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Safe and Seamless Transfer of Control Authority Exploring Haptic Shared Control during Handovers

Davide Maggi
Institute for Transport Studies
University of Leeds

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Doctor of Philosophy March, 2022

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The candidate contributed substantially to the conception and design of the study. The candidate wrote the article, and approved of the version submitted for publication. Richard Romano, Oliver Carsten and Joost De Winter provided contribution in conception of the study and contributed to review the manuscript. The candidate, Richard Romano, Oliver Carsten and Joost De Winter gave final approval of the version submitted for publication.

The work in **Chapter 3** of the thesis has appeared in publication as follows: Maggi D, Romano R, Carsten O. Transitions Between Highly Automated and Longitudinally Assisted Driving: The Role of the Initiator in the Fight for Authority. Human Factors. August 2020. doi: 10.1177/0018720820946183.

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The work in **Chapter 4** of the thesis has appeared in publication as follows: Maggi D, Romano R, Carsten O. Handing control back to drivers: exploring the effects of handover procedure during transitions from Highly Automated Driving. Transportation Research Part F: Traffic Psychology and Behaviour, 84, 9 - 20. doi : 10.1016/j.trf.2021.11.008.

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ABSTRACT

This research aimed at investigating the impact of lateral assistance systems on drivers' performance and behaviour during transitions from Highly Automated Driving (HAD). The thesis focused on non-critical transitions and analysed the differences between system and user-initiated transitions. Hence, two experiments were developed and conducted in driving simulators to address questions relating to how handover procedures, which provide varying levels of lateral assistance, affect drivers' performance and behaviour at different stages of the transition. In particular, it was investigated which type of assistance yields better results depending on who initiated the transition of control. Drivers were induced to be Out-Of-The-Loop (OOTL) during periods of HAD and then exposed to both system and user-initiated transitions. Results showed that after user-initiated transitions, drivers were generally more engaged with the steering task and the provided assistance was not helpful and, in some cases, caused steering conflicts and a comfort drop. On the contrary, after system-initiated transitions, drivers were not engaged with the steering control and were more prone to gaze wandering. Strong lateral assistance proved to be most beneficial within the first 5 seconds of the transition, when drivers were not committed to the steering control. The provision of assistance at an operational level, namely when drivers had to keep the lane centre, was not enough to ensure good performance at a tactical level. Drivers were able to cope with tactical tasks, presented as lane changes, only after around 10 seconds from the start of the transitions in both user and system initiated cases (Chapter 3 and Chapter 4). The introduction of non-continuous lateral assistance, used to trigger steering conflicts and, in turn, a faster steering engagement, did not yield particular benefits during user-initiated transitions but it might have triggered a faster re-engagement process in system-initiated ones (Chapter 5). The results suggest that assisting drivers after user-initiated transitions is not advisable as the assistance might induce steering conflicts. On the contrary, it is extremely beneficial to assist drivers during system-initiated transitions because of their low engagement with the driving task. The thesis concludes with a general overview of the conducted studies and a discussion on future studies to take this research forward.

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Abbreviations

ACC	Adaptive Cruise Control
ADS	Automated Driving System
CSR	Continuous Rating Scale
DDT	Dynamic Driving Task
DOF	Degree-Of-Freedom
HAD	Highly Automated Driving
HMI	Human-Machine Interface
LCT	Lane Change Task
LDA	Lane Departure Assist
LKA	Lane Keeping Assist
MLP	Mean Lateral Position
NDRT	Non-Driving Related Task
NHTSA	National Highway Traffic Safety Administration
NRS	Numerical Response Scale
ODD	Operational Design Domain
OOTL	Out-Of-The-Loop
RSME	Rating Scale of Mental Effort
SA	Situational Awareness
SAE	Society of Automotive Engineers
SDLP	Standard Deviation of Lateral Position
SWRR	Steering Wheel Reversal Rate
TLC	Time to Lane Crossing

TOR	Take-Over Request
TTC	Time-To-Collision
UoLDS	University of Leeds Driving Simulator
WHO	World Health Organization

CHAPTER 1

GENERAL INTRODUCTION

1.1 Introduction

Over the past few decades, safety and its enhancement have been key points in road-related studies. These studies span from vehicle design to roadway architecture, encompassing any practice, design, equipment and regulation whose aim is the minimization of the occurrences and consequences of traffic accidents.

However, despite the introduction of increasingly smarter and safer systems, road accidents are still a great issue (NHTSA, 2014; WHO, 2021). As reported in the National Motor Vehicle Crash Causation Survey (NHTSA, 2008) and in the report by the Department of Transport on road crashes in Great Britain (DfT, 2021) and clearly stated by the Center for Internet and Society at Stanford Law School (2010), the real bottleneck would be the drivers' guidance as they claimed that "Some ninety per cent of motor vehicle crashes are caused at least in part by human error" (USDoT, 2016). Even before this observation, research around the world was focused on the implementation of automated systems capable of achieving by themselves, the partial or full control of the longitudinal and lateral dynamics of a vehicle (Reynolds, 2001). Currently, car manufacturers offer features capable, to some extent, of automating the driving tasks (Tesla "Autopilot", 2015; Audi "Traffic Jam Pilot", 2017; Mercedes-Benz "Drive Pilot", 2019; BMW "Traffic Jam Assistant", 2019; Cadillac "Super Cruise", 2020; Honda "Traffic Jam Pilot", 2021).

While trying to reduce the impact of drivers' errors on road-safety, the use of ever higher levels of Automated Driving Systems (ADSs) will gradually shift the driver's main role from active controller to mere supervisor. This change of roles will not come without drawbacks and, despite the undeniable part of automation in reducing road traffic accidents and their consequences (Winkle, 2016), it has been highlighted how drivers are actually not good at the supervisory task (Mackworth, 1950; Molloy & Parasuraman, 1996; Parasuraman & Riley, 1997; Hancock, 2017; Greenlee et al., 2018), which introduces new issues to cope with.

Current ADSs all exhibit limitations and, therefore they can be used only in well-defined situations. These restrictions, either due to limitations of the sensing capability of the sensors on which those systems are based (Hasirlioglu et al., 2016, 2017; Ruiz-Llata et al., 2017) or due to design limitation or the Operational Design Domain (ODD) of the automated feature (Seppelt & Lee, 2007; Cualain et al., 2012), might entail dangers. Indeed, drivers may not be fully aware of the capabilities of the systems or they could overestimate them (de Winter et al., 2014; Muslim & Itoh, 2017) and that, in turn, could lead to other problems such as complacency (Wiener, 1981; Bagheri & Jamieson, 2004; Parasuraman & Manzey, 2010), loss of manual control skills (Wiener, 1988), behavioural adaptation and loss of situation awareness (Hancock et al., 2013; Lu & de Winter, 2015), which altogether have been already identified within the *Out-Of-The-Loop phenomenon* (Endsley & Kiris, 1995). This phenomenon refers to the fact that drivers are no longer required to continuously monitor the surrounding, make decisions and provide inputs and, henceforth, they gradually lose awareness and control skill (see Section 1.2.2). Since these systems are steps toward the development of fully automated vehicles (Flemisch et al., 2008), further improvements must be done while waiting the latter to be introduced on our roads (Chan, 2017). This means that drivers may have to resume manual control at certain moments during their drives, giving place to actual transfers of control authority between the ADS and the driver, no matter whether for functional limitations or hardware failure.

Mainly due to the hypothesized low criticality of driver-initiated transitions, in which drivers are assumed to be aware and responsible of their actions (Lu & de Winter, 2015), authority transition studies have been mainly focused on system-initiated transitions, during which the system explicitly requires drivers to take over the partial or full control of the vehicle within a certain time interval. Indeed, in the latter case, one can not take for granted either drivers' situational awareness or readiness to intervene because of the aforementioned *Out-Of-The-Loop phenomenon* (Merat et al., 2014).

However, the lack of situational awareness and the loss of manual control skills will always affect the drivers, who could potentially want to resume manual control at any moment for any reason and the ADS would here too be required to provide a safe handover. Indeed, after prolonged exposures to autonomous driving, drivers may detach themselves from the driving tasks, thus losing their capability to safely control the vehicle motion and introducing, during transitions, a source of instability and, potentially, a threat to road safety. The loss of operational control skills would directly affect drivers' comfort (remember that yaw rate and lateral acceleration, which are used to define control stability, are the main controlled variables to ensure drivers' comfort (Kilinc & Baybura, 2012)) and could become a major issue while resuming control of the vehicle, especially when drivers need (or want) to perform manoeuvres at a tactical level (i.e. overtaking a vehicle, changing lane, taking an exit, etc.). Moreover, requiring the necessary control skills entails a cognitive process that needs to be added to the undergoing cognitive processes aimed at collecting information from the environment and from the system itself (Rose, 1989). Thereby, the loss of operational control increases both physical and mental effort and, therefore should not be neglected while designing an adequate handover strategy.

Haptic shared control has been highlighted from literature as a promising solution to facilitate the transfer of control authority and even communications between the driver and the ADS (Flemisch et al., 2008; Mulder et al., 2012; Wada et al., 2016), which have been considered as two agents trying to cooperatively control the vehicle dynamics (Millot & Lemoine, 1998). However, research on this topic has been mainly focused on the development and testing of different haptic strategies during assisted driving (SAE Level 1 and Level 2) rather than providing evidence of its usefulness during actual transitions. Hence, the extent of control authority that should be handed over and the modality through which this authority should be relinquished back to the driver still need to be properly defined.

The following sections will analyse the vehicle-automation trend and its impact on drivers' behaviour and, ultimately, on road safety. A relevant discussion concerning transitions of control will be addressed to better outline the scope and focus of this thesis.

