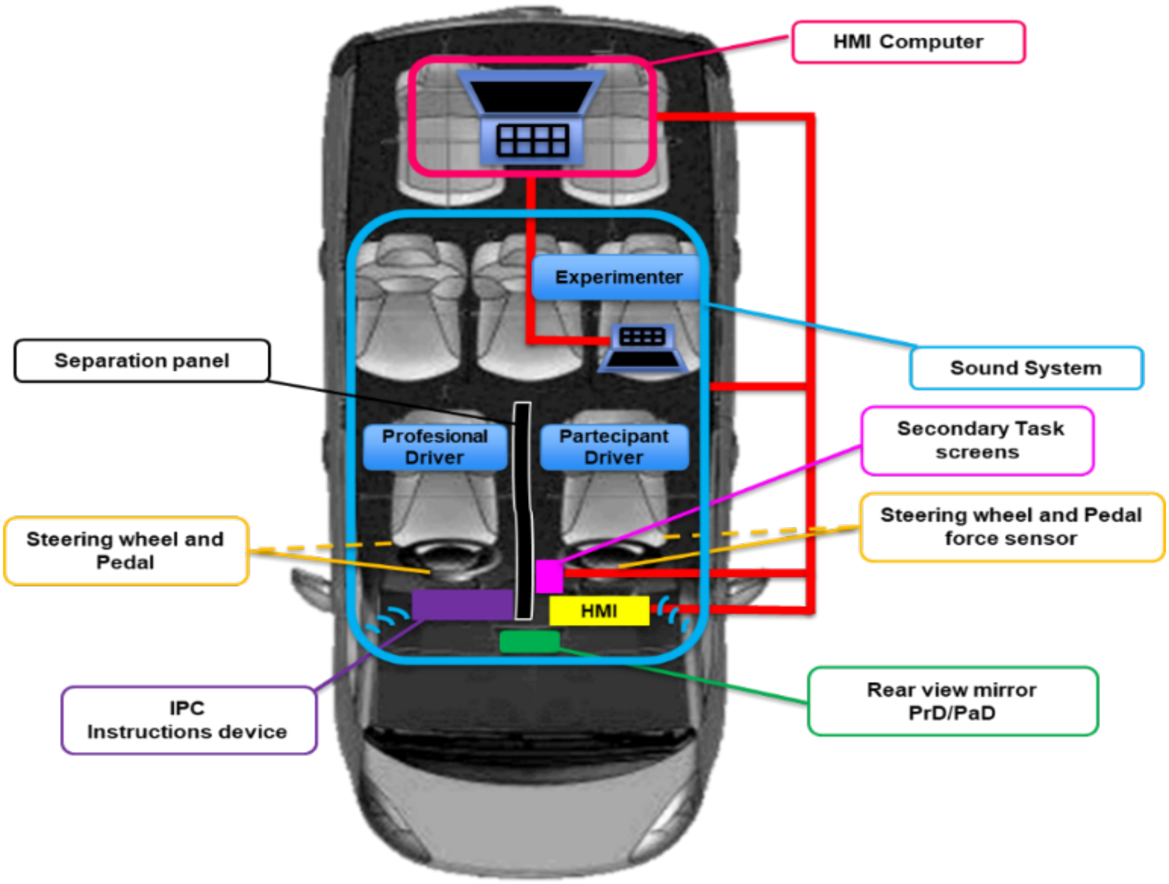


Figure A1 4 Citroën Gran Picasso 4 WoOz layout

6.1.1.3. Stanford University (2015 and 2017)

Stanford University developed 2 WoOz vehicles. The first WoOz vehicle by Stanford University (Baltodano et al., 2015), carried out by the Centre for Design Research, intended to introduce the Wizard of Oz methodology as a simulator of an automated vehicle on open public roads, describing in detail the protocols for building the system. The aim was to investigate attitudes and concerns that real users may have towards automated driving vehicles in the real world. The developed prototype was left-hand drive vehicle with the inclusion of separation panel, place between the left

and the right part of the vehicle. The participant was sitting on the passenger right seat, having in front a fake steering wheel with a display to carry out secondary activities.
Particular attention was paid to the construction of the separation, which must hide the Driver Wizard from the participant but, at the same time, allow the first not to lose visibility on the mirrors and see through the passenger window.
In the cabin there were 3 GoPro for recording the experiment, positioned as follows:

- Passenger: recording of facial expressions and hand movements
- Driving wizard: recording of road events, speedometer and steering wheel manoeuvres
- Experimenter: recording the investigator's actions and events inside the cabin.

Finally, was evaluated the effectiveness of the haptic feedback as a pre-indication of the manoeuvre that would be operated by the Wizard driver, the evaluation takes in consideration also the haptic feedback position (placed in the pneumatic platform or in the shoulder). In Figure A1 5 the Citroen Gran Picasso 4 WoOz layout is shown

