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How to navigate the intermediate levels of vehicle automation?

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ABSTRACT

As the world moves towards higher levels of vehicle automation, the interplay between human drivers and automated systems becomes increasingly complex. This paper addresses the challenges of navigating the intermediate levels of vehicle automation, the transition stage from human driven vehicles to automated vehicles. The step-by-step introduction of automated features introduces new risks, such as mode confusion and over-reliance on automation, as well as mental underload or overload which lead to decreased driver performance and increased crash risk. In addition, during the transition, automation technology is still maturing and also has its limitations. In our view, we should aim to integrate the strengths of both human drivers and automation to enhance traffic safety and driver comfort. This paper aims to contribute conceptually to the scientific discourse on vehicle automation and to focus future research. It presents four key concepts that have proven to be meaningful to change perspective, including the Driver/Automation Fitness Plane, the definition of human-centered driving modes, and the mediator approach to seamless collaboration between driver and automation. These concepts are designed to facilitate a safer and more intuitive interaction between humans and automated systems, leveraging interdisciplinary perspectives on technology, behavior, cognition, and design. The paper concludes with a discussion on the potential of automation and calls for a human-centered approach to fully realize the benefits of vehicle automation.

Introduction

Engaging in daily traffic is a routine for most of us. What we may not realize every day, is that a reliable traffic system is a great societal value, ensuring we reach our destinations safely and timely. The significance of reliable mobility is underscored by its direct impact on our quality of life. Mobility constraints can limit our ability to visit loved ones or attend meetings of interest. Essentially, a loss in mobility is a loss of independence and a risk of social isolation. A smoothly functioning, safe, and inclusive transportation system is not just a personal asset but a valuable societal attribute.

Transition towards higher levels of vehicle automation

Our traffic system is in a transition. The concept of self-driving vehicles, once a distant fantasy, is now inching closer to reality. In fact, some of these technologies are on the verge of hitting our roads. We see an increase of new technologies in the vehicles on the road, such as longitudinal and lateral control as well as hands-off driving features. The emergence of robotaxis navigating the streets of San Francisco also exemplifies the tangible progress in integrating these innovations into real-world transportation.

The transition to full automation is a gradual process unfolding over years, possibly even decades. Technological advancements are driving the transition. Research across the globe is progressing into a wide variety of smart mobility technologies, with enormous potential for enhancing comfort, safety, sustainability and inclusivity within our traffic system.

SAE levels of automation

The progression toward self-driving vehicles is occurring incrementally. The most commonly used framework for defining the steps in the transition are the levels of automation as developed by the Society of Automotive Engineers (SAE) (SAE, 2021). These SAE levels represent a staged transition from human-operated vehicles (level 0) to fully autonomous vehicles (level 5) (see Fig. 1), with each level introducing more technology and reducing the human driver's role. On the left side

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of the spectrum, the human is in the driver's seat, while on the right, automation has the control of the vehicle. At the intermediate levels, defined here as SAE levels 2, 3 and 4, the responsibility for driving is shared between driver and automation.

The challenge is in the transition: The intermediate levels of automation

Currently, we are navigating these intermediate levels. Many vehicles on our roads are equipped with level 1 and level 2 technologies. The next step is transitioning to level 3 and level 4, where drivers can take their hands off the wheel, their feet off the pedals, and even take their eyes off the road. At these levels, drivers may get 'out of the loop' and engage in other activities. This transition will likely start for just some specific traffic situations and gradually expand as technology matures.

The intermediate levels are particularly challenging because the technology is not yet mature and because of the variations in the available automation technology, not only between vehicles, but also for the same vehicle the availability will vary within a trip (van Nes and Duivenvoorde, 2017). On the short term, the availability of certain automation features depends on the situation, such as road type, weather conditions and road condition. The Operational Design Domain (ODD) of a system defines the specific conditions under which an automated technology is designed to properly operate, including environmental, geographical, infrastructure, and time-of-day restrictions. Over time, the ODD of the automation technology will increase with the advancement of the systems. New features are implemented when available, sometimes this could be as seamless as a software update overnight. Such variations in the availability of automation within and between trips are prone to confusion for the driver.

Human factors concerns

While technology continues to mature, we are increasingly utilizing it. Despite the potential to improve traffic safety, we see that the use of this new technology is also introducing new risks (Dutch Safety Board, 2019; Aria et al., 2016; Cunningham & Regan, 2015; Harms et al., 2020). There are plenty of examples across the globe where drivers misunderstand or misuse their novel systems. This is a particular concern at the intermediate levels of automation, where both humans and automated systems have a role in the driving task. A key concern is **mode confusion** (Wilson et al., 2020), which occurs when drivers lack sufficient awareness of the system's current mode of operation and the distribution of tasks between the system and the driver. In several instances, drivers expected the automation to be in control and relied too heavily on the system. This is what we call **over-reliance** (Mahr & Müller, 2011). In a way, over-reliance is a logical consequence of the fact that drivers are exposed to systems that operate well in many circumstances, but not in all. When the automation is performing increasingly well, the driver becomes more or less a backup for the system, essentially waiting in a dormant mode to take action when needed. However, humans are not good at that. The relation between performance and task load (De Waard & Van Nes, 2021; Pattyn et al., 2008; De Waard, 1996), shows that humans have an **optimal window of performance**. If the task load is too high, we get stressed and our performance goes down, this could for example happen in take-over situations (Li et al., 2022). But if the task load is too low, we get bored and sleepy and our performance also goes down (De Waard & Van Nes, 2021; Körber et al., 2015; May & Baldwin 2009; De Waard, 1996). In particular at the intermediate levels of automation, we as drivers will be relatively often exposed to these overload (e.g. take-overs) and underload (e.g. monitoring) conditions. The technology pushes us, humans, into a role we are not good at. As we increasingly rely on automation technologies, the challenge is to carefully design the relation between automated systems and human drivers.