1.2 In-vehicle automation

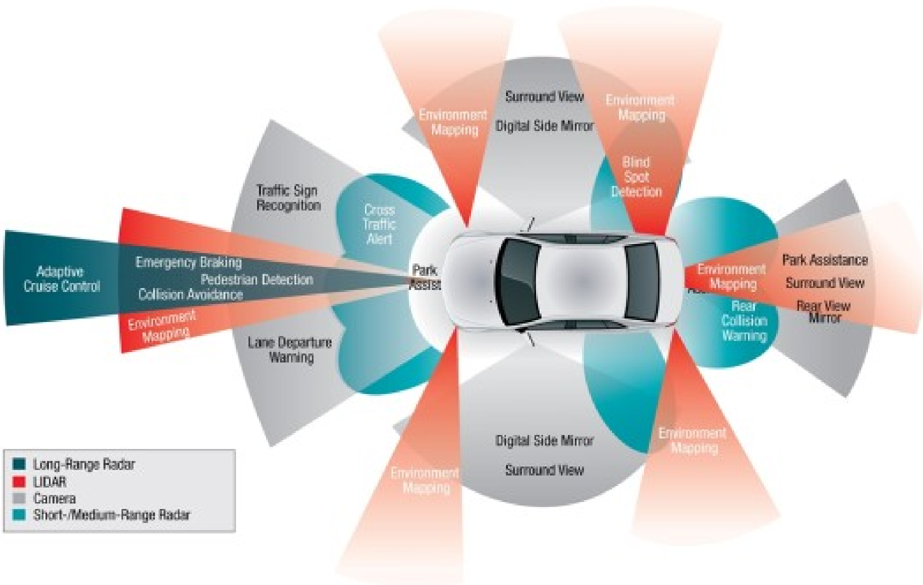

Figure 1: Sensing Technologies that allows vehicle-environment interactions (Source: Parrish (2015))

The term "automation" has been broadly adopted to define or address systems capable to some extent of relieving the operators (i.e. humans) from the burden of performing tasks and/or sub-tasks of a specific process. These systems are equipped with artificial sensors and actuators that allow them to interface with the environment and/or with humans (Sheridan & Parasuraman, 2005).

In-vehicle automation is represented by automated driving systems capable of performing some or all of the tasks and sub-tasks usually associated with driving and carried out by the driver (SAE, 2018). Fully automated vehicles are able to perform the driving task in complete autonomy, without any human intervention. Hence, these vehicles are equipped with a number of technologies (see Figure 1) that provide means to collect information, and make and execute decisions based on the comprehension of that information. However, whenever the automation capabilities do not endorse such autonomy, for the driving task to be successful, automated vehicles require an active cooperation between the ADS and the driver. Hence, the primary functions (i.e. monitoring and control) are split between automation and human and, as discussed in the following, their distribution is at the base of any definition of “levels of driving automation”.

1.2.1 Classification

Even though the German Federal Highway Research Institute (BASt), the Society of Automotive Engineers (SAE) and the National Highway Traffic Safety Administration (NHTSA) have developed their own definitions of “levels of automated driving” (Gasser & Westhoff, 2012; NHTSA, 2013; Society of Automotive Engineers, 2021), the criteria defining these levels are similar and all refer to how the primary functions (i.e. monitoring and control) are distributed between the human and the automation. Within the scope of this thesis, the focus on human-vehicle interactions is confined to time intervals in which the system changes from one state to another, namely authority transitions. In the framework of automated driving a state has been defined either as a level of automation (Flemisch et al., 2008; Merat et al., 2014; Varotto et al., 2015) or the active and non-active states of a feature/function within a specified level of automation (Pauwelussen & Feenstra, 2010; Gold et al., 2013; Miller et al., 2014; Nilsson et al., 2015). Thus, before getting in deep with the analysis of authority transitions, it is worth taking a look at the levels of automation as defined by SAE International.

The SAE classification system is based on six different levels, ranging from fully manual to fully ADS. In the latest update of this worldwide accepted classification (SAE, 2021) the levels are defined as (see Figure 2):

- **Level 0 (No Automation):** ADS issues warnings and may momentarily intervene but has no control over vehicle dynamics.
- **Level 1 (“hands-on” - Drive Assistance):** The driver and the ADS share control of the vehicle. This level of automation comprises systems

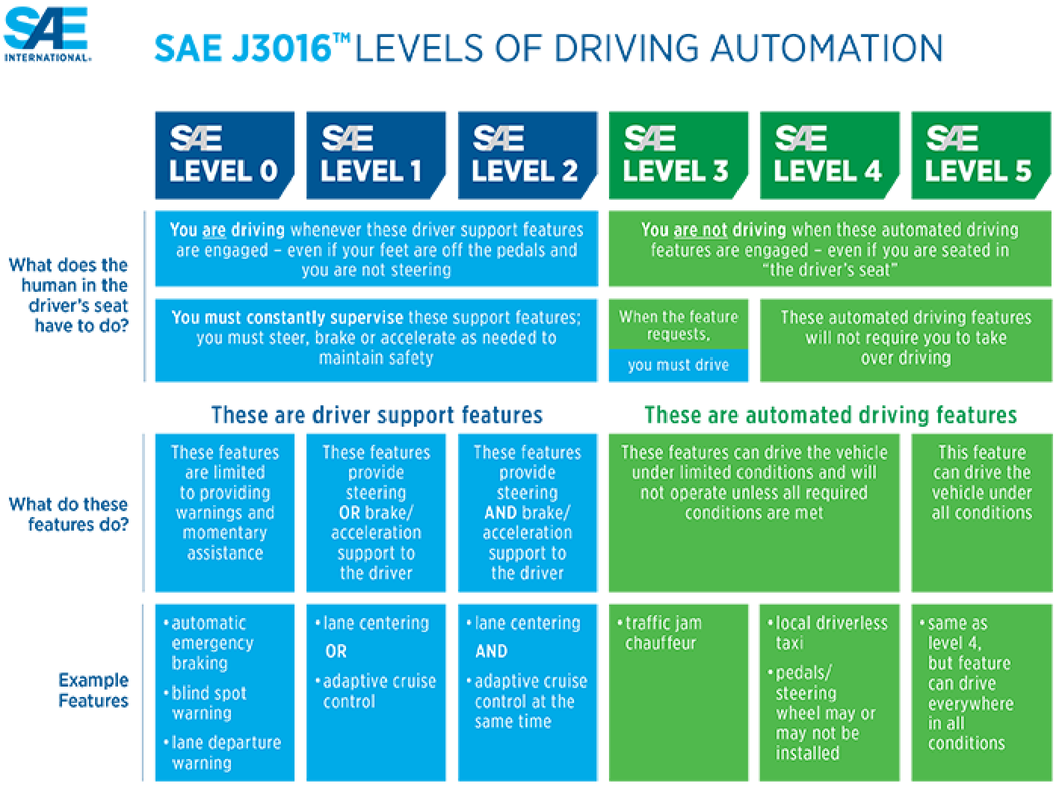

Figure 2: Levels of Automated Driving as defined by SAE International (Source: SAE (2021))

such as the Adaptive Cruise Control (ACC) and Lane Keeping Assist (LKA). In both cases drivers are relieved of only longitudinal (with ACC) or lateral (with LKA) control but, nevertheless, they must be ready to retake full control at any time.

- **Level 2 ("hands-off" - Partial Automation):** The ADS takes full control of the vehicle (accelerating, braking, and steering). The driver must monitor the driving and be prepared to intervene immediately at any time if the ADS fails to respond properly. An example of SAE Level 2 of automation is Tesla Autopilot. Although this level has been labelled as "hands-off", contact between hands and steering wheel is often mandatory to ensure drivers are always ready to intervene.

- **Level 3 ("eyes-off" - Conditional Automation):** Drivers can safely turn their attention away from the driving tasks, e.g. the driver is allowed to engage in secondary tasks such as reading, texting or watching a movie.

The vehicle will handle situations that call for an immediate response, like emergency braking but the driver, whenever prompted by the vehicle, must still be prepared to intervene within a predefined amount of time.

- **Level 4 ("mind-off" - High Automation):** As level 3, but no driver attention is ever required for safety, i.e. the driver may safely go to sleep or leave the driver's seat. Within the specified ODD, like traffic jams, the vehicle will safely accomplish the full control of the vehicle but, outside of these, the vehicle must be able to safely abort the trip, i.e. park the car, if the driver does not retake control when prompted.

- **Level 5 ("steering wheel optional" - Full Automation):** No human intervention is ever required.

Although many car manufacturers have claimed Level 5 autonomous vehicle would have been a reality by 2020, no commercially available Level 5 or 4 vehicles exist. Today, we are standing in between SAE levels 2 and 3 and, from the new forecasts (TSC, 2017), the driver is yet expected to be an indispensable figure for years to come. Given this, in order to reduce road accidents and to push automation towards levels 3 and 4, it is imperative to develop a deep understanding of drivers' related aspects whilst they are called to interact and cooperate with the above automated systems.

1.2.2 Automation-driver interactions

Bainbridge argued that there will be a change in humans' primary functions when working with automated systems, namely "monitoring" and "control" (Bainbridge, 1983). In terms of vehicle automation, this means that the introduction of higher levels of automation would have relieved the drivers from the burden of continuously controlling the vehicle motion and monitoring the road but it would have introduced the necessity for them to monitor the task execution and taking back the control of the vehicle whenever they deem it advisable to do so. Instead, according to the above classification drivers will not be asked to monitor the task execution in higher automation levels (i.e. SAE Levels 3 and 4) but they should be able to regain full authority within a predefined amount of time. To miss the requested take-over would likely result in a crash with SAE Lv.3 vehicles, which do not have any programmed safety manoeuvres, and in the abortion of the trip with SAE Lv.4 vehicles, which will perform a minimum risk manoeuvre and stop the vehicle in a safe location. This implies Bainbridge was basically correct: drivers will have, when prompted to and within a limited amount of time, to resume monitoring the environment and the ADS and to take over control of the vehicle longitudinal and/or lateral dynamics. However, the discrete time-limited slot within which these tasks need to be accomplished makes their performance even harder. Moreover, it has been proven that as automation level increases, drivers involvement with the driving task and, consequently, also their capability to safely take-over, decreases (Flemisch et al., 2008).

Drivers, during automated driving, experience what have been defined as the Out-Of-The-Loop phenomenon, which means drivers are not directly aware of the traffic situation because they are not actively monitoring, not making decisions and not providing input to the driving task (Kienle et al., 2009).