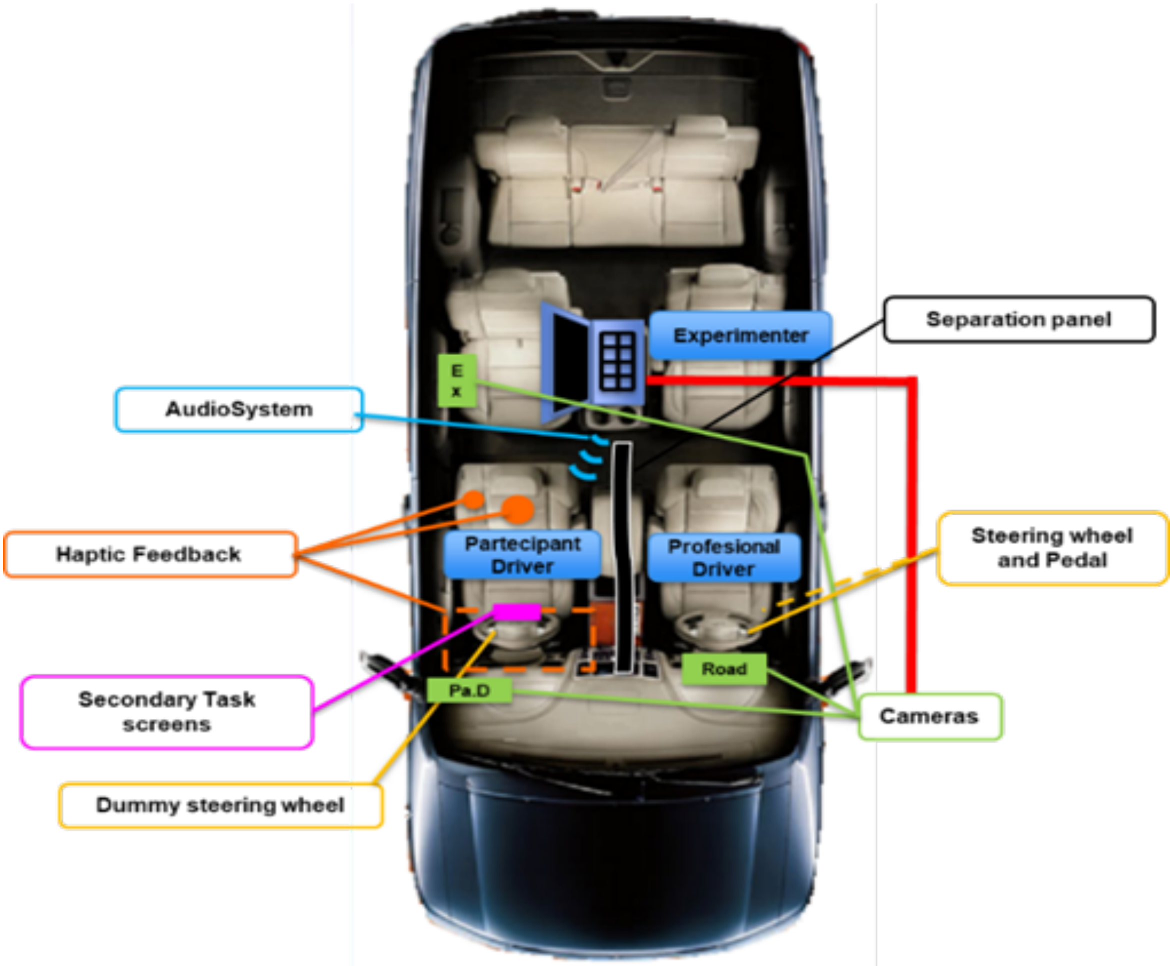


Figure A1 5 Stanford University, layout of first prototype of Wizard of Oz

<u>The second WoOz vehicle</u> was presented in 2017; the study (Wang et al., 2017) wanted to create a low-cost automated driving simulator, for the study of human-machine interaction in the road setting. As WoOz vehicle was used a Jeep with right-hand drive controls integrated with a display, for the driving Wizard; on the left side, for the participants, a dummy driving interface with steering wheel and pedals was installed.

The participant's steering wheel consisted of a portable driving game controller with force feedback functionality and of an external steering wheel sensor that detected the position and movement of the actual steering wheel.
Finally, a set of LEDs was used for communication purpose with the driving Wizard; the system was integrated with software that controlled and coordinated the information flows from each of the separate components.
The experimental layout also included an audio system, presenting auditory feedback for system activation and attention request. In Figure A1 6 the Citroen Gran Picasso 4 WoOz layout is shown.