This challenge extends beyond road traffic to other transport modes, including aviation, maritime, and rail transport. In these domains, there is also a continuous and consistent increase of automated systems and a need for a deeper understanding of the interaction between these

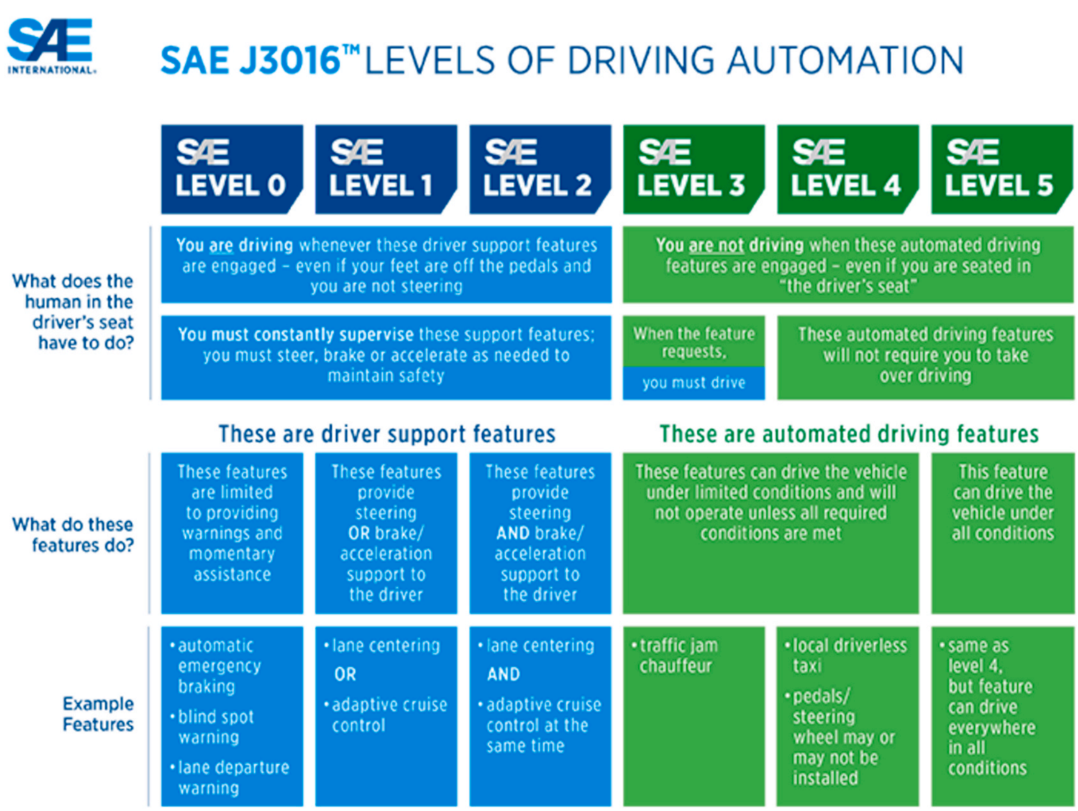

Fig. 1. SAE levels of driving automation (SAE, 2021).

automated systems and the human users (pilots, captains, and train drivers) to ensure safety and acceptance.

Changing perspective

The transition towards higher levels of automation is predominantly steered by technological readiness or technological advancements. And, as indicated, despite the promising potential of automation technology, these developments are also introducing new risks.

This paper argues that ensuring safety during the transition to automated driving requires a shift in perspective. We must move away from a predominantly technology-driven perspective and adopt a more human-centered approach. Instead of viewing the introduction of new technology as a goal, we should see it as a 'means to an end' to improve driver safety and comfort. We should take human needs, motivations, capabilities, and limitations as a starting point, and using technological innovations to steer towards safer solutions. Such a more balanced approach, leveraging the distinct strengths of both humans and automation while recognizing their respective limitations and weaknesses, holds significant safety potential.

To accomplish this, we must fundamentally alter our approach to integrating the strengths and weaknesses of human drivers and automation, and we need to gain a more comprehensive holistic understanding of the intricate interplay between the two. The challenge lies in designing a system that fosters smooth collaboration between automation and users, capitalizing on their complementary strengths. Addressing these challenges requires a multi-disciplinary effort. Engineers, human factors experts, and designers have to join forces to tackle these complex issues collaboratively.

The MEDIATOR project

This was the main vision underlying the MEDIATOR project. MEDIATOR was a 4-year project (May 2019 – April 2023), co-funded by the European Commission. MEDIATOR pursued a paradigm shift away from a view that prioritizes either the driver or the automation, instead integrating the best of both. This paper presents some of the main concepts developed in the initial phases of the MEDIATOR project, most of these concepts were shaped in the proposal phase. Over the years, these concepts have proven a wider relevance and deserve an existence beyond the project.

Outline

Aiming to contribute conceptually to the scientific discourse on vehicle automation, the paper introduces four key concepts to comprehensively address the human factors challenges during the transition to higher levels of vehicle automation, taking an integrated approach. Each section presents a key concept. Section 2 introduces the driver/automation fitness plane—a foundational framework emphasizing the significance of both driver and automation fitness and illustrating how we can navigate between them. Section 3 is introducing the mediator concept, being a conceptual idea for seamless collaboration between driver and automation based on fitness levels. Section 4 presents the human-centered driving modes, a novel approach to define automated driving modes from a human-centered perspective. Section 5 tackles the intricate challenges in designing the Human Machine Interface (HMI). Finally, Section 6 wraps up the paper with a reflection on the results, and suggestions for further research and development.