Effects of being OOTL have been extensively studied (Endsley & Kiris, 1995; Parasuraman et al., 2000; Saffarian et al., 2012):

- Decreased driver readiness and longer reaction times, affected by engagement in secondary (non-driving) tasks and psychophysical states of the driver like fatigue and stress (Martens & van den Beukel, 2013);
- Reduced situational awareness, as defined by Endsley the *"perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future"* (Endsley, 1988);
- Influenced workload, which, during HAD, would be too low (under-load) and, during take-over conditions, could become too high (over-load), negatively affecting drivers' performance (de Waard, 1996; Flemisch et al., 2010);
- Overreliance: the longer a driver uses the system without failure, the more likely it becomes that the driver is relying on it. This could possibly result in the driver failing to detect automation failures, when the system

is in fact unable to handle the situation (Wiener, 1981; Parasuraman et al., 1993);

- Long-term skill decay: once the drivers' primary function has been shifted, drivers are most likely to be disengaged from the driving task and, as a result, they gradually lose the skills of performing that task (Rose, 1989);

- Behavioural adaptation, depending on drivers experience and behaviour, the change of roles could push drivers to engage in secondary tasks, and even to neglect their new role of supervisors (Merat et al., 2012).

After periods of automated driving, the lack of SA requires drivers to scan the environment (Level 1 - Perception) and comprehend what is happening around (Level 2 - Comprehension) so that they can predict a plausible future state for the environment (Level 3 - Projection) and make decisions accordingly. Whilst this process takes place, the mental workload undergoes a rapid change from a state of underload to a state of overload (de Waard, 1996). However, at least for what concerns highway scenarios, the most of drivers' gaze is focused toward the road centre, as the region from which a hazard is more likely to come (Carsten et al., 2012; Zeeb et al., 2015; Wang et al., 2017; Louw, Madigan, et al., 2017), which means drivers behave as they were in manual driving, collecting just the minimal amount of information needed to safely accomplish the specific driving task. In this sense, if drivers want to stay in the current lane, they will focus on the road centre and, if they want to change lane, they will focus on the respective side mirror (i.e. the one facing the target lane) and on the target lane. In other words, drivers selectively seek information in response to a tactical decision based on their subjective assessment of their own current SA (Boer & Hoedemaeker, 1998). This seeking process is based on a set of needs, which has been categorized into motivational and constraining ones. The satisficing trade-off between these two categories is used to schedule tasks and manage attention (Boer & Hoedemaeker, 1998). During manual driving, drivers, in order to define their own needs, are motivated by two simple questions (Boer, 1999):

i. What is the goal or purpose of a particular trip?

ii. What stands in the way of achieving this goal?

However, during manual driving, drivers can have a continuous perception of the surrounding environment, which should allow them to build a better prediction of how the situation is expected to evolve. On the other hand, during automated driving, these questions are likely to become irrelevant since the fact the driver is experiencing autonomous driving means that the goal of the trip and the trip itself have been already defined and what stands in the way is no longer a concern for the driver but only for the ADS. Therefore, during and after automated driving, how do drivers define their needs?

Bringing back the motivational needs listed by Boer & Hoedemaeker (1998), automation inherently sets a limit to “expediency” (i.e. the need to get somewhere fast) and “kick” (i.e. the need of pushing the car to its limits) and makes easy and safe “pleasure” (i.e. the need to enjoy the external and internal environment). The reason is because some of the “constraining needs” are embedded into the design of vehicle automation so that automated driving will always be respectful of safety and social norms and it will try to provide comfortable driving. Hence, in this new framework (namely HAD rather than manual/assisted driving), the aforementioned questions are likely to be shifted a step backward, becoming the questions drivers pose themselves while deciding whether or not to take over automation or, from another perspective, they will be the questions drivers will use to define their momentary needs once and if called to.

Hence, revisiting the above in this new “transition framework”, assuming that the following process takes place within each time window Δt, drivers make themselves the following three questions:

1. What do I want to do?
2. What do I know?
3. What do I need to know to do it?

By answering these questions, drivers select specific information that need to be gathered and redirect their attention (namely, their gaze) toward the source of those information.

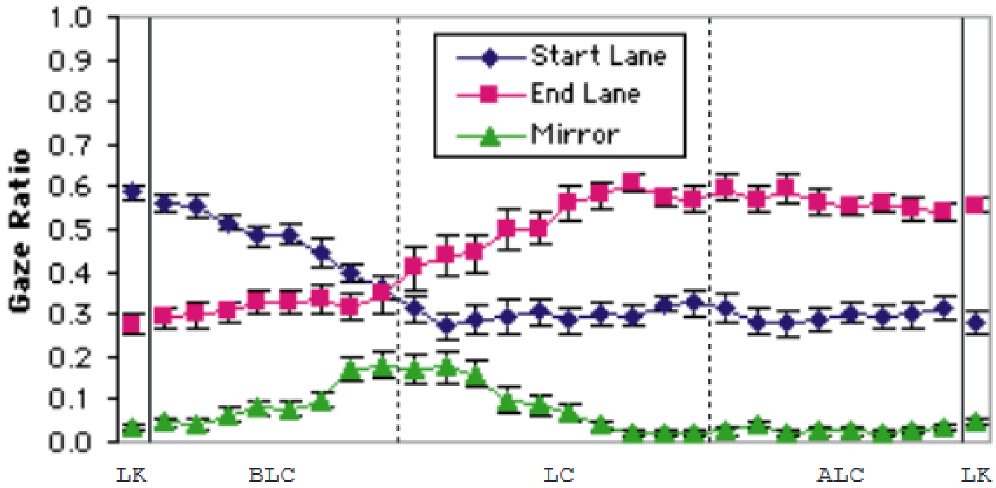

Figure 3: Gaze dwell ratios for the start lane, end lane, and mirror during initial lane keeping (LK), before the lane change (BLC), during the lane change (LC), after the lane change (ALC), and later lane keeping (LK) from Salvucci et al. (2001)

In this sense, we are supposing that whenever drivers redirect their focus, they want to gather some information and, thereof, that visual information are the building blocks of SA. One may argue that redirecting the focus implies drivers already know where they are, which, during HAD, it is not true because of the OOTL phenomenon, but the gathering information process is mostly based on experience rather then on the analysis of the environment. The drivers' driving experience allow them to redirect their focus toward the area from which they know the information is likely to come (Rasmussen, 1983).

This behaviour is well reported in lane change studies (Salvucci et al., 2001; Salvucci & Liu, 2002; Doshi & Trivedi, 2009; Guo et al., 2014), where drivers' gaze accurately describes this selective information-gathering process (see Figure 3).

Zeeb et al. (2015) and Louw & Merat (2017) used gaze dispersion and fixation time in order to define drivers' state during HAD (SAE Lv.3): the first classified drivers as high, medium and low-risk and related these classes to braking reaction time; the second has shown how gaze dispersion can be used as an index of the drivers' engagement with the driving task (horizontal dispersion) and with the system (vertical dispersion).

Both these approaches rely on the assumption that authority transitions are merely time periods in which the vehicle sees a passive change in the source of the received inputs (namely from the ADS to the driver). Hence, driver and automation are treated as independent entities and their respective performance are extracted from individual features/actions rather than a sum of cause/effect interactions. However, for the driving task to be successful, automated vehicles require an active cooperation between the ADS and the driver (Hoc et al., 2009).

If automation should somehow facilitate cooperation, by handling sub-tasks harder to manage for human beings (Dingus et al., 1997; Walker et al., 2001), this requires of operators a knowledge of how to properly interact with the ADS (Lee & Seppelt, 2012; Salas et al., 2006; Sundefinedtren & Laumann, 2015).

1.2.3 Cooperation concepts and automation-related flaws

Human-Machine Cooperation (HMC) studies led to defining the model of an agent according to two dimensions (Millot & Lemoine, 1998):

1. The agent's ability to control the process, also called *know-how*;

2. The agent's ability to cooperate with other agents concerned by the process, also called as *know-how-to-cooperate*.

Both are then split up into two parts, the *internal* and the *external*.

The *internal know-how* takes into consideration the agents' competences and capacity, which for a human agent mainly concerns knowledge, rules and skills to control the process (Rasmussen, 1983) and it is linked with expertise, experience and practices of an agent. The *external know-how* is considering the ability of an agent to get information from the process and the ability to act on the process. Hence, the internal know-how allows agents to build up a representation of the current situation of the process using a top-down approach. This is made possible because agents are interacting with the process via their external know-how (Pacaux-Lemoine & Itoh, 2015).

For example, drivers know that, to safely change lanes, they should:

i. Gather information of the current situation in the target lane and the whereabouts of vehicles around them (information gathering - External know-how);

ii. Plan a sequence of actions based on the information at their disposal and their comprehension (information analysis & decision making - Internal know-how);

iii. Execute the planned operations to accomplish the maneuver (action making - External know-how).

Similarly, the *internal know-how-to-cooperate* allows an agent to build up a model of other agents in order to ease the cooperation with them. Agents gather and analyse information about others in order to infer their know-how and know-how-to-cooperate. The *external know-how-to-cooperate* is the ability of an agent to have information about other agents and provide information to other agents (Millot & Pacaux-Lemoine, 2013).

In ideal cooperation, the knowledge-base of the two agents should be the same (i.e. the agents possess the same perception of the world) but in a real context this condition is hardly fulfilled (Pacaux-Lemoine & Itoh, 2015). Of course, in car-driving, both agents, the human driver and the ADS, are able to gather information and each one has his/her/its own "sensors"; drivers will try to gather information by means of their eyes (visual cues), ears (acoustic cues), hands and body (tactile cues) whereas the ADS will do the same by means of miscellaneous sensors such as cameras, Lidar, Radar, InfraRed LEDs, etc.. The capacity of the driver to effectively sense the environment is limited, especially whenever the driver has problems to gather visual cues, such as night or bad weather condition. However, the capacity of the vehicle and vehicle controller are limited nevertheless (Hasirlioglu et al., 2016, 2017; Ruiz-Llata et al., 2017).