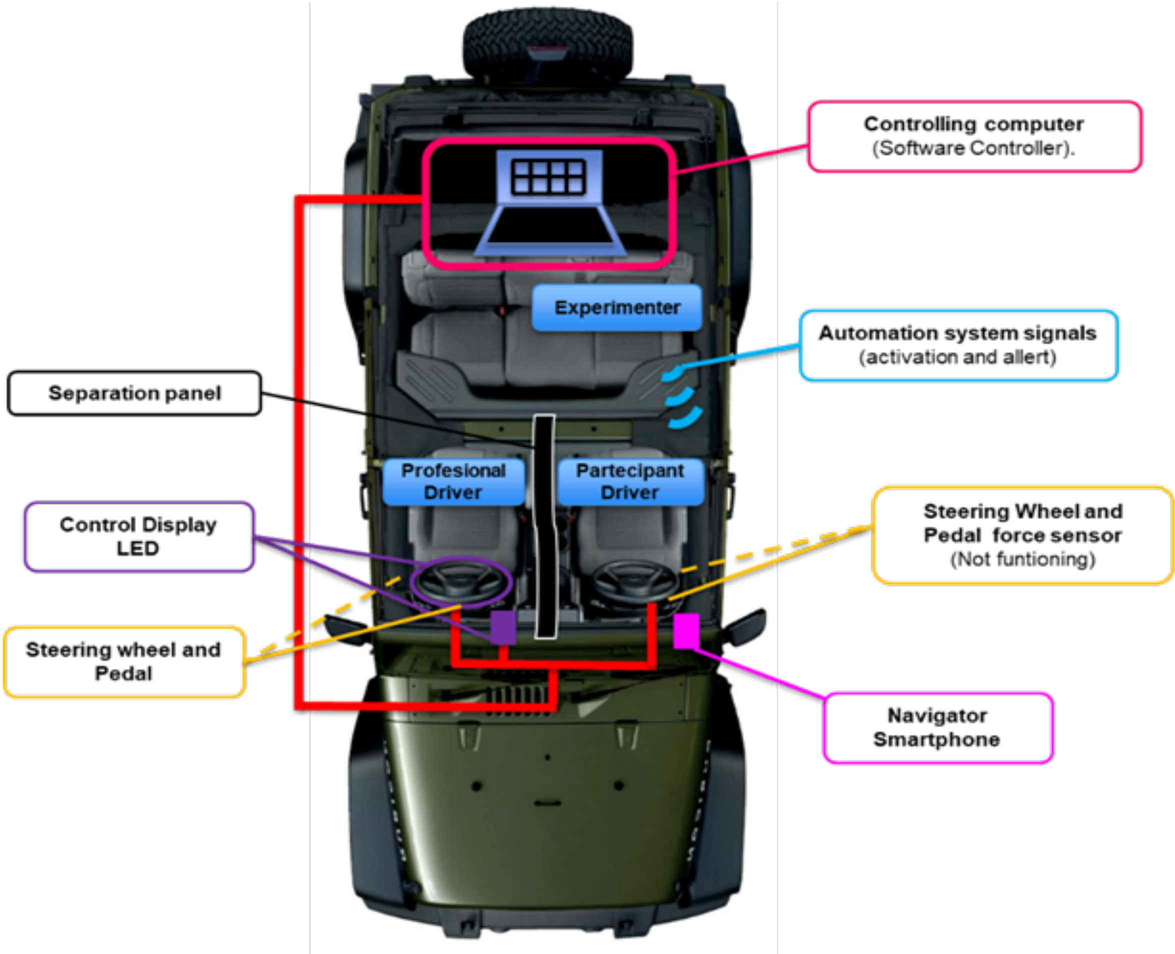


Figure A1 6 Stanford University, *layout of second prototype of Wizard of Oz*

6.1.1.4. Audi (2017)

Audi in collaboration with the German universities of Munich and Magdeburg, during the 2017, made a WoOz vehicle to study the phenomenon of drowsiness when using an autonomous driving vehicle (Weinbeer et al., 2017). In particular, the study analysed the correlation between the level of sleepiness and the readiness of the users to intervene when the vehicle system sends an attention request. The layout of the WoOz vehicle was built on a right-hand drive AUDI A7, to which were added fake driving controls on the left passenger side. The controls include pedals and a steering wheel, with limited functionalities (turns right and left), integrated with a display in the central part, containing all the information about the trip and used for carrying out secondary tasks.

The left side, dedicated to the participant, also featured three screens, which represented 3 driving lanes and a tablet positioned in the centre of the dashboard.
In this experimental case, the participant was aware of the Wizard driver function, but, despite this, was decided to obscure the participants view, trying this way to maintain the appearance of an autonomous system. The separation was realized with a curtain. Lastly, the WoOz vehicle included four video cameras for recording the participant's activity and an audio system; the images from the camera system were sent in real time to two screens placed in the rear seats, where two experimenters analysed participant's behaviour in the various phases of the experiment. In Figure A1 7 the Audi A7 WoOz layout is shown.

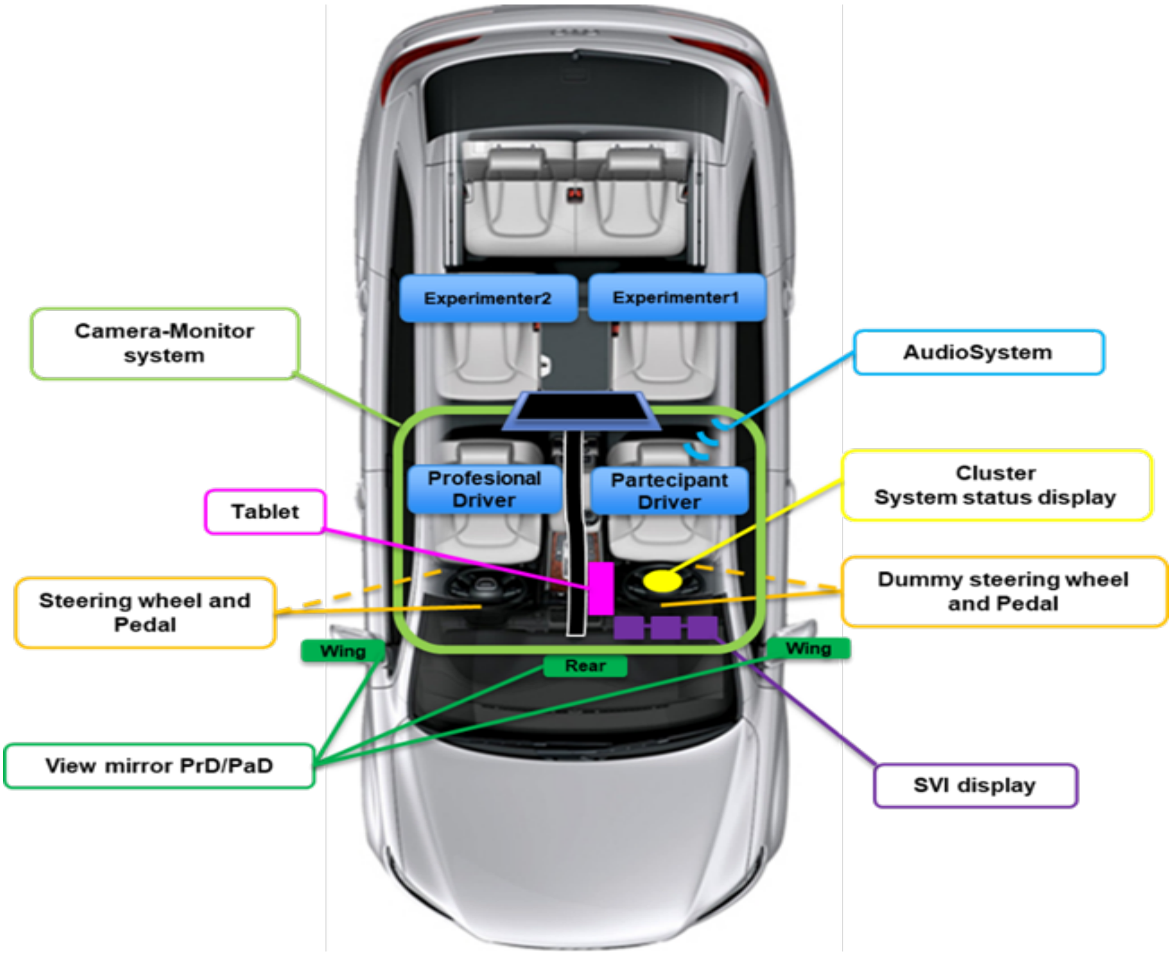


Figure A1 7 Audi A7 Wizard of Oz layout

6.1.1.5. Volvo (2018)

The Volvo in collaboration with Halmstad University and Monash University, (Osz et al., 2018), wanted to outline a new way of performing WoOz experiments on user experience (UX), which specifically targets driving with different levels of self-driving modes, combining experimental and ethnographic WoOz tests. The goal remained the overall understanding of the user experience and expectations from the autonomous driving and, more specifically, the construction of an interdisciplinary collaborative testing approach. The equipment was built on a Volvo XC90; the test participant is on the front left seat, meanwhile the Driver Wizard and HMI Wizard are on the rear seats; the experimenter can be positioned in front or in the rear seat, depending on his/her role in the study (Figure A1 8).