The fitness Plane: Navigating driver fitness and automation fitness

Having identified the necessity of a balanced approach, using the qualities of both the human and the automation, this section introduces a collaborative framework to identify which of both qualities to use: the Driver/Automation Fitness Plane. This collaborative framework emphasizes the importance of collaboration while considering both driver fitness and automation fitness when navigating the intermediate levels of automation.

Fitness is key

To secure safety on our roads, it is essential that drivers are fit to drive. By 'fit to drive', we mean that a driver should possess the capability and mental condition to safely operate a vehicle. When a driver is not fit to drive, it elevates the risk of crashes. Unfitness could have many causes, for example it could be the result of involvement in non-driving related tasks such as texting, or impairment due to fatigue, physical pain or emotional condition. In practice, drivers are not flawless; they make errors and are prone to fatigue, impairment, and distraction, all of which contribute to increased risk (de Winkel et al., 2024).

Simultaneously, automated systems are not flawless either and at the intermediate levels the safety and reliability of operation are often limited to specific situations (ODD). Certain conditions, like adverse weather (rain, fog, snow, or intense sunlight), can disrupt sensor performance, impacting the fitness of automated features such as lateral and longitudinal control. Note that the fitness of the automation could relate to a single system, or to a set of systems or to fully Autonomous Driving Systems (ADS). It is also important to acknowledge that automation can be partially fit; for example, longitudinal control might function well, while lateral control does not. In that case, the lateral control is considered unfit.

Driver and automation fitness

At intermediate levels of automation, the driving task is shared between the driver and the automation. To secure the safety of the joint driver/automation system, we must consider both driver fitness and automation fitness.

Driver fitness pertains to the drivers' condition at a specific moment and their competence in carrying out the driving task. Driver fitness relates to cognitive and physiological factors like alertness, attention, physical and emotional state, all of which influence drivers' capacity to drive safely.

Similarly, we can define automation fitness. It concerns the automation's condition at a given moment and its capability to perform the driving task. Automation fitness is affected by factors such as sensor performance, quality of data processing, actuator performance and factors determining the ODD, which collectively impact the automation's capacity to drive safely.

The Driver/Automation fitness Plane

These two dimensions, driver fitness and automation fitness, form the foundation of what we refer to as the Driver/Automation Fitness Plane (Fig. 2). The Driver/Automation Fitness Plane provides a framework for observing and comprehending the dynamics in both driver and automation fitness throughout a trip, as well as for effectively managing safe and timely transitions between driver and automation. Both driver and automation fitness are subject to change during one and the same trip. For instance, a driver might become distracted or fatigued during a trip, leading to a decrease in driver fitness. Similarly, if lane markings have deteriorated, the lane-keeping system may not function properly anymore, resulting in reduced automation fitness.

In the Driver/Automation Fitness Plane, we identify key markers that signify the level of degraded performance of both the driver (horizontal axis) and the automation (vertical axis): (−) indicates a partial degraded performance, while (!) denotes a state where the driver or the automation is considered unfit for driving.

Throughout a trip, the vehicle control, which is a collaborative effort between the driver and automation, essentially moves within the Fitness

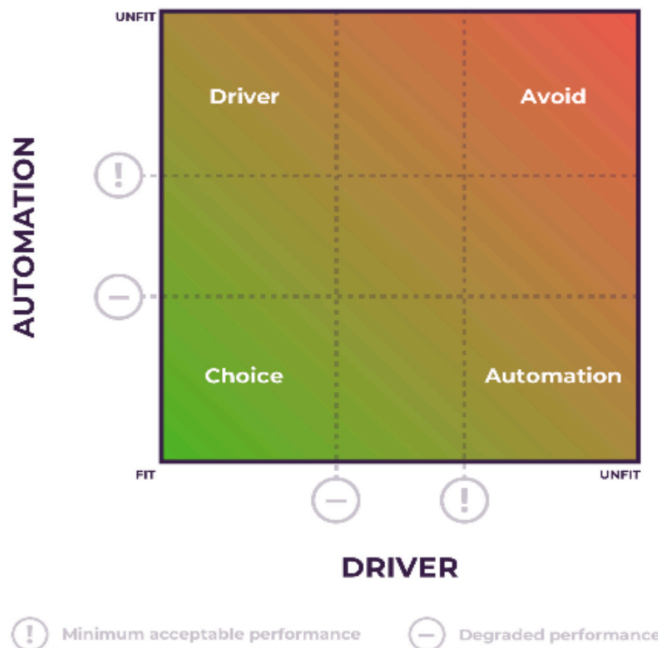

Fig. 2. Driver/Automation Fitness Plane.

Plane. A decline in driver fitness shifts the position to the right, while an improvement moves it to the left within the plane. Conversely, a decrease in automation fitness results in an upward movement, while an increase leads to a downward shift within the plane. The four corners of the Fitness Plane define the four different situations. Below each situation is defined as well as how to balance between driver and automation fitness in this situation and if a shift of control between human and automation is desired.

The green zone: a safe and comfortable space.

In the lower left corner of the Fitness Plane, both driver and automation are sufficiently fit to safely control the vehicle. This green zone is a comfortable situation where the driver can choose between being in control or handing over to the automation. If the driver retains control, the automation can serve as a backup or even offer to take over to enhance the driver's comfort.

An interesting approach for managing control between the driver and the automation within the green zone is the concept of shared control (Flemisch et al., 2003; Flemisch et al., 2012; Abbink et al. (2012); Inagaki, 2003). Shared control refers to a collaborative arrangement where both humans and automated systems contribute to the control of the driving task. Instead of complete autonomy by either the human or the machine, shared control allows for a dynamic division of responsibilities based on the strengths and limitations of each, leveraging the unique capabilities of both humans and machines to enhance overall performance, efficiency, and safety.

Driver in control.