Hence, the *internal-know-hows* of the two agents are likely to be different. Following the classification system known as the Skill-Rule-Knowledge (SRK) model (in Figure 4), drivers and automated system' information processing relies on different bases (Rasmussen, 1979, 1983):

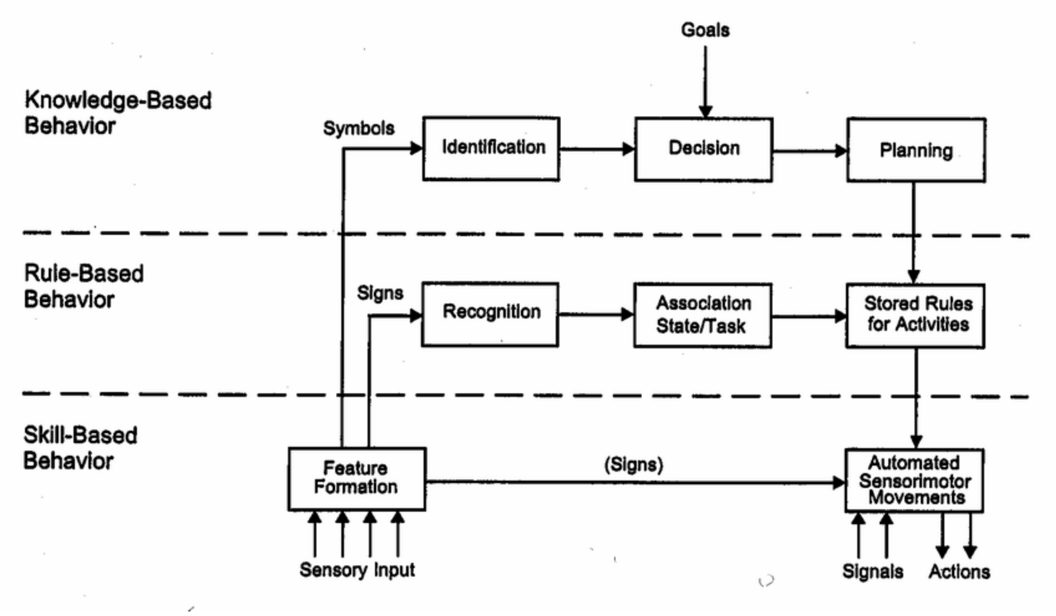

Figure 4: SRK Rasmussen's model (from Vicente (1999))

i. Their knowledge will be based on different ways of gathering information and, over that, the automated system also possesses built-in knowledge, such as the mathematical model of the vehicle itself and even a model of the driver (Rasmussen, 1983);

ii. Their rules will be based on different sources: experience for the driver and algorithms and optimization functions for the automated system;

iii. Their skills will be due to different factors: expertise and practice for the driver and operational functionality for the automated system.

Yet, even the *know-how-to-cooperate* of the two agents will present discrepancies since the two agents do not speak the same language and, therefore, in order to establish an actual communication channel, a Human-Machine Interface (HMI) capable of making them understanding each other in the most straightforward way possible is required (Damiani et al., 2009).

Moreover, the concept of establishing an effective cooperation and so of sharing the amount of authority while driving, can be extended to two different point of view (Pacaux-Lemoine & Itoh, 2015):

Horizontal Extension - all or parts of the problem solving process (i.e.

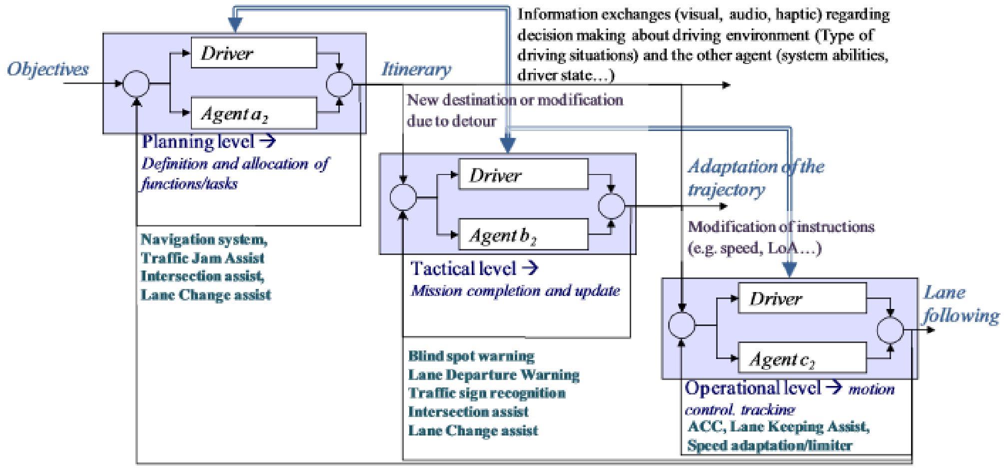

Figure 5: Vertical Extension - Levels of activities (Pacaux-Lemoine & Itoh, 2015)

information gathering, information analysis, decision making and action implementation) could be taken into account in the sharing process. Notice that this does not mean that all agents have authority on the process but rather that all agents are involved in the negotiation for the allocation of the above authority at every single step since each agent has the ability to perform them;

Vertical Extension - the agents focus on tasks that are not on the same time span. The global objective is the same, but local objectives can be different regarding the delay each agent has to complete his/her/its own task. Nevertheless, the completion of one task can have an impact on the performance of the other task. In car driving, three levels of activity are usually depicted, the strategic, tactical and operational levels (Michon, 1985) (see Figure 5).

In this context, all the automated related issues and the OOTL phenomenon itself can be seen as the results of a mismatch between the know-how drivers think they have and their true one. By applying these considerations to SAE levels of automated driving one can say:

- With Lv. 0, drivers manage all aspects of the driving task. The number of warnings that the ADS can issue is limited and reading the user manual is not always necessary to understand their meaning. Following SAE definition, “monitoring” and “control” (i.e. the external know-how) are all in drivers' hands, who build an internal know-how as close to the real situation as experience allows them to. The know-how-to-cooperate is of little importance at this level: drivers know how the vehicle will respond since the ADS has not changed that yet and, on the other side, the ADS is too limited to have insight of any sort. There is no horizontal extension since there is no sharing process and the vertical extension is all taken care of by the driver.

- With Lv. 1, drivers have the ability to let the ADS take care of part of the operational control (i.e. or longitudinal or lateral control). Although there is a horizontal expansion of the process, drivers are still responsible for the higher levels of activity (strategic and tactical). This implies drivers know-how-to-cooperate is well structured: to de/activate these features drivers need a basic understanding of their functioning and, nevertheless, their repetitive use leads to a refinement of drivers' know-how-to-cooperate. By being always in-the-loop, drivers' know-how is not depleted and, in fact, ADS can actively support it since its sensing capabilities (external know-how) have been enhanced to perform basic operational tasks.

- With Lv. 2, drivers have the chance of handing the full operational control to the ADS, which sensing capabilities have been further enhanced to carry out more than one operational task simultaneously. As in Lv. 1, drivers must retain the higher levels of activity (vertical extension), thus actively nourish their know-how. However, the repetitive use of all of the ADS features leads to a depletion of drivers' know-how-to-cooperate, which, influencing their external know-how, impacts also their knowledge of the system capabilities (internal know-how). Moreover, the ADS know-how-to-cooperate does not discourage drivers' abuse nor misuse. Namely, the ADS does not consider drivers' tendency to overrely and overtrust a mostly capable system. Publicity about the system sometimes lacks transparency, thus feeding the users an incomplete, or wrong, model of the system, which influences their internal know-how.

- With Lv. 3, drivers' know-how is heavily affected. Because the ADS is capable of driving the vehicle by itself, drivers lose contact with the driving task (they are allowed too) and their understanding of the system becomes of little importance since by design the two agents will never share the control of the vehicle. Drivers still retain the strategic level of activity, namely, they can decide where to go and whether or not to activate autonomous driving but, once the ADS has been granted control, the cooperation, already at critically low levels, goes to zero. The implementation of driver monitoring systems might allow the ADS to build up an approximated driver's model but there is little consensus concerning the type of monitoring strategy to adopt (Khan & Lee, 2019), especially considering the variability of human-based measures. Nevertheless, inferring drivers' state during HAD provides limited insight into their future performance while controlling the vehicle. Moreover, drivers will be called to take-over and instantly gain control as soon as they reach the interfaces. This means the ADS know-how-to-cooperate has a huge flaw, not taking into consideration the basics of automation-induced behaviour, with all the consequent safety threats.

- Lv. 4 resembles Lv. 3 but, on the contrary, the ADS is able to perform minimum risk manoeuvres. This, as seen in Section 1.2.1, means the vehicle will be able to safely stop in case drivers fail to respond to the take-over request. However, in this case, drivers know-how-to-cooperate is somehow eased by the introduced functionality; drivers will not have to worry about their loss of contact with the task because the know-how-to-cooperate of the ADS has already taken in account their impossibility of maintaining the necessary know-how throughout autonomous driving.

- With Lv. 5, the strategic level is all that remains to drivers, who can decide where to go. Drivers are actually just passengers. The rest is completely handled by the ADS, thereof the know-how-to-cooperate is reduced to a simple (yet not trivial) matter of designing the right interface to allow the two agents to communicate.

Hence, as automation levels grow higher, the cooperation will always find two major issues:

1 - Drivers' know-how and know-how-to-cooperate will be more and more degraded;

2 - ADS and drivers will become more and more individualists in their respective approach towards each other, as they are currently studied in today's research.

As discussed in Section 1.2.2, those are not new concepts. The first point summarizes within a different framework what has been identified as the OOTL phenomenon and the second point describes the research over-interest in analysing this phenomenon on statically-designed experiments with ADS that undergoes little or no cooperation with the driver. Remember that interactions do not imply cooperation, but they are an indispensable factor for cooperation to take place as they constitute the external know-how and know-how-to-cooperate, with which the agent can exchange information about themselves and their respective know-hows. Since cooperation is thought to be essentials to successfully perform the driving tasks, it is worth analysing what are the HMIs that could ease the cooperation process.