Figure A1 8 Set-up of the Volvo Wizard of Oz vehicle

The equipment was built on a Volvo XC90; the test participant is on the front left seat, meanwhile the Driver Wizard and HMI Wizard are on the rear seats; the experimenter can be positioned in front or in the rear seat, depending on his/her role in the study.
The peculiarity of this vehicle is that the driving controls of the Wizard driver are operated through a joystick, replacing the double steering wheel seen in the previous examples; furthermore, the separation between the driving Wizard and the participant is not total but partial.
In addition, for the completion of participants' secondary tasks, the layout is composed by an audio feedback system and a display (positioned in the middle of the dashboard), eye tracker, cameras and logging system for vehicle data and extra sensors, and "speakers" for audio feedback (which can be of any type depending on the study). In Figure A1 9, the layout of the Volvo XC90 Wizard of Oz vehicle is shown.

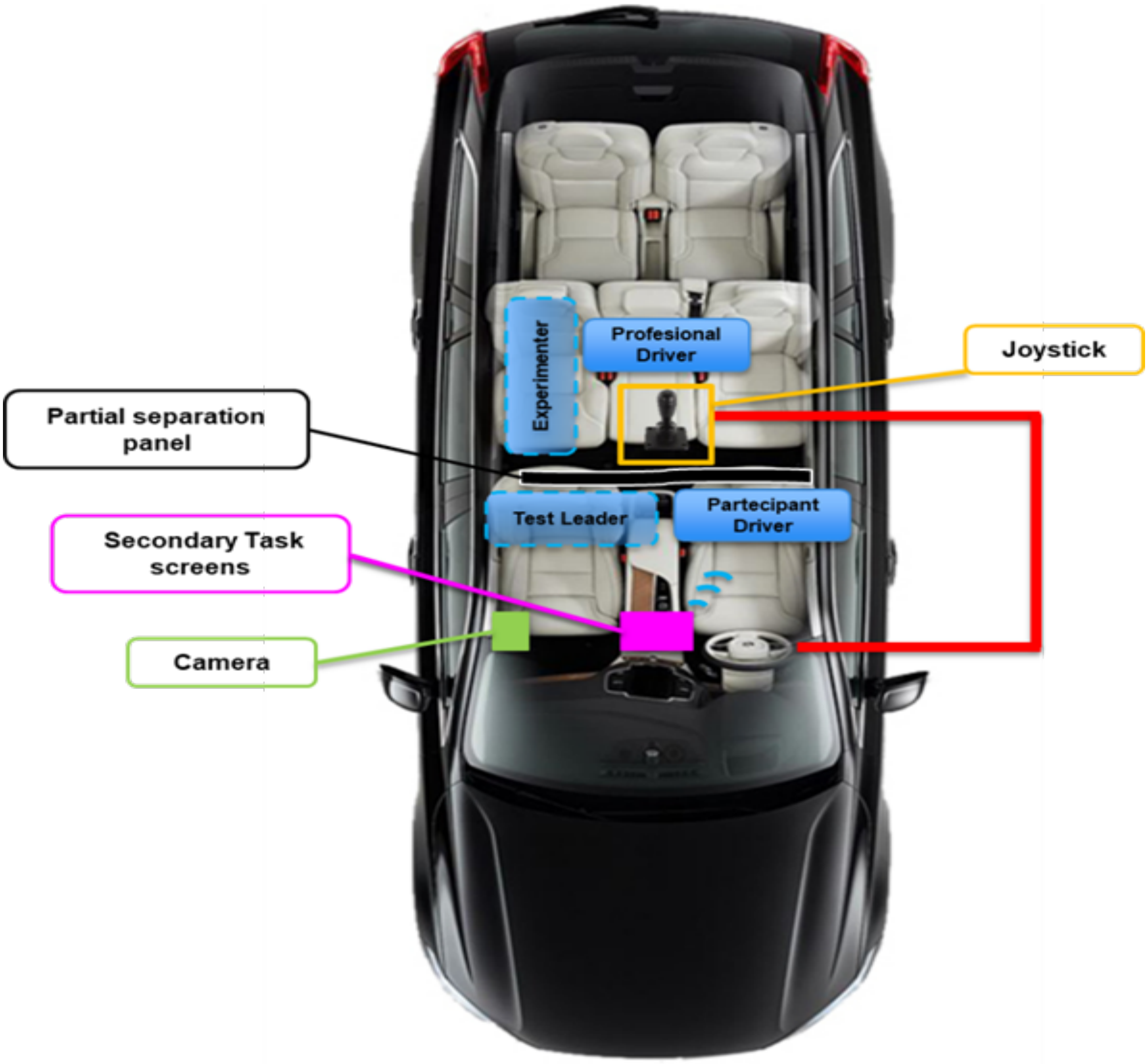


Figure A1 9 Volvo XC90 Wizard of Oz layout

6.1.1.6. Bosh (2018)

Bosch, in collaboration with BMW and the Würzburg Institute for Traffic Sciences, wanted to analyse the behaviour of drivers in situations where the autonomous system requests the resumption of the driving control (Berghöfer et al., 2018).

Interest was focused on the effects of naturalistic activities, not related to driving, on the time to resume control and on the prevision of the time required, studied through the behaviour model of the naïf driver's gaze and other characteristics of the participant.

The layout of the Wizard vehicle was built on a left-hand drive BMW 520D, where the participant was sitting, while the Wizard driver took control of the ride via a joystick installed in the right armrest, passenger side, and a double pedal board.

The participant was informed of the role of the Driving Wizard and no kind of separation was used between the two. The HMI interface, controlled by the experimenter on the rear seats, consisted in the information on the status of the system displayed on the instrument cluster and on the Head Up Display (HUD) and via audio feedback (Figure A1 10).