In the upper left corner of the fitness plane, the automation fitness is degraded and the driver is sufficiently fit to safely control the vehicle. Here, the safest option is the driver taking control of the vehicle. This occurs when the vehicle goes beyond the ODD of the automation, for instance, when heavy rain sets in, causing sensor failure reducing the performance of the automation. In the scenario the automation fitness gets degraded, the driver needs to take control of the vehicle. As soon as the automation fitness has improved again, we get back in the comfortable green zone.

Automation in control.

Conversely, in the lower right corner of the fitness plane, the driver's fitness is degraded, while the automation is sufficiently fit for safe vehicle control. An example could be when drivers in manual mode become distracted by a phone message, diminishing their fitness. In this scenario, the driver fitness degrades and the automation should (offer to) take the control of the vehicle.

The red zone: a space to avoid.

The upper right corner of the fitness plane represents a situation where both driver and automation lack the fitness required for safe control. Clearly, this scenario should be avoided. When this occurs, the vehicle should be brought to a safe stop. However, simply reaching a standstill is not a satisfactory solution. The true challenge lies in preventing this situation proactively by design.

Mediation actions

The Fitness Plane encourages taking a proactive approach to maintain driver and automation fitness by ensuring at least one of them maintains fit to drive. The field of design solutions to manage driver and automation fitness is yet to be explored. Automation fitness could, for example, be managed by robust system design and backup systems and by using available information about factors that are known to impact sensor performance to make predictions about automation fitness. This information can be used to better inform and prepare the driver for upcoming changes in availability of automation.

Driver fitness could be managed by implementing corrective and preventive actions to maintain or improve driver fitness when needed. Corrective actions aim at enhancing driver alertness to mitigate instances of driver unfitness, such as distractions or fatigue. For example, this could be the (compelling) suggestion to take a break and have a coffee. In addition, we embrace a more novel and proactive approach of preventing the (potential) development of degraded driver fitness. As an example: we know that if a driver is exposed to an underload situation for a longer period of time, this is likely to induce boredom or task induced fatigue (Matthews and Desmond, 2002). In this case, a preventive action could be to somehow engage the driver in a task and as such increase the task load and reduce boredom or fatigue. As a last resort, if no other safe options remain, emergency actions can be initiated.

The driving context

In addition to driver fitness and automation fitness, it is important to consider the impact of a third dimension: the driving context. This dimension involves situational characteristics such as weather conditions (such as snow, rain, fog, or bright sunlight), road conditions (like lane marking visibility and road maintenance work), and the traffic situation (including traffic density, the presence of pedestrians/cyclists, or traffic jams). These conditions influence the task requirements and, in turn, the required level of fitness: what is deemed a sufficient level of fitness for a simple task might not suffice for a more complex one. Therefore, it is crucial to assess and predict driver and automation

Fig. 3. Three-dimensional representation of the Driver/Automation Fitness Plane: driver fitness, automation fitness and driving context.

fitness within the relevant context. Fig. 3 illustrates the three-dimensional Driver/Automation Fitness Plane including the driver fitness, automation fitness as well as the driving context.

The mediator concept: Mediating control between human and automation

Who is fittest to drive?

Considering the inherent strengths and weaknesses of both the driver and the automation, there are significant benefits to be gained from actively managing and mediating control between the human driver and the automation, thereby ensuring that control is entrusted to the most suitable entity at any given moment.

To achieve this, it is essential to continually monitor both driver fitness and automation fitness, providing a real-time assessment and prediction of their capabilities. When combined with an understanding of the task demands in the specific driving context, it becomes possible to determine the best collaboration between human and automation for safe driving and how the driving tasks should be optimally distributed between driver and automation. This idea forms the conceptual basis for the *Mediator* system. The Fitness Plane serves as a guidance for determining control distribution and directions for interventions such as corrective and preventive actions.

The principle of mediating control between the human and the automation by a mediator is a conceptual idea, which could be embodied in a separate smart decision-making system or as an integrated part of the automation. For the sake of simplicity, within the context of MEDIATOR project, the Mediator system was approached as a separate system. Most important is the conceptual idea. The mediator concept is a way of looking at and shaping the relation between the human and the automation; it changes the perspective from a technology-centered approach to utilizing the qualities of both.

The mediator concept

The mediator concept entails the idea of offering an intelligent support (system) to the driver, enabling safe and comfortable switching between the human driver and the automation, integrating the best of both human and automation performance. Fig. 4 illustrates the principle of the mediator concept. The idea is that a *Mediator* monitors the driver state and determines, continuously and in real time, to what extent the driver can be expected to respond appropriately and timely. To do so, it monitors and predicts the driver state, such as the driver's level of alertness and the level of attention (from fully focused on the driving task to fully distracted by non-driving tasks, e.g., smartphone use). At the same time, the *Mediator* monitors and predicts the automation state (e.g., what systems are switched on or off, how confident it is about the reliability of current and predicted performance).

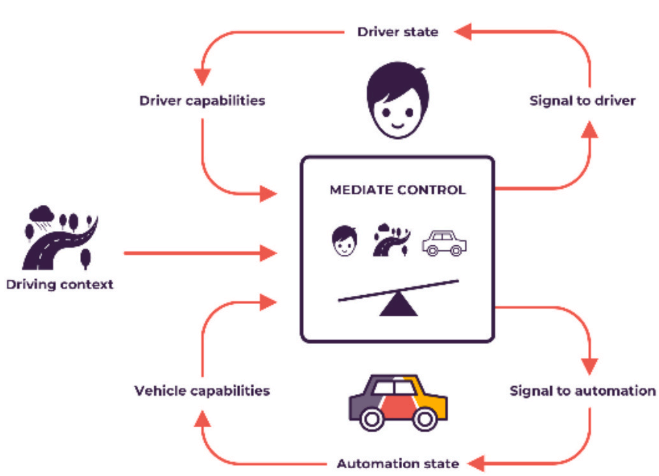

Fig. 4. A systematic representation of the mediator concept.