1.2.4 Human-Machine Interfaces (HMIs): a mediation towards cooperation

Past studies have pointed out that the diversification of drivers' functions and the consequential OOTL phenomenon, especially lack of situational awareness (Merat & Jamson, 2009; Kircher et al., 2014) and loss of driving skills (Merat et al., 2014), might lead to critical situations when drivers are asked to take over (SAE Lv. 3/4). Indeed, transitions have been perceived as difficult tasks as the driver has to face high mentally demanding tasks, namely collecting information, assessing risk and performing actions based on the outcomes of the previous cognitive process (Flemisch et al., 2008).

Thus, not only are transitions time periods in which the vehicle sees a passive change in the source of the received inputs (namely the driver and the ADS) but they can be termed as cooperative processes, through which the agents (humans and ADS) undergo an actual negotiation in order to decide what should be their respective rights and duties. In this metaphor of transitions as cooperative processes, the two agents would undergo a conversation, discussing which part of the vehicle dynamics should be handed/taken over as well as to what extent these authorities should be granted (i.e. transition sequences). The easier the conversation (i.e. *external know-how-to-cooperate*), the lower would be the induced mental workload (i.e. the proportion of mental capacity which must be allocated to get the information) and the more efficient it is, the higher would be the regained situational awareness (i.e. *know-how*). This conversation takes place thanks to Human-Machine-Interfaces (HMIs), which provide a communication channel between the ADS and the driver.

Explored communication strategies are:

Haptic: those communications take place through forces exerted on the interfaces (i.e. pedals and steering wheel). This type of communication has been proven very effective at providing feedback, as it offers some advantages over other types of feedback channels (Flemisch et al., 2008):

- Haptic feedback can be directly linked to the actuator on which a reaction of the driver is required;
- The feedback can not only be linked to the actuator but can also be used to show the kind of reaction that is needed, e.g. the steering wheel can be turned in the correct direction by the automation to trigger a steering reaction from the driver;
- Haptic interaction is bidirectional. That means that continuous communication between the driver and the ADS can be established.

Haptic feedback on the steering wheel has been found to be effective in inducing faster obstacle evasion (Balachandran et al., 2015), in enhancing motor learning on a steering task (Crespo & Reinkensmeyer, 2008) and even in regaining full control of the vehicle whenever a system failure occurs (Muslim et al., 2016). Haptic feedback on the pedals has shown to improve car-following performance (Mulder et al., 2008), reducing the number of control activities (i.e., braking and accelerating) which, in turn, has direct effects in fuel-efficiency (Jamson et al., 2015).

Another relevant aspect of haptic communication is that it is the only one which allows the creation of a bi-directional channel between the driver and the ADS. Through a haptic interface, drivers can communicate to the ADS their intentions and, vice versa, the ADS itself can communicate to the driver the action it is going to perform and can even give clues on the actions the driver is asked to perform.

Wada et al. (2016) exploit the haptic channel to discern between cooperative/uncooperative drivers, adopting the intention recognition algorithm developed by Nishimura et al. (2015). However, their concept of cooperation was applied at the operational level only (i.e. vehicle control), where agents had to agree on the required actions to be considered as "cooperative".

On the other hand, the vehicle can also establish a communication with drivers. Through vibration on the steering wheel and on the pedals, the vehicle has been proven capable of warning the driver of impending threats and, in particular, of making drivers aware of the urgency with which they should intervene (Kern et al., 2009; Sadeghian Borojeni et al., 2017). Moreover, with the exertion of torques on the steering mechanism, the vehicle has been shown capable of aiding the driver with the driving task (Mars, Deroo, & Charron, 2014; Balachandran et al., 2016).

Notice that vibrations on the steering wheel and on pedals are defined as tactile communications but they are worthy of mentioning in this context because, as opposed to other tactile communications, they share the same limitation of haptic communications: they are possible only when the two agents share the interface or, in other words, when drivers are actively involved in the driving task and have their hands and/or feet on the interfaces (namely the steering wheel and the pedals).

The above refers only to one of the two types of shared control architectures: Haptic Shared Control and not input-mixing (or "blending") Shared Control. The former influences the physical interaction with the control interface (e.g. the steering wheel) whilst the second influences the input to the controlled system (Rossetter & Gerdes, 2006). With input-mixing shared control, the driver cannot overrule the system and may not even be aware of the system activity. Input-mixing has also been defined as *uncoupled* because, on a steering task, to take place needs a steer-by-wire architecture, decoupling the steering wheel from the wheels and allowing the electronics in between to decide how the system would behave (i.e. coupled or uncoupled) (Marcano et al., 2020). In contrast, haptic shared control allows both human and the automation to exert forces on the control interface and this controls are directly linked to the actuators as well, thus this architecture is *coupled* (Marcano et al., 2020). LKA is the most common example of a haptic shared control configuration.

Acoustic: auditory signals have been so far the most commonly used types of signals to forward warnings or just to catch the attention of the driver. The auditory modality has several important characteristics:

- it is omnidirectional, the signal can be received from any direction;
- the auditory sense can receive information at almost all times;
- it is transient, that is it is only available at a particular moment.

A further advantage is that it is possible to use language, which may be more informative as compared to the information conveyed with haptic or visual interfaces (Bazilinskyy & de Winter, 2015). Because of the aforementioned, a generic auditory signal (i.e. the classic "beep") usually represents the first step during HAD in order to re-gain drivers attentiveness, which, in Level 3 and 4, can not be taken for granted (Melcher et al., 2015; Zeeb et al., 2016; Forster et al., 2017). Using acoustic signals in the form of actual speech has been proven to be a powerful instrument to explicitly inform drivers of the required actions (think about commands of navigation systems) but, on the other hand, this kind of signal requires a lead-time (i.e. the time required to deliver the signal) far longer than generic acoustic signals (Bazilinskyy & de Winter, 2015).

Visual: jointly with auditory signals, visual signals have largely been used as warning signals. However, any visual signal is useful only if there is visual contact between the driver and the source of the signal and this explains the common decision of using an auditory signal first. Visual displays

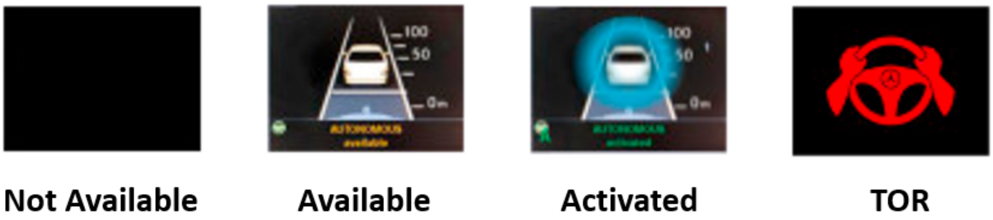

Figure 6: States of the ADS through visual displays (Source Zeeb et al. (2016).

on the dashboard have been proven usable and allow comprehensible HMIs during HAD in order to both ask the driver to take over and to communicate the automated driving availability (Melcher et al., 2015; Forster et al., 2017). Moreover, visual signals have been also used to influence drivers' actions after the take-over and to redirect drivers' attention towards the source of an impending hazard (Borojeni et al., 2016). Visual icons paired with text have been shown to support situational awareness but the interpretation of those signals requires more time (van den Beukel et al., 2016). Even if diverting drivers' attention from the road might entail dangers and should be used with caution (Regan et al., 2013), a recent study has shown that visual warning signals should not constitute distracting factors while driving as long as the glances drivers give to them are no longer than two seconds (Hajiseyedjavadi et al., 2018).

Tactile: tactile communication is based on located static and/or dynamic vibrations of the driver seat and, given the fact that the sense of touch is less involved during driving tasks (Ho & Spence, 2008), it has been proposed as an effective alternative to visual and acoustic signals. Tactile communication capability has been analysed when used for forwarding warning signals and also more complex messages (Schwalk et al., 2015) and it has been proven effective especially in rear-end collision prevention (Scott & Gray, 2008). Nevertheless, this communication channel should always be considered as a complement to auditory and visual communications, since the correct response to this type of communication suffers a high variability (Petermeijer, Cieler, & de Winter, 2017).

Motion-based: motion-based communications in the form of deceleration or acceleration has been used by the ADS in order to regain drivers' attention (as visual or auditory signals) but it has also been used as a way for the driver to communicate the intention of regaining control of the car, especially of the longitudinal dynamic while deciding to overrule the ACC (Pauwelussen & Feenstra, 2010).

Summarizing the above, visual, acoustic and tactile warning signals are by far the most well-known communication strategies used to deliver warnings to the driver. Their main limitation is that they are "one-way" channels, namely the communications come from the vehicle to the driver only. The haptic channel instead is bi-directional: it can deliver information to the driver (through torques and vibration) and can monitor the drivers' actions, which in this framework are actual messages drivers sent to the vehicle. Another significant difference between them is that the communication takes place at the input interface (i.e. the steering wheel or pedals), on which the reaction is required (influencing capability). The drawback of the haptic channel is that it is open only when drivers are actually driving, or at least, have their hands on the steering wheel or/and their feet on pedals whereas the other three channels, are almost always open.

1.3 Transition of control authority

Recalling the state definition of an in-vehicle ADS provided in the previous section (see Section 1.2.1), transitions of control authority have been defined as periods of time in which the system changes from one level of automation to another (Flemisch et al., 2008; Merat et al., 2014; Varotto et al., 2015) or even when an activation or de-activation of a function (an Advanced Driver Assistance System for example) of a specified level of automation takes place (Pauwelussen & Feenstra, 2010; Gold et al., 2013; Miller et al., 2014; Nilsson et al., 2015).