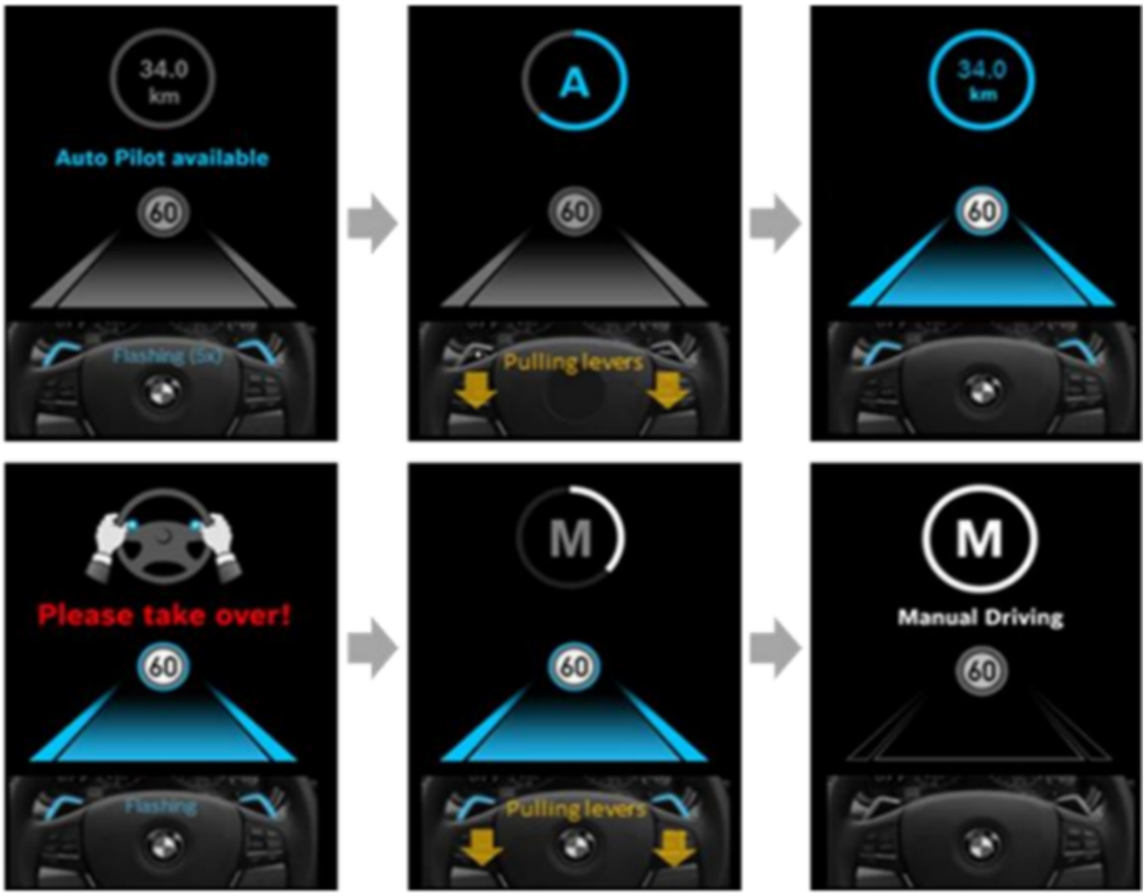


Figure A1 10 HMI graphics projected on instrument cluster

The participant's station was equipped with a screen to perform secondary activities, an eye-tracker, to measure the position and movement of the driver's eyes; the passenger compartment was equipped with a video recording system. In Figure A1 11 the Bosh WoOz layout is shown.

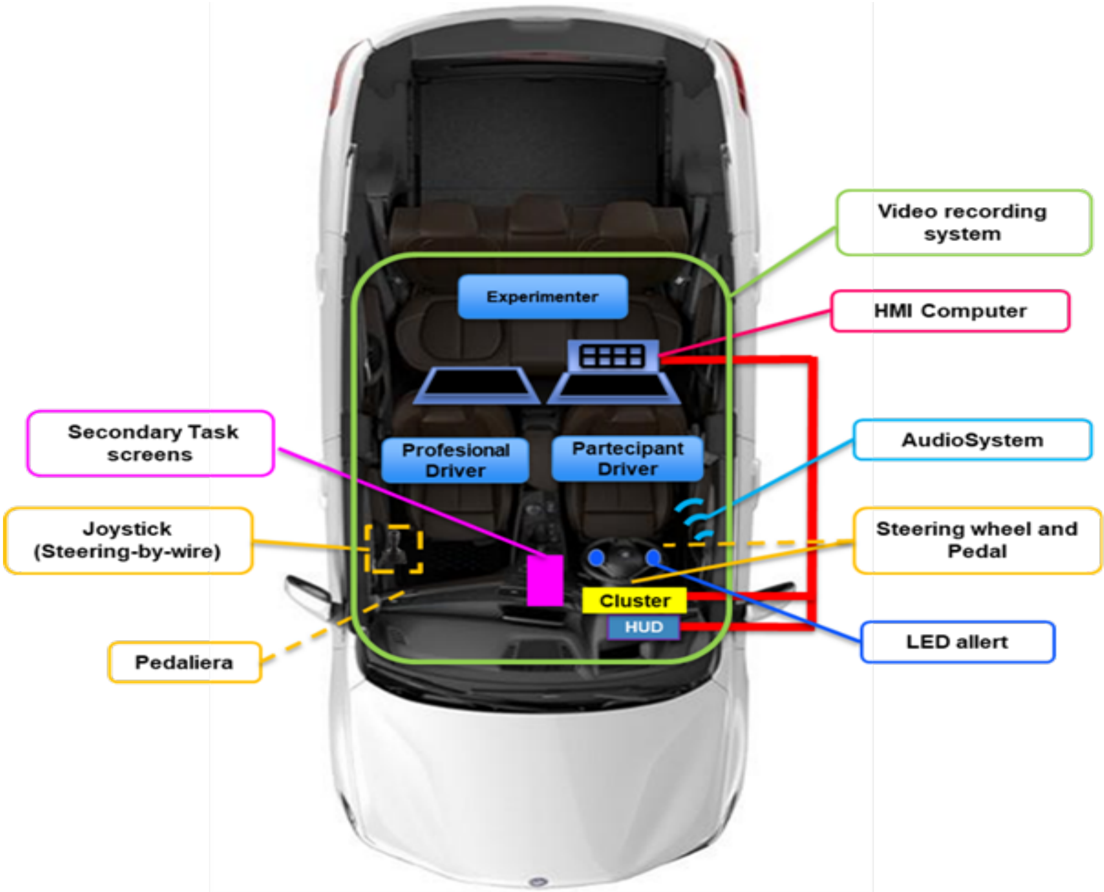


Figure A1 11 Bosch Wizard of Oz layout

6.1.1.7. BMW (2019)

BMW presented several research studies using the Wizard of Oz methodology inside a car; the two studies taken into consideration were carried out in collaboration with the Technical University of Munich and the Human Factors department of the University of Ulm, and both published in 2019 (Omozik et al., 2019). The WoOz vehicle used in both cases had the same layout, using a left-hand drive vehicle, model BMW X5 SUV, but had different aim:

- Investigate the effects of non-driving related activities on driver fatigue in prolonged automated driving in a real road traffic environment.
- Investigate the effects of user adoption of automated driving and the time taken by users to show the first behavioural changes, in particular related to relaxation time.