The *Mediator* compares the full picture of the driver's fitness and the automation fitness with the requirements of the current and upcoming driving context. Based on this information, and using artificial intelligence technology, the *Mediator* decision logic evaluates the current and anticipated performance levels of both the driver and the automation. It categorizes these state levels as sufficient, degraded or insufficient. Subsequently, the system determines who should be in control of the vehicle, and whether any necessary transitions of control should take place. In this decision, it takes into account the degree of confidence in these assessments. Additionally, the system assesses if corrective or preventive actions are needed to enhance or maintain driver fitness, such as waking the driver up or urging them to cease distracting activities.

In short, the *Mediator* continuously and in real time monitors, predicts and weighs the information about the driving context, the driver state, as well as the automation state, while taking account of the general capabilities of the driver and the vehicle.

This mediator concept builds on the task-capability model of Ray Fuller (2005), which states that driving errors occur if the task demands exceed the driver capabilities. While the driver's part of the mediator concept reflects this Fuller model, our concept extends it significantly by also looking at the automation state and the vehicle's capabilities in relation to the task demands in the specific driving context. Based on the assessment of driver and automation fitness, the *Mediator* determines how to secure safe driving and if corrective or preventive actions are needed or if a shift in control is desired.

Mediation of control: a smart decision-making process

To decide if and which action to take, the *Mediator* utilizes a smart decision-making process, relying on markers of degraded performance and the minimum acceptable performance on the axes of the Fitness Plane (see Fig. 2). More specifically, the *Mediator* detects and predicts situations where an action is required, such as degraded driver performance, degraded automation performance or expected driver discomfort. To select appropriate actions, the *Mediator* optimizes for driver safety and driver comfort. For instance, when a driver has become distracted there is a safety risk due to the driver's reduced situational awareness. A safe option would be for the *Mediator* to immediately issue an alert directing the driver's attention back to the road (a corrective action). However, an action that abruptly cuts off a phone call could be perceived as highly uncomfortable or even frustrating by the driver. A more balanced approach considering both safety and comfort could entail a gradual increase of intrusiveness of an action. This approach prioritizes safety by ensuring the distraction is addressed in a reasonable timeframe, while also providing some accommodation for comfort by not completely disrupting the activity. Personalization of the action selection per driver further aids in optimizing for individual needs and wishes.

The decision-making aims to balance trade-offs between driver and automation fitness and between driver safety and comfort. Artificial Intelligence techniques can help automate and optimize this complex decision process. They allow handling uncertainty and unpredictability by continuously updating its decisions based on real-time data. By leveraging Artificial Intelligence, the *Mediator* enhances its decision-making capabilities, enabling it to handle the complexities of real-world driving scenarios. By this smart decision-making process, the *Mediator* ensures that control is always allocated to the most capable entity, whether it be the human driver or the automation system, thereby maximizing safety and comfort on the road.

Human-centered driving modes: Beyond SAE levels of automation

While we navigate the intermediate levels of automation, it is crucial to address the complexity that arises from the varying availability of automation technology within and between trips and take the human needs and limitations into account. In this section we elaborate on why and how to take a human-centered approach to ensure safety and comfort during the intermediate levels of automation.

From a technology-driven to a human-centered approach

The intermediate levels are most challenging to navigate because at these levels, the driving task is shared or divided between the driver and the automation. We are on the verge of transitioning to SAE levels 3 and 4 technology, enabling drivers to be 'out of the loop' for certain periods of time. This introduces a layer of complexity and it appears to be very difficult to clearly communicate the different driving modes to the driver (Christoph et al., 2019; Carsten & Martens, 2019).

Reflecting on these concerns, it seems that, although the SAE levels of automation effectively describe technological advancements, this framework is now being applied far beyond the original purpose. It has almost become a paradigm in the field, a framework within which researchers and policy makers operate, guiding their understanding of this phenomenon and shaping their (research) questions. Amongst other things, this categorization is now also used for defining the levels of automation the vehicle provides to drivers. Yet, they were not originally designed for this purpose, and research demonstrates that they are not well-suited for this purpose either [Novakazi et al. (2021)]. The SAE classification does not resonate from a driver's perspective – the SAE levels are complex to understand from a driver's perspective and hard to communicate. The SAE categorization is primarily technology-focused, and assumes new technologies could take over specific parts of the driving task while leaving the driver responsible for remaining tasks.

However, to facilitate a safe transition, we should reverse our approach, from a technology-driven approach to a human-centered approach, defining a clear role for the drivers and how technology can support them. We see a need for logical human-centered automated driving modes, to enhance comprehension and therewith secure safety.

Towards human-centered driving modes

When we consider automation modes from a driver's perspective, the key question that arises is: What 'levels' are relevant to distinguish for comprehending such modes?

For the driver, the first and foremost concern is understanding who is in control of the vehicle and bears the ultimate responsibility for driving—whether it is the driver or the automation. When the driving task is shared or divided, it becomes crucial to constantly delineate which aspects of driving are to be managed by the driver and which by the automation. This ties directly into the notion of mode awareness, where it is imperative that the driver maintains a constant understanding of the current driving mode and the accompanying responsibilities. Clarity in task responsibility is a constant requirement. Any misunderstanding of the driver's role can have direct safety implications.

This brings us to the second pivotal aspect from a driver's perspective: if the automation is in control, the drivers need to know the remaining 'time budget', being the duration for which they can be 'out of the loop'. This duration defines, and sometimes restricts, the type of activities one can engage in. If it is only a brief span, one might decide to send a quick text message or grab a snack. In contrast, if the timeframe is more extended, one could consider working on a journal article, watching a movie, or simply taking a moment to relax. In fact, what drivers need to know is the time available, or what we call the 'time budget', for non-driving related activities before they must resume control of the driving task.