1.3.1 Classifications

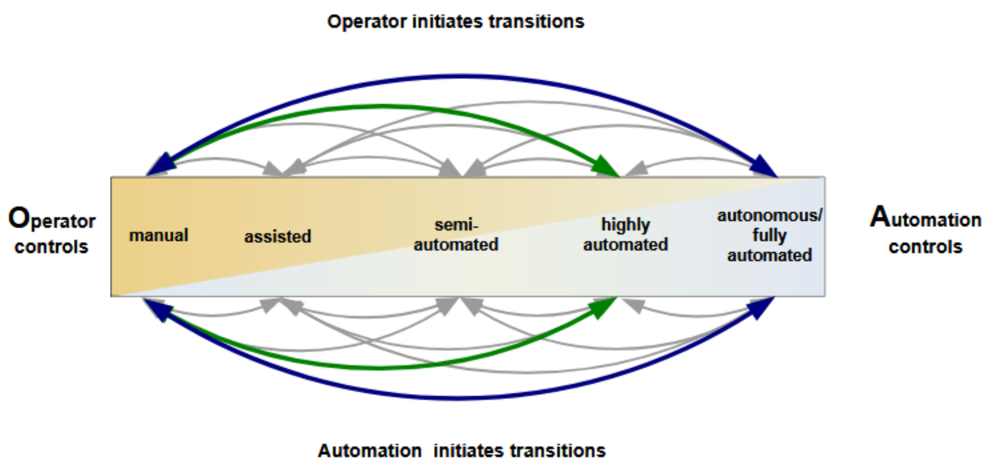

Figure 7: All possible transitions occurring between operator and automation at different levels of automation (grey arrows) and example of possible transitions occurring between operator and automation in a dual-mode vehicle for manual and highly automated driving (green arrows) and manual and fully automated driving (blue arrows) (Martens et al., 2007).

Labelling the human as "operator" and the assistance or automated subsystem as "automation", Martens et al. (2007) classified transitions between these two figures according to three questions:

- Who has "it"?
- Who should get "it"?

- Who initiates the transition?

These questions have been used to define in which direction the control is transferred, for example from operator to automation and who triggers the transition, either the operator or the automation. Table 1 summarizes the four different classes of transitions defined using this ontology, where the letter "A" stands for the system automation and "H" for the human operator, the underline character indicates who is in control, the arrow specifies in which direction the transition goes and the inferior letter "i" defines who initiates the transition of control. Given that, $H \rightarrow A$ (speak "H to A") means the level of automation changes from a lower to a higher level of automation and, vice versa, $H \leftarrow A$ (speak "H from A") means the level of automation changes from a higher to a lower level of automation.

Therefore, the first two classes of Table 1 describe the transition of control from the driver to the automation, which is either initiated by the driver (H_i) or automation (A_i). In a similar way, the remaining two classes describe the transition from automation to driver.

Table 1: Transition of control from human to automation from (Martens et al., 2007).

	$\underline{H_i} \rightarrow A$	$\underline{H} \rightarrow A_i$	$H_i \leftarrow \underline{A}$	$H \leftarrow \underline{A_i}$
Who has "it"?	Human	Human	Automation	Automation
Who should get "it"?	Automation	Automation	Human	Human
Who initiate the transition?	Human	Automation	Human	Automation

Hoeger et al. (2011) extended the above notation by including transitions between different levels of automation so that, for example, a driver-initiated transition from Highly Automated Driving (HAD) to driver-assisted driving was designated as $DA_i \leftarrow HA$. Moreover, they introduced a notation in order to describe failed/refused transitions.

Arguing that whenever a transition of control occurs then control will always transfer, (Lu et al., 2016) proposed a slight deviation from the above classifications. Their classification is based on three criteria:

i. Who initiates the transition?

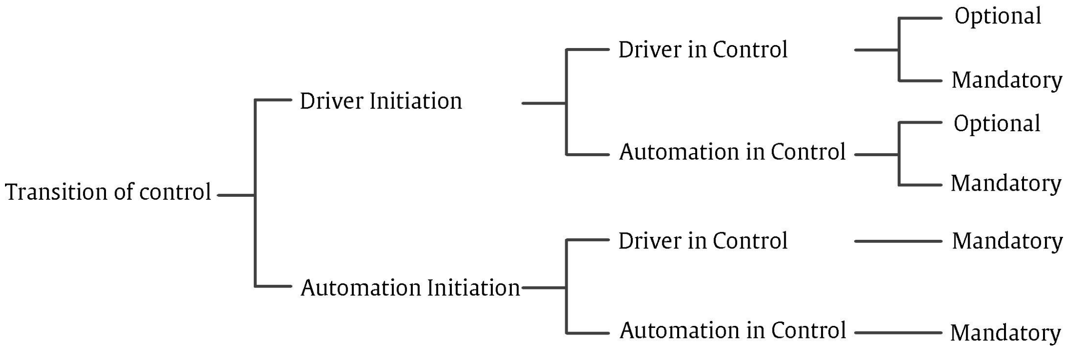

Figure 8: Categorization of control authority transition (Lu & de Winter, 2015).

ii. Who is in control after transition?

iii. Is the transition mandatory or optional?

Based on these criteria, they defined six possible categories of transition: Driver Initiation - Driver in Control (DIDC) mandatory, DIDC optional, Driver Initiation - Automation in Control (DIAC) mandatory, DIAC optional, AIDC mandatory, and AIAC mandatory (see Figure 8). In addition, DIDC and AIAC transitions had been defined as active transitions (self-activation), DIAC and AIDC transition, instead, as passive transitions (triggered intervention).

In transitions from automated to manual driving, the drivers can not be considered either aware of the situation or ready to intervene, and this, given the findings already analysed on the effects of high automation levels on drivers behaviours (see Section 1.2.2), could explain the major research interest on these kind of transitions (i.e. AIDC). On the other hand, driver-initiated transition assumes that, as far as the drivers themselves initiate the transition, they are aware of the situation and prepared to take over, even if the transition is mandatory due to a system failure.

Thus, in relation to HAD, AIDC transitions have been extensively studied in driving simulator experiments, especially with the purpose of quantifying the effects of secondary/distracting tasks on drivers' take over capabilities when the ADS meets its operational limits and the driver is required to take over (Merat et al., 2014; Naujoks et al., 2014); AIAC transitions have been studied as transitions taking place whenever the ADS communicates the availability of automated driving and, once that happens, drivers are always allowed to disengage themselves from the control of the vehicle (Eriksson & Stanton, 2017b).

1.3.2 Vehicle initiated and driver initiated take-overs: a motivational gap

In the literature, the take-over issues within HAD have been extensively addressed in the AIDC condition: effects of HAD on take-over (Lu et al., 2017; Louw & Merat, 2017; Eriksson & Stanton, 2017a), effects of different notification strategies (Bahram et al., 2015; Petermeijer, Cieler, & de Winter, 2017; Forster et al., 2017), influence of demographics (Körber et al., 2016; Wright et al., 2016) and traffic density (Radlmayr et al., 2014a; Gold et al., 2016). The focus has been directed on drivers' reactions and interventions with respect to changes of the environment complexity and of the take-over requests while using secondary tasks to manipulate their level of disengagement with the driving task. Moreover, most of the studies have been focused on critical conditions, where evasive manoeuvres and short reaction times were necessary in order to avoid an accident, such as hitting a lead vehicle or an obstacle or regaining the control of the vehicle after a sudden system failure.

On the other hand, as Eriksson & Stanton (2017b) have underlined, the other kinds of transition (i.e. AIAC, DIDC and DIAC), which hardly require evasive manoeuvres but would constitute the most common scenarios for control transition, have found little interest, maybe due to their hypothesized low criticality. However, because of the paucity of such studies, there has not been any evidence presented supporting that hypothesis. There are instead a number of studies presenting evidence of the effects of HAD on drivers, effects such as loss of situational awareness and driving skills that would bring vulnerabilities to the system regardless of the direction of the transition (Endsley, 1995; Endsley & Kiris, 1995; de Winter et al., 2014; Louw et al., 2015).

Eriksson & Stanton (2017b) studied for the first time the drivers' behaviour while relinquishing control to automation (HAD) and the results showed a control transition time (defined as the time between the notification of the availability of HAD and the complete disengagement of drivers from the driving task, namely hands-off and feet-off conditions) ranging from 2.82s up to 23.8s, which made them underline the importance of a personalised design rather than a mean or median, which would exclude a large portion of drivers. Moreover, when take-over requests are prompted without any time restriction, take-over times showed a similar trend, ranging from 3.17s to 20.99s with a median of 6.06s which, again, led them to underline the importance of an intra-individual design. Even if relevant, this study is mainly focused on a time budget perspective and it ignores the modalities with which the system should provide safe hand-over assistance which should guarantee that the driver's loss of skills and SA will not affect safety while performing any kind of transition. The need of a personalised design is somehow a simplistic conclusion based on few data and based on the acknowledgment of data variability as dependent on individual differences. However, there could be a number of factors leading to the observed variability and the understanding of the nature of these factors might lead to the design of features aimed and capable of significantly reduce the influence that these factors (e.g., traffic, weather, drivers' fatigue, stress, distraction, coffee intake, hours of driving, etc.) have on driving performance.

Moreover, concerning driver-initiated transitions, there would be the need to understand drivers' intention before they trigger the transition. Furthermore, drivers' actions should be subjected to system monitoring, which in turn should discern desired over casual interventions and be ready to assist the drivers while reengaging the driving task according to the specific situations. Thus, adhering to this safety design philosophy, it is necessary to define adequate procedures to hand over the control of the vehicle, depending on who is initiating the take-overs and on the specific situations. For example, there might be a need for an ADS to delay a requested takeover by a driver because the external situation would make that too risky.