The peculiarity of this vehicle was that the driving Wizard, hidden from the view of the participant, was placed in the rear seats in a central position; the separation was achieved using a one-way mirror, so as to allow the Wizard driver full visibility of the driving environment. The driving controls consisted of a steering wheel and pedals, integrated with a screen, connected to the camera system that recorded the road events. The participant's position was placed in the usual driving position, on the left; completed with a screen to perform secondary activities and an eye-tracker, to measure position and movement of the participant-driver's eyes. When the autonomous driving function was activated, controlled by the driver Wizard, different feedbacks were used to communicate the status of the system, through the LEDs on the steering wheel, the audio feedback and the information displayed on the instrument cluster. The cluster interface presented the ego-vehicle in a lane, the current speed, an icon indicating the status of the autonomous driving, and any intervention request messages. In Figure A1 12 the BMW X5 WoOz layout is shown.

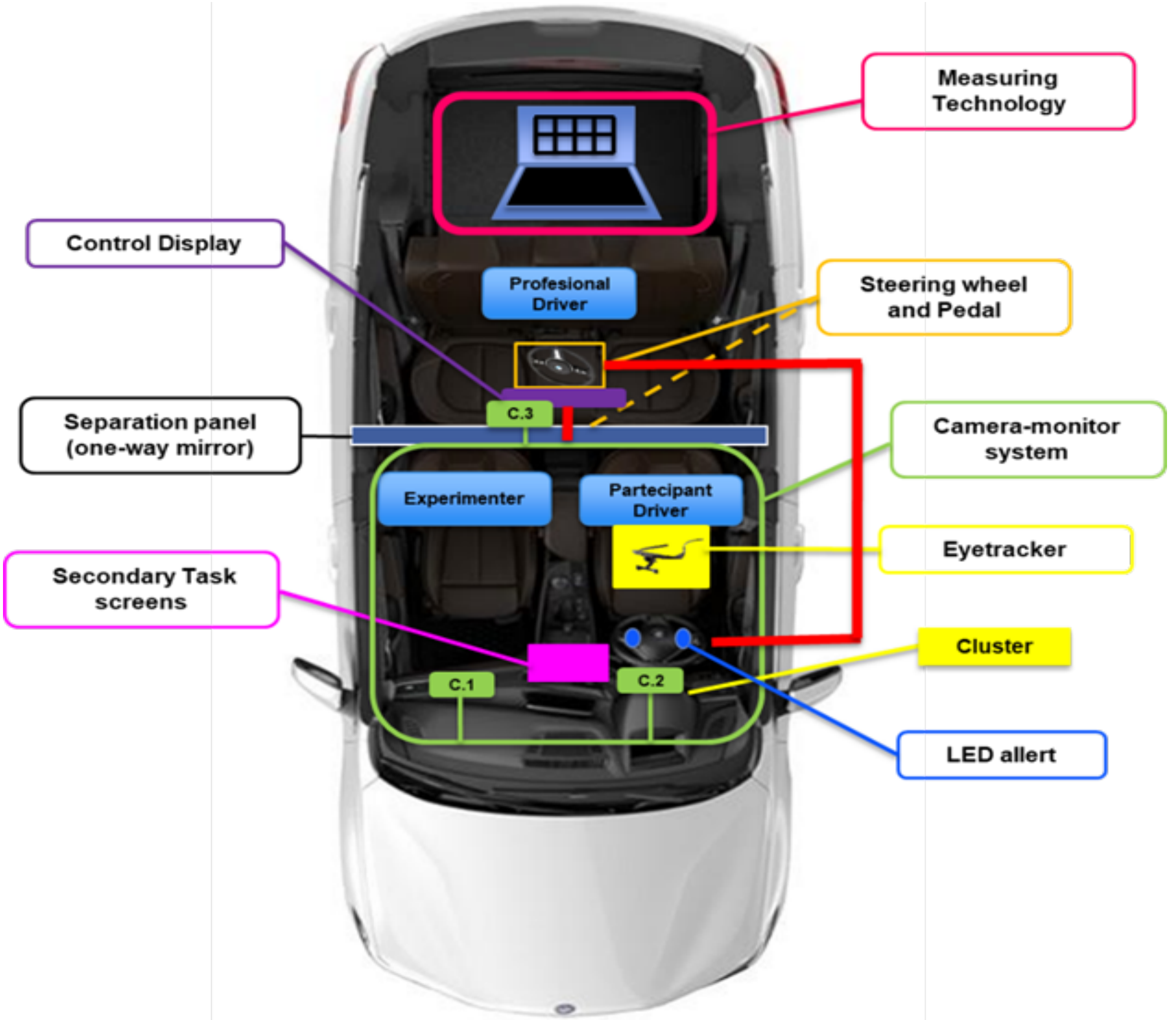


Figure A1 12 BMW X5 Wizard of Oz layout

6.2. Small laboratory tests on the road

With the aim of deducing the functional requirements for the Mediator Human Factor (HF) in-vehicle prototype it was decided to have a first iteration on-road test using the basic prototype named Sim-Panda to allow involved group of experts to have a somehow “automated” vehicle experience.

Participants

The on-road test involved five participants, who were FCA experts, not working in ADAS and Automated vehicles domains. The choice of involving experts allowed deducing indispensable requirements, not possible to be highlighted by naïve users, for the creation of the basic

MEDIATOR ADS-level prototype that is evaluated with the involvement of naïve users in WP3, in Italy and Sweden tests.