These two principles, mode awareness and time budget when automation is in control, are used for shaping a typology of three driving modes.

Continuous Mediation — Driver Constant in Control

In this mode the driver retains full responsibility for the driving task. While various support systems, such as longitudinal and lateral control, and overtaking systems, may be (temporarily) available, in this mode the driver is constantly in charge and ultimately responsible for ensuring safe driving rests with the driver. This means that the driver must be actively engaged in the driving task at all times. Effective coordination between the available systems and the driver is essential and requires 'continuous mediation'.

Driver in Stand-By — Brief Periods of Non-Driving Tasks

This mode facilitates the driver to briefly engage in non-driving related tasks while leaving control to automation. The driver can be out of the loop for short durations, subject to certain conditions, having ensured automation's ability to control the vehicle momentarily. However, in this mode, as opposed to the next *Time to Sleep mode*, the availabe time budget is short and the driver should remain stand-by all the time so that they can resume control within just a few seconds.

Time to Sleep — Extended Non-Driving Periods

In this mode, drivers are relieved from the driving task for extended periods, potentially up to several hours. Drivers have the opportunity of dedicating their time to non-driving activities that are more immersive and for longer durations. The automation has to indicate the time available for non-driving activities and to provide timely actions to guide the driver back to the *Driver in Stand-By mode*. Once automation systems can provide *Time to Sleep mode* from door to door, full automation is achieved (similar to SAE level 5 autonomous driving).

The three driving modes as outlined above, are designed from the driver's perspective, based on the mental model and the information needs of the driver. These modes are easy to understand for drivers and therefore easier to communicate than the often-used SAE levels. These more human-centered definitions of the driving modes are an essential prerequisite for designing the Human Machine Interface (HMI).

HMI design challenges: Exploring the design space

In the mediator concept (Fig. 4), the HMI design is represented by the arrow in the upper right corner, the 'signal to the driver'. This HMI plays a crucial role in effectively communicating information from the *Mediator* to the driver, and vice versa. The design of the Human Machine Interface (HMI) of the *Mediator* should encompass both explicit and implicit signals. Where explicit signals are quite straightforward, such as sounds and visuals (e.g., a beep or icons on the dashboard), implicit signals are more subtle and include indirect communication, this could include for instance subtle haptic signals, vehicle movement, temperature or ambient lightning.

The human-centered driving modes, as discussed above, are designed to be easy to understand from a driver's perspective. Taking these modes as a starting point, significantly reduces the complexity of the HMI design requirements. Still, there are three key challenges in designing the HMI: ensuring continuous mode awareness, facilitating switching between modes, and managing driver fitness by preventive or corrective actions.

Ensuring mode awareness

Mode awareness refers to the driver's continuous and clear understanding of the current operational mode of the vehicle and the corresponding distribution of responsibilities between the driver and the automation (Kurpiers et al., 2020; Sarter et al., 2007). Without sufficient mode awareness, the driver might become confused about the activated mode and its capabilities. This situation is referred to as 'mode confusion' which can lead to 'mode errors' (Boos et al., 2020; Sarter and Woods, 1995).

At the intermediate levels of automation, a driver could be exposed to varying automation modes throughout a trip. Drivers should constantly be aware whether they are in control and finally responsible for the driving task (Continuous Mediation), whether they must be stand-by for resuming control if needed (Driver in Stand-by), or whether the vehicle is in full control (Time to Sleep).

Particularly within the Continuous Mediation mode, eliminating any ambiguity concerning task responsibility and the availability and status of the systems is a significant point of attention. This driving mode is particularly prone to confusion, because a range of systems could be available and availability could change frequently and suddenly. An HMI design challenge is to anticipate and avoid too frequent and potentially unnoticed changes in system availability. It is the HMI that plays a vital role in continuously and intuitively communicating this information. This communication should not be overly intrusive but present enough to foster a clear understanding. One way to realize this is showing the driver the remaining time in the current mode, the so-called 'time budget' (see above). By continuously communicating the time budget to the driver, the system is transparent for how long a certain mode will remain available while at the same time indicating the time-window for engaging in non-driving related tasks.

Transitioning between modes

The time budget not only cultivates mode awareness but also provides crucial support for another significant HMI challenge: transitioning between the different modes.

To secure safety, it is important that a driver is well aware of such a change in the driving mode and the associated change in control and responsibility. Existing research on transition of control primarily focuses on the most critical scenario—unplanned takeovers—where the driver unexpectedly needs to resume control due to automation failure (Zhang et al., 2019). However, we argue taking a proactive approach to prevent such unexpected transitions by design as much as possible. To secure safety, transitions must be anticipated and initiated in time. In instances of uncertainty about the automation's performance, it must be ensured that the driver is in Stand-by mode. If the mode Time to Sleep is activated, a timely switch to Stand-by mode needs to be accomplished. Or, on the other hand, if uncertainty is too high, Time to Sleep cannot be accommodated and the driver needs to remain in Stand-by mode, potentially for a longer period of time. Working with the three driving modes, the transition from automation to human is simplified to the transition from Stand-by mode to Continuous Mediation mode. The reverse transition, from human to automation, concerns the switch from Continuous Mediation to Stand-by and potentially from Stand-by to Time to Sleep.

Managing driver fitness

A third distinct HMI design challenge concerns managing driver fitness. This challenge is particularly relevant in C*ontinuous Mediation* mode, but it remains crucial when the driver is in S*tand-by mode*, as in this mode they must be sufficiently fit to resume control promptly.