Past studies, by introducing a pattern in the handover process, have been able to recognise drivers' intention to intervene, reducing the chance that unwanted intervention could have been forwarded to the actuators (wheels steering and braking systems) and, on the other hand, have found that drivers were more comfortable whilst using this solution to explicitly declare to the system

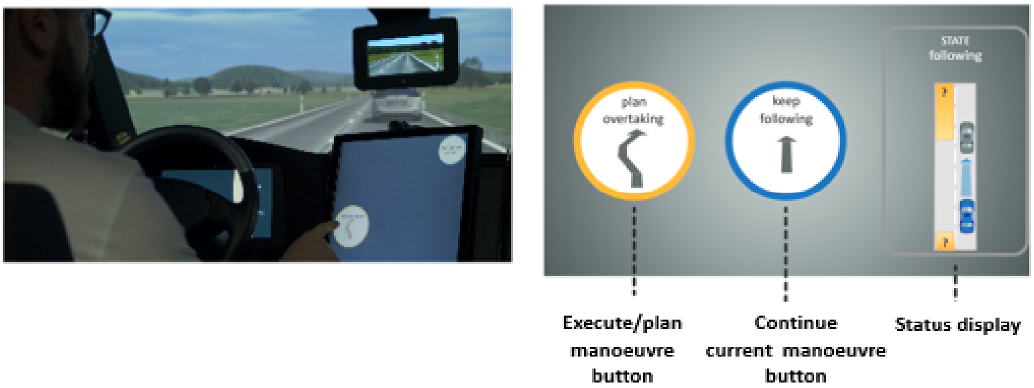

Figure 9: Drivers' intention recognition and tactical decision approvation interface (adapted from (Walch et al., 2017, 2018)).

their intentions (Walch et al., 2017, 2018). These patterns, consisting of a sequence of actions, have been used both as means for drivers to declare their intention to intervene to the ADS and as tools for the drivers to explicitly approve any ADS tactical decision (i.e. any manoeuvres) (see Figure 9).

1.4 Handovers

1.4.1 Handovers: Situations and procedures in literature

Every time a transition takes place, one agent will have to take over the control of the vehicle and the other one will have to relinquish (or hand-over) that control (Shaikh & Krishnan, 2012; Wintersberger et al., 2017). Within a HAD framework, the hand-over task has usually been performed by the ADS, which is called to relinquish the control of the vehicle back to the driver after prompting a Take-Over Request (TOR).

Walch et al. (2015) proposed four different handover procedures:

- **Immediate hand-over**, complete shift of control from one second to the other, e.g. when drivers grasp the steering wheel;

- **Step-wise handover**, control is handed over step by step, e.g. first longitudinal control followed by lateral control, or vice versa;

- **Driver monitored hand-over**, drivers monitor the system behaviour, e.g. by grasping the steering wheel (force feedback) and, after a certain period of time (countdown), the control is handed over;

- **System monitored hand-over**, the system monitors the inputs of the driver for a certain period after the handover. In cases wherein the driver input may result in an unsafe situation, e.g. too harsh braking that threatens to result in a rear-end collision, the system can adjust the inputs.

After presenting the above classification, the authors decided to observe the drivers' behaviour during the take-over only when they are asked to instantly resume both lateral and longitudinal control of the vehicle (Immediate hand-over). The author wanted to understand whether drivers were able to take over immediately and to observe their behaviour during a take-over.

Disregarding the procedure through which the hand-over is provided, McCall et al. (2018) provided a distinction of handovers based on the context within which they take place. Handovers situations were divided into:

- **Scheduled**, whenever the need for hand-over is known in advance, such as, for example, when the vehicle is entering an area not suitable for automated driving;

- **Non-scheduled**, whenever the hand-over is not planned, perhaps due to a sudden change in road conditions or whenever drivers decide to take over when there is no specific need for them to do so; in this case, one can distinguish between driver and automation initiation.

They argued that whenever a scheduled or an automation-initiated non-scheduled hand-over occurs, the responsibility will lie with the drivers as far as, after the prompt of the take-over request, they will have time to become fully aware for the situation. Similarly, in driver-initiated non-scheduled hand-overs, the drivers should be deemed responsible as far as one can assume they will be aware of their actions and no system should prevent them to take over. On the other hand, in emergency (non-scheduled) hand-overs, where the system initiates the procedure, the system is also responsible for what happens next, no matter the presence or not of any driver intervention. Ambiguities on responsibility come into play whenever the driver initiates the emergency hand-over mainly because there are unsolved issues, within which the most relevant are:

1. How the system should react?
2. Has the driver the right to override the system?
3. How the system can distinguish between an intentional take-over and an unintentional one?

Yet, these three questions are not limited to emergency hand-overs but actually to all kinds of driver initiated transitions as far as drivers' actions might be unsafe, perhaps just due to lack of skills or experience (Wright et al., 2016).

Answering these questions brings us back to the procedure through which the hand-over should take place. Providing an immediate shift of control from HAD to manual driving is likely to result in a hazard, and a step-wise hand-over would limit the authority of the driver to only lateral or longitudinal control for a period of time within which the driver might want to have both and this, in turn, might induce a certain level of discomfort. Moreover, the step-wise procedure provides an immediate authority over one of the controls (longitudinal or lateral), and, even if this solution is beneficial in terms of induced workload, it will not represent an absolute solution to the lack of SA and skills issues. Saito et al. (2018), provided evidence of a higher workload experienced by drivers when the lateral control is immediately handed over, in opposition to cases in which the handover is more gradual. Hence, given the findings already analysed on the OOTL phenomenon (see Section 1.2.2), from a safety design perspective, any procedure giving immediate control of all or just part of the driving tasks without any supervision or limitation should not be considered feasible or safe.

Adopting Walch et al. (2015) taxonomy, with a driver monitored handover, through the use of force feedback on the steering wheel, the system would be capable of aiding the driver in the driving task (Mars, Deroo, & Charron, 2014; Balachandran et al., 2015) and could provide as well a smooth shift from fully automated to assisted or manual control by only acting on the amount of force provided (Mulder et al., 2012). Hence, long exposure to force feedbacks would produce a higher SA and, in the meantime, it would reintroduce the driver to the necessary skills for controlling the lateral dynamics of the vehicle (Crespo & Reinkensmeyer, 2008). However, specifying an a-priori period of time (countdown) after which the control should be handed over to the driver as defined by Walch et al. (2015) does not seem a proper and safe approach, especially accounting for intra-individual differences in take-over time (Eriksson & Stanton, 2017b). Moreover, the amount and type of force feedback and, thus the amount of control authority, should depend on the behaviour of the driver during the take-over, a concept which brings us to the system monitored procedure where the driver's inputs are monitored and filtered in order to not result in unsafe situations. This last procedure could result in the most critical situations. Denying the drivers to act on the system could be as dangerous as allowing them to do so: if the system fails to react to a threat, such as an obstacle or a vehicle stuck in the middle of the lane, and the override is not allowed, the vehicle will collide with the obstacle; on the other hand, if the driver harshly pushes the brake by mistake or changes lane without any precaution and the override is allowed, the vehicle could be involved in a collision.

In research, driver-monitored and system monitored handovers have been almost exclusively focused on lateral control, whilst letting the ADS deal with the longitudinal one. This choice may find explanation in past studies on transitions during HAD, where the focus was not on handover procedures but on drivers' behaviour while regaining control of the vehicle. These studies provided evidence on drivers' behaviour when both lateral and longitudinal control were handed over (Gold et al., 2013; Radlmayr et al., 2014a; Lorenz et al., 2014; Louw, Markkula, et al., 2017), even with the introduction of limits to how much the longitudinal controller could decelerate (Merat & Jamson, 2009). However, when the purpose was to analyse only the drivers' performance when resuming lateral control, the longitudinal control was fully managed by the ADS (e.g. ACC) (Mulder et al., 2012; Wada et al., 2016; Muslim & Itoh, 2017; Saito et al., 2018; Kondo et al., 2019).

1.4.2 Actual lateral-control handover research

Even though the situation and procedures of handovers have been clearly defined, few studies have focused on the development and testing of driver-monitored and system-monitored procedures in actual transition to and from HAD.

Mulder et al. (2012) presented haptic shared control as a promising tool to seamlessly support the driver from manual to automatic control (of lateral dynamics only) and vice versa. They provided evidence that haptic shared control can actually enhance safety performance (defined as a reduction of 11% in peak lateral error) with less control activity (16% reduction of the steering wheel reversal rate with respect to the manual control), but they did not provide any evidence that those enhancements could be reproduced in an actual handover scenario. Moreover, the system was designed as an aid during lane-keeping and, thus, the reduction of control activity might be a symptom of complacency and underload of the driver which, in real handover scenarios, might induce longer take-over times, lowering down the drivers' willingness to regain awareness and control.

Wada et al. (2016) proposed a solution to the handover issue based on the concept of initiative holder and intent consistency. The proposed solution, focused only on lateral control and, based again on haptic shared control, allowed the driver to take over control by only exerting torques on the steering wheel. If the driver was deemed un-cooperative the ADSs would enter the "control transferring mode" and lateral control would be gradually transferred to drivers according to their torque inputs.

However, allowing the drivers to obtain control whenever their intentions deviate from those of the ADS could be dangerous, especially if the system has no means to determine drivers' state or, at least, visual attentiveness, which could reveal unintentional, possibly dangerous, actions. This approach assumed that whenever the drivers want to overrule the ADS, they are fully aware of what they are doing and, therefore, they should be allowed to do so. Evidence in HAD experiments has proven quite the opposite on driver SA,

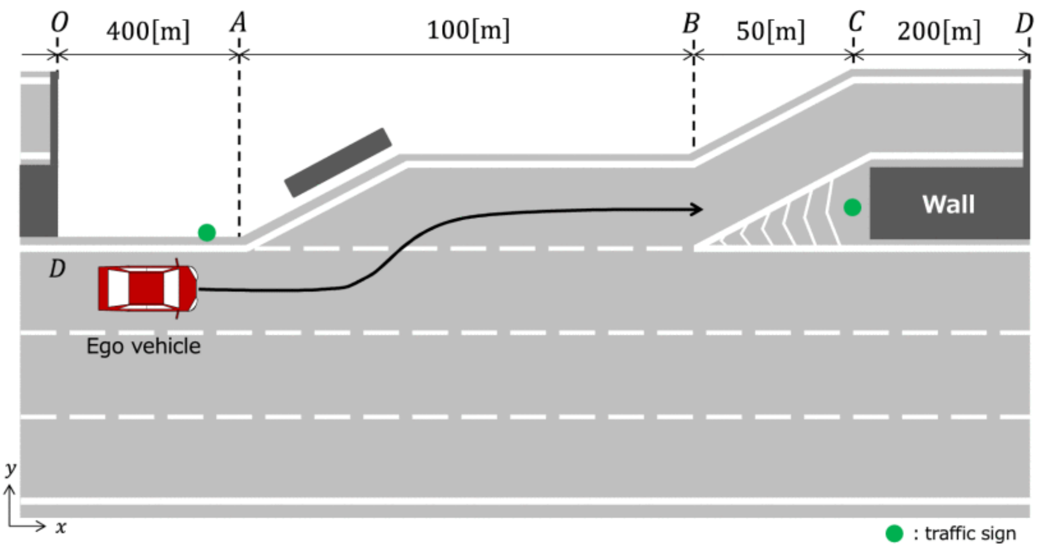

Figure 10: Experimental scenario adopted to induce handover (Saito et al., 2018).

which makes that hypothesis dangerous from a safety perspective.