Apparatus

The on-road test was done using the Sim-Panda prototype vehicle, which does not have any automated driving function as previously described. Summing up, the test vehicle is a Fiat Panda with right side drive and on the left side there is an added not functional steering wheel and pedals. So, the participant, sits on the left, can have the impression of experiencing an automated vehicle, but the professional driver on the right side has always the control of the vehicle.

A basic HMI, displayed on the expert participant smartphone was used.
Three messages appeared, when appropriate, on the smartphone display to indicate to the user when the drive could be automated or when the driver has to resume his/her control through the following messages: "*Now you can remove the hands from the steering wheel*", "*Prepare to take the control of the vehicle*" and "*Take the control of the vehicle*".

Scenario

The test with Sim-Panda was conducted on public roads in Pomigliano (Naples) in Italy.
The road path was chosen to include some of the use cases identified by MEDIATOR to test the automated driving (highway entrance, highway exit, roundabout, zebra crossing).
To minimize potential risks during the trip and to maintain the illusion of an automated car, the wizard driver imitates the expected defensive (e.g., not exceeding speed limits and being attentive to other road users) and forward-thinking driving style of an automated vehicle.

In Figure A1 13, the route used during the test is shown. This route with the car in autonomous mode, obviously, was followed if there wasn't abnormal traffic in the individual sections, otherwise the experiment couldn't be credible.

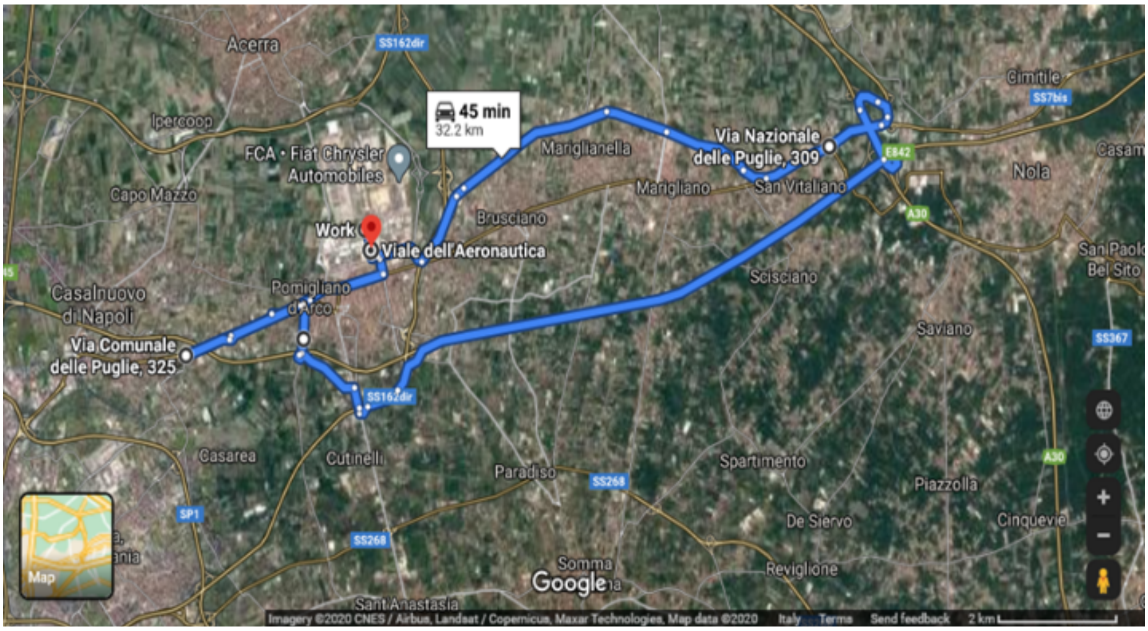


Figure A1 13 Trial route during the test with Sim-Panda

Tasks

The test vehicle was always driven by the professional driver (driver wizard) on the right seat. The participant could leave, when notified by the HMI, the control of the vehicle and he had to resume it again when requested by of the simplified HMI.
In fact, a WEB app was developed to allow the wizard driver to send messages on the participant smartphone when there was takeover or handover requests, in relation to specific points of the trip (on motorway, close to a roundabout, etc.), always privileging the driving safety. The WEB App was managed by two different QRCODE, one for the wizard driver (to send message in safety) and one for the participant (to visualize on his own smartphone the action to do).
The wizard driver had only two push buttons to use (to ensure a safe driving):

- Push button 1 to send the message 1
- Push button 2 to send the message 2

In total, three messages were planned to be sent to the participant:
Message 1: "*Ora puoi lasciare il volante*" (Now you can remove the hands from the steering wheel). This message was active for 10 seconds and after it disappeared
Message 2: "*Preparati a riprendere il controllo del veicolo*" (Prepare to keep again the control of the vehicle). This message was active for 5 seconds and after it disappeared.
After 5 seconds, the third message appeared
Message 3: "*Riprendi il controllo del veicolo*" (Resume the control of the vehicle). This message was active for 5 seconds.

Procedure

Before each on-road test, the participant was:

- Welcomed and thanked for participation into the study and informed about the aim of the test by an interviewer by phone. The interview was conducted by remote due to COVID 19 restrictions
- Requested to follow the strict COVID 19 protocol (e.g. both occupants have to use masks and to sanitize their hands…)
- Requested to read and sign privacy and informed consent documents in compliance with the GDPR guidelines and to follow safety driving rules. Due to the fact the FCA involved experts have in their professional roles the task of driving vehicles during on-road trials, the MEDIATOR Ethical approval procedure was not applicable
- Asked to answer some questions regarding the acceptance and the trust a priori (before the test)
- Given instruction by the experimenter through a cover story, explaining that the car had somehow an automated driving and motivating the presence of the driver on the right seat due to the prototype version of the car.

The experimenter explains to the expert participant that the automated driving involved control of the steering wheel, throttle and braking system and that in some moments he would be able to leave the control to the automated system.

Moreover, the participant was told that the system gave the vehicle control back to him when the external conditions no longer allowed the automated driving (e.g., roundabout, pedestrian crossing, highway entrance, highway exit).
The participant was instructed to keep his attention always on the road because if the external scenario conditions change, a message would have told him to resume the vehicle control.