In C*ontinuous Mediation* mode, the use of automated support systems may diminish alertness and situational awareness, impacting overall driving performance. This effect is commonly referred to as task-induced fatigue or mental underload (Jarosch et al., 2019). On the other hand, mental overload poses a risk when multiple systems require the driver's attention, potentially hindering their ability to comprehend various signals and systems.

The HMI design challenges encompass the development of corrective and preventive actions (see above) or as a last resort emergency actions. Corrective actions aim at enhancing driver alertness and mitigating instances of driver unfitness, such as distraction or fatigue. An example of an HMI corrective action is a (compelling) suggestion to stop driving and take a break while having a coffee. More effective corrective actions are to be explored. One could for example think of a vibration in the seat, reducing the temperature or increasing the amount fresh air.

Additionally, we advocate for the design and development of preventive actions to proactively address and prevent potential instances of driver unfitness. The design of such preventive actions is yet to be explored.

Exploring the design space

Given the complex and fundamental nature of the design challenges addressed above, we need to move beyond conventional solutions like adding a beep or introducing a new icon on the dashboard.

In designing the HMI, it is essential to consider a wide range of design elements to effectively convey information to the driver. These elements include, but are not limited to, vehicle dynamics, haptic feedback, auditory signals, and visual cues, including elements such as temperature, surround sound, ambient lightning, and entertainment. Additionally, the challenge involves creating an HMI that supports two-way communication—delivering sufficient information to the driver while also enabling the driver to communicate with the automation system. To gather input from the driver, various modalities can be employed, such as passive indicators like eye movements, head pose, or seating posture, as well as active inputs that are deliberately provided by the driver. For creating such novel and effective HMI design solutions, there is much to gain from embracing a holistic design research approach.

Design research is a holistic and iterative research approach. It is a systematic process by designers to understand the challenges at hand, explore the design space, and create solutions. To achieve the best outcomes, design research must be firmly rooted in the extensive knowledge base of human factors insights and leverage the latest advancements in vehicle automation technology. Co-creation with experts plays a pivotal role in ensuring success, fostering the integration of the different perspectives and expertise.

This design research approach endeavors the establishment of overarching HMI design principles and guidelines which can be used by industry in designing their vehicles as well as by policymakers to shape regulations.

Discussion

The safety potential of vehicle automation technology is promising, however when the transition is driven by technology the potential may not be realized. To realize the potential, the perspectives presented in this paper help steering the transition by shifting the paradigm and adopting a more human-centered approach. In this final section, we explore the attributes and constraints of each key concept introduced, along with providing recommendations for further development.

The Driver/Automation fitness Plane

The Driver/Automation Fitness Plane, presented in Section 2, provides a framework for conceptualizing and overseeing the dynamic interaction between the driver and automation. Mapping the fitness of both the driver and automation on this two-dimensional plane gives insight if there is sufficient fitness to drive with the combined system of the driver and the automation. In addition, the Fitness Plane indicates when and which actions are needed to uphold safety.

Implementing this conceptual idea poses practical challenges. Further research is required to investigate how to effectively monitor and predict real-time fitness levels of both the driver and automation. Additionally, there is a need to define precise markers and metrics for degraded performance that warrant mediation. The incorporation of contextual factors into fitness evaluations also requires further research. Further refining the Fitness Plane to address these issues will enhance its applicability.

The Fitness Plane serves as a collaborative framework that extends beyond the SAE levels of automation. It demonstrates that the interaction between driver and automation is a dynamic playing field. It is not a zero-sum game about adding technology and expecting the driver to handle the remaining driving tasks. The Fitness Plane illustrates how both driver and automation performance can vary throughout a trip and identifies corners where SAE cannot come. It presents a continuous spectrum of driver and automation availability, indicating when and why control should allocated between the driver and automation. In addition, it shows the potential of shared control, where both human and automation contribute to the control of the vehicle. We see great value in further exploration of this promising concept to enhance navigating 'the green zone' of the Driver/Automation Fitness Plane. When leaving this zone, it directs attention towards other potential actions to mitigate the potential risk of unfitness, including transition of control, and preventive, corrective and emergency actions.

The mediator concept

The mediator concept is the implementation of the Driver/Automation Fitness Plane. The *Mediator* is a system that measures the driver and automation fitness, subsequently weighs and interprets the joint condition, and finally decides when and which action is needed to uphold safety and comfort. The mediator concept builds on the state-of-the-art technology to determine and predict driver and automation fitness and to assess how to divide the driving task in the current and predicted driving condition: not looking at either the human or the automation but using the best of both. Interestingly, although vehicle automation is creating several new usability challenges, it could also be used as part of the solution.

For further advancement of the mediator concept, substantial research and development is needed to mature towards an implementable system. This entails developing and integrating monitoring technologies, smart decision-making algorithms, and unambiguous and intuitive HMI designs. The smart decision-making requires optimization for both safety and user experience. A good assessment of this complex trade-off also requires further research. In addition, further exploration of mediator configurations and decision logic, including pilot testing, is required to facilitate the maturation of this concept. Such further advancement of the *Mediator* as a system requires an interdisciplinary approach, integrating technical knowledge on vehicle automation, understanding of human factors related to driver performance and driver state, expertise in information processing and smart decision-making techniques (artificial intelligence) as well as human-centered design expertise.

The mediator concept is an innovative approach enabling a smooth and safe collaboration between the human and the automation. This, in turn, can be expected to contribute to increasing driving comfort as well as building trust in automation and gaining acceptance for using automation. To even further enhance comfort, trust and acceptance, a *Mediator* can be tailored to accommodate the personal needs and preferences of drivers without compromising safety. Additionally, the *Mediator* plays a proactive role in urging drivers to make the most of available vehicle systems. Some drivers still tend to overlook available systems in their vehicles, often due to a lack of familiarity. *Mediator's* role to leverage automation not only promotes the use of these systems among current users but also encourages a safe uptake by those who are not yet utilizing them.