Saito et al. (2018) and Kondo et al. (2019) decided to add a button in order to safely recognize the intention to intervene, maintaining again the past strategy as a useful feature for cases such as collision avoidance but again, this feature was only based on steering torques and, as such, it was exposed to the same vulnerability discussed above. Moreover, the strategy was tested in a scenario in which a lane change is required to catch an exit from a motorway/highway and drivers were already in the adjacent lane (see Figure 10).

Results of this updated strategy suggested that transferring the control authority to the driver can lead to unstable steering (steering angular velocity RMS and yaw rate RMS) irrespective of the intention of the driver of getting such control. Moreover, the gain tuning, defining the modality through which the control authority is relinquished, affects the perceived workload and, thus, should be carefully designed.

Saito et al. (2018) did not make any use of the time periods, in which the drivers have engaged the driving task (i.e. they intentionally press a button and put their hands on the steering wheel) but the system does not provide them with any valuable haptic feedback and does not gain any information from their steering activity (here addressed as "State V - Dead Zone"). However, this state could have been used by the system to grasp drivers' state and, perhaps, tuned the "Authority transferring control" (i.e. the strategy with which the lateral control is handed over to the driver) to best match the drivers' needs (Steyvers & Waard, 2000; Lyu et al., 2017).

Although the study of Saito et al. (2018) is extremely relevant within the context of both handover procedures and driver-initiated transitions, the unsolved issues highlighted in Section 1.4.1 remain, although this study provided the following guidance:

- 1. "How the system should react?"
  The ADS should provide a gradual transfer of lateral control (longitudinal control not mentioned) from fully automated to fully manual is desirable;

- 2. "Has the driver the right to override the system?"
  Whenever the drivers provide uncooperative steering actions, the system enters the transferring mode so that they are able to override the system, regaining full authority of lateral dynamics;

- 3. "How the system can distinguish between an intentional take-over and an unintentional one?"
  The drivers have to press a button so that the system knows their intention to intervene.

Yet, the experimental design used makes it difficult to assess the real usefulness of such a strategy: in Saito et al. (2018) drivers were instructed to gaze ahead during ADS and in Kondo et al. (2019) drivers were blindfolded, both situations far from a plausible one, in which drivers engage with secondary tasks; secondly, the study did not consider the effects of other vehicles on drivers' behaviour when resuming control, which has been proven to have measurable effects on the quality and safety of the take-over (Radlmayr et al., 2014a; Gold et al., 2016) and, thus, it did not consider as well possible ways with which the system could aid the driver to cope with traffic; third, the lateral control was fully handed over within a fixed amount of time (Saito et al., 2018) or based on a intention recognition algorithm (torque based), disregarding whether it was safe or not to do so. Nevertheless, whenever the system is within the dead zone (State V), drivers can grasp the steering wheel, undergoing a period of time in which they can reengage the driving task, even if in a passive, non-proactive manner. These periods of time might have different effects depending on the individuals and, thus, might affect differently the actual handover.

These studies represent the state of the art of handover strategies of lateral dynamics but they have been more interested in emergency handover in which the driver has to regain control in order to avoid cones or take an exit when the ADS can not handle these situations. However, they do not provide any evidence of its performance within the ODD of the ADS, when the driver may just want to take over to experience the pleasure of driving. These studies did not investigate how drivers behave during nominal conditions, when the vehicle is still within its ODD and the driver, perhaps, just wants to change lane. The proposed guidance would have provided the driver all the rights to change lanes without any restriction, which makes one pose the second question: how to enhance the safety of this system in order to prevent hazards? Moreover, this system considers just a fixed-time handover strategy that again seems more suitable for emergency scenarios, where any further delay could introduce risks, but it does not explore the potentiality of haptic shared control when the ADS and the driver are actually cooperating.

To understand how drivers would behave during transitions in nominal condition, all the experiments described within this thesis have been conducted based on the assumption that the system is not affected by any type of malfunctioning or failure, which might influence the trust drivers have on the system and, in turn, the final results and conclusions. Another hypothesis concerned the driver state: the driver has always been assumed to be in good mental condition and therefore, not affected by either drowsiness, fatigue or stress, which may influence their performance. Nevertheless, the state of the driver was manipulated during the experiments with the introduction of secondary tasks during HAD. However, to better understand how the handover should be managed, it has been deemed of great importance to investigate how unexpected occurrences, taking place during the handover when the process of authority transfer is not yet completed, influence drivers' behaviour. These occurrences should give a better understanding of the drivers' re-engagement with the driving task and what are the parameters of the handover strategies affecting it the most. The Out-Of-The-Loop phenomenon affects both awareness and physical control and different driving sub-tasks require drivers to perform different operations. These operations do not always require drivers' full situational awareness, nor fast reaction. For the drivers to keep a steady trajectory within a lane, for example, it is not necessary to have a complete understanding of the current situation since knowing the relative position of the vehicle within the lane and the relative speed compared to the leading vehicle will suffice. In other situations, drivers may be required to face more challenging tasks, which were not directly related to the transition but related to the usual DDT.

In order to define these occurrences I considered studies dealing with the investigation of the external motivation of the drivers for deactivating an ADAS (ACC especially); usually drivers, disengage the system in order to (Varotto et al., 2015):

- Adapt the speed to a lane change manoeuvre, especially in dense traffic conditions;
- Overrule the system due to an offensive or defensive behaviour: the drivers brake (or accelerate) in order to create a sufficient (defensive behaviour) or insufficient (offensive behaviour) gap for a vehicle in an adjacent lane for merging;
- Adapt the speed to avoid illegal overtaking.

However, from a human factors perspective, internal motivations (trust especially) are far more interesting than external ones but, however, far more difficult to analyse. Empirical studies have shown how drivers' trust in longitudinal assistance systems are way greater than their trust in lateral assistance systems (Kidd et al., 2017) and, thus, drivers tend to deactivate the last ones while keeping active systems such as the forward collision warning (Reagan & McCartt, 2016). Within the framework of driver-automation interactions, this means that conventional lateral assistance systems (e.g. Lane Keeping Assist (LKA) or Lane Departure Warning (LDW)) are not appreciated by drivers. Therefore, during handovers, the lateral assistance should be carefully managed in order to not become a source of discomfort and/or conflict.

From the above findings, keeping always a longitudinal driving system activated seemed a reasonable approach; in this way the studies could focus on the lateral control, avoiding possible effects due to individual differences in speed selection (Winsum & Godthelp, 1996; Cavallo et al., 2018), either induced by different steering competence, individual preference or by sudden variations of the environment.

On the other hand, by removing the possibility to brake or accelerate, drivers are forced to respond to changes in the environment only with lateral movements and, thus, their possible actions are limited to a mere lane-change manoeuvre. However, thinking about the usual actions drivers perform while traveling in a motorway, this limitation was not expected to represent a source of discomfort, given the assumption that all the changes of the environment would not occur suddenly and, thus, drivers would have a reasonable amount of time to adapt their path according to the situation.

1.5 Transfer of control: performance evaluation

Once the TOR has been prompted, the transfer has here been studied as a passive time-flow starting with the TOR and mostly considering the TOR modality as the Independent Variable (IV). Therefore, the main research interest has been focused on the evaluation of reaction times and their relationships w.r.t. TOR modalities (Bahram et al., 2015; Petermeijer, Cieler, & de Winter, 2017; Forster et al., 2017), traffic condition (Radlmayr et al., 2014a; Gold et al., 2016) and demographics (Körber et al., 2016; Wright et al., 2016). However, among different studies, it can be noticed that there is a certain lack of repeatability: experiments performed in almost the same experimental conditions have non-consistent results both in terms of reaction time and TOR lead time (Eriksson & Stanton, 2017b). Some studies performed a detailed analysis of the events taking place after the TOR, measuring the time between TOR and every action drivers undergo such as the first glance to the road, the grabbing of the steering wheel and the first measurable steering action, but the majority of them have been mainly focused on the reaction time defined as the time elapsed between the TOR and the first measurable steering action (or pushing action on a pedal) as a proof of the regained control authority of the human driver (Eriksson & Stanton, 2017b). It has been proven how gaze behaviour could reveal both the perceived level of risk (Zeeb et al., 2015) and the driver re-involvement in the driving task (Louw & Merat, 2017). Subjective questionnaires have been used to investigate TORs acceptance, usefulness and workload from a driver prospective (Forster et al., 2017). It has been found that drivers prefer multi-modal TOR, especially an auditory signal followed by a visual one, over TOR which makes use of only one of these signals alone (Petermeijer, Bazilinskyy, et al., 2017).

Hence, the success of the transfer has usually been evaluated in terms of:

- Effectiveness of the TOR: How quick is the specific TOR in having the driver involved in the driving task again?
- Subjective-Quality of the transition: How has the TOR been perceived by drivers?
- Objective-Quality of the transition: How is the driver driving after resuming control?

As stated above, most of the research studies evaluated the transition only by answering the first two questions. Some studies introduced an unexpected event (e.g. a vehicle ahead breaking harshly, an accident or on-road workers) right after prompting the TOR, thus trying to evaluate drivers' reaction time alongside their "performance" in avoiding the