During the trip the participant involved in the test, accompanied and supervised by the wizard driver in the Sim-Panda and by the interviewer connected by mobile, was asked to follow a Thinking aloud protocol to explain what he was experiencing while he “had the control” of the vehicle or while the vehicle was ”in autonomous mode”.

After each test, the participant was asked to:

- answer some questions regarding the preliminary acceptance and the trust a posteriori (after the test)
- give possible suggestions to improve the basic HMI tested
- comment about his roles (driving or passengers) and at the end of the interview, the experimenter debriefed the participant, explaining to him the role of the wizard driver and informing him about the double commands in the vehicle
- At the very end, the vehicle was sanitized after each test.

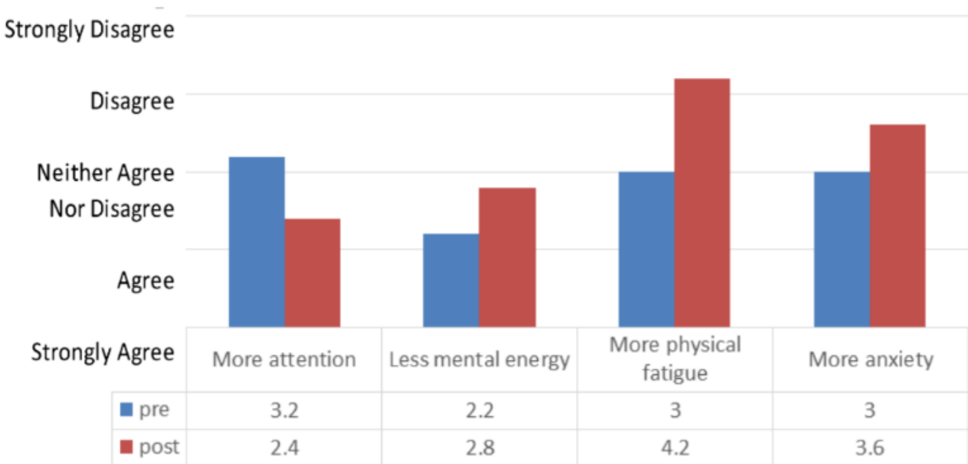
Results of Sim-Panda on-road experiment

Five FCA experts not working in ADAS and Automated Vehicles domains were involved, and they have the following characteristics:

- Age: average 40.6 (min 36 - max 44) years
- School: all high school diploma
- Gender: all male
- Driving km per years: average 98.000 (min 90.000 - max 100.000)
- Use of ADAS: all several time per week.

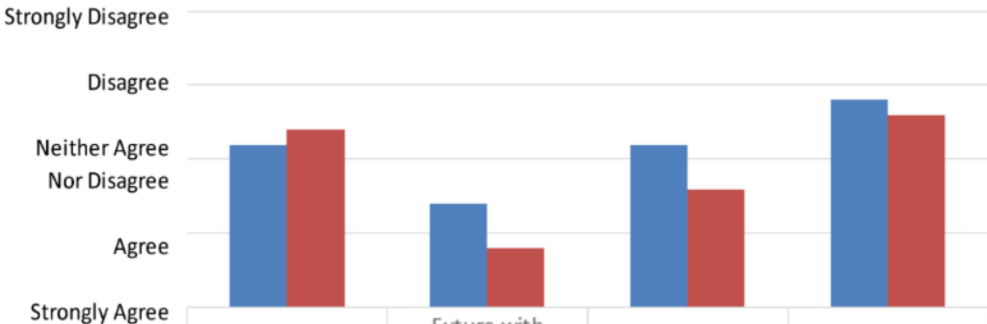
The following figures show the results of the experts’ evaluations acceptance dimensions before and after the study on driver effort, automated vehicle performance and intuitiveness behaviour, driver safety, NDRTs possibility, driver trust dimensions.

The ratings have not a statistical valence due to the small number of experts involved in the test, but they were used jointly with the qualitative analysis of the expert’s comments.



	More attention	Less mental energy	More physical fatigue	More anxiety
pre	3.2	2.2	3	3
post	2.4	2.8	4.2	3.6

	More ecological vehicle	Improve vehicle performance	Greater danger for driver	Clear driving control owning	More safe autonomous vehicle	More trust	Greater detection vehicle capability
pre	1.8	2.6	3.8	1.4	2.6	2.4	2.2
post	2.4	2.2	4	2.2	2.6	2.2	2.8



	Feeling a better person	Future with autonomous vehicles acceptable	Greater fun	More time for pleasant activities
pre	3.2	2.4	3.2	3.8
post	3.4	1.8	2.6	3.6

Figure A1 14 Pre and post acceptance questionnaire

The participants before the study rated as neutral the *level of the attention*, of the *physical fatigue* and of the *anxiety*. After the study, participants evaluated the *physical fatigue* during the automated driving less than before the trial. There are no differences before vs. after with the other dimensions.

Participants rated *performance*, *safety* and *trust* rather high and there were any differences between the scores before and after the experiment, *Feeling a better person* was rated neutral while imagine a *future with acceptable autonomous vehicles* was rated as rather high. A *greater fun* was rated neutral, and to have *more time for pleasant activities* was rated high. There weren't differences were found between the scores before and after the experiment.

The usage of the simple Sim-Panda WoOz prototype didn't cause any differences in a priori and a posteriori automated driving acceptance dimensions scores.
This is important for the credibility of the basic prototype involved into the definition of the MEDIATOR functional requirements.

6.3. Feedback for the Mediator Human Factor in-vehicle prototype

Collected evaluations and suggestions regarding the WoOz , as actuated in the Sim-Panda, are listed in the following lines, and can be considered as input for the Mediator Human Factor in-vehicle prototype development:

- the WoOz in the Sim-Panda was a credible experience, then it can be a good example to be considered the transitions to the “automated driving” were perceived as fluid
- the use cases in which transitions (roundabout, highway exit, zebra crossing…) where tested were adequate and made credible the WoOz behaviour
- in general, to increase the trust in the automated driving system the HMI could inform the driver about traffic and road detection and what manoeuvres the system intends to do
- add automatic gear lever to the wheel
- add more HMI solutions to keep possible naive driver anxiety under control.