In conclusion, the mediator concept holds the potential to contribute not only to heightened safety but also to increased comfort, trust and acceptance. It could play a pivotal role in facilitating the smooth and safe integration of new automation technologies into vehicles, especially within the intermediate levels of automation.

Human-centered driving modes

Section 4 discussed the value of defining human-centered automated driving modes, in particular when navigating the intermediate levels of automation, and it introduced an initial endeavor to establish such modes.

Defining human-centered driving modes offers significant benefits. They construct a taxonomy from the driver's perspective, leading to a clearer and more communicable understanding of the different modes. This is crucial for enhancing mode awareness and, consequently, traffic safety. The three presented driving modes (*Continuous Mediation*, *Driver Stand-by* and *Time to Sleep*) are easily understandable, capturing the most essential parameters for defining and designing distinct levels. Therewith, this taxonomy also assists in defining the design space and design challenges for shaping the relationship between humans and technology.

While this first taxonomy of human-centered driving modes shows promise, it also has limitations and there are opportunities for improvement. Firstly, there is potential for enhancing the visualization and for improving the naming of the modes for better clarity. Secondly, future iterations should consider how the different driving modes relate to the interaction with other road users. As the driving mode has a direct impact on the interaction with other road users, the taxonomy of driving modes would need to explicitly address this as well.

In conclusion, the presented taxonomy of human-centered driving modes takes the human perspective rather than the technological advancements as the starting point. Such a taxonomy would be an effective tool to bring the essence of our human factors knowledge to the decision tables, in automotive industry as well as policy, and to enhance the much-needed shift in focus, from technology-driven to human-centered approach.

HMI design challenges

The HMI design for vehicles operating at intermediate levels of automation faces significant challenges, including the enhancement of mode awareness, facilitating safe transitions between modes, and managing driver fitness. While these concepts are widely recognized, designing and evaluating effective solutions remains largely unexplored.

The time budget approach, presented in this paper, is a promising concept for the design of the driving modes from a driver's perspective. The time budget indicates the time that the automation can operate safely without human supervision. Explicit and implicit communication of the time budget holds potential to significantly enhance both mode awareness and safe transitions between modes. Moving forward, the next step would involve creating effective design practices for the communication of the driving mode in operation, the time budget for this driving mode, and the transition between modes. In addition, effective design practices are needed for managing driver fitness as part of the vehicle's HMI.

Reflecting on the field, we see that much of the human factors research related to vehicle automation is deterministic and evaluative in nature. It compares various design options to identify the most effective intervention or application, mainly in response to emerging technologies rather than aiming to help guiding technology. This type of research can be useful for gaining understanding in the mismatch between technology and users. However, it does not necessarily contribute to creating the most effective solution. To bridge this gap, we need research that focuses on exploring effective design solutions, taking humans as the starting point for identifying effective HMI solutions with the results being input to technology, rather than the other way around.

Design research has the potential to make a unique and essential contribution to the field of HMI in vehicle automation. Design research is an holistic and iterative research approach explore the design space and create effective solutions. Building on the extensive knowledge on human factors and on state-of-the-art technology, the proactive design research approach enables us to make significant steps forward to innovative HMI design solutions. Being proactive is necessary in order to keep up with the rapid pace of technological advancements.

How to navigate the intermediate levels of automation?

This all brings us back to the main question of this paper: How to navigate the intermediate levels of automation? Navigating the intermediate levels of automation comes with a range of challenges. Overlooking the field, we see that there is a need for a paradigm shift: changing perspective from a technology-driven approach to a human-centered approach. The ongoing transition to higher automation levels insufficiently takes advantage of the human strengths in situations where technology is (still) immature. So, regrettably, there is a mismatch between the technology and the user, which is worrying, especially in road traffic where a minor misinterpretation could lead to a severe collision within a matter of seconds.

This paradigm shift could be facilitated by the main concepts introduced in this paper. The Driver/Automation Fitness Plane, the mediator concept and the taxonomy of human-centered driving modes are tools to foster a more human-centered approach to the implementation of vehicle automation. In addition, proactive, holistic and iterative design research is needed to explore the design space and develop best practices and guidelines for HMI design.

Besides securing safety, a human-centered approach can also be beneficial to foster inclusivity. By aligning solutions to individual needs, capabilities and limitations, this approach fosters consideration of all potential users, including special groups such as the elderly and disabled individuals. Consequently, it directs attention towards creating a transportation system that is more accessible and inclusive, thereby contributing to broader societal equity and mobility.

Finally, a human-centered approach can be expected to significantly influence the adoption rates of new technology. When technology aligns with user needs, is user-friendly, and fosters trust, it is more likely to be embraced by a broad audience and lead to better integration and safe adoption of autonomous vehicles into everyday life.

In conclusion, realizing the full potential of vehicle automation technology necessitates a paradigm shift. We need to shift from a mainly technology-driven approach to one guided by human needs and capabilities. By viewing technology as a means rather than an end in itself, we can optimally exploit the potential safety benefits of partly automated vehicles as well as making them more comfortable, attractive and accessible for all. The current paper aimed to take several theoretical steps towards such a paradigm shift by introducing the mediator concept. Obviously, there is still a long way to go to make this concept work in daily practice. Whereas studies on specific aspects of the mediator concept have shown promising results (e.g.,Rauh et al., 2023; Tinga et al., 2023), extensive additional research efforts are needed to fully develop and validate it. To this end, close co-operation between industry and academia is essential.

CRediT authorship contribution statement

Nicole van Nes: Writing – original draft, Visualization, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization. **Michiel Christoph:** Writing – review & editing, Project administration, Investigation, Conceptualization. **Ingrid van Schagen:** Writing – review & editing, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

No data was used for the research described in the article.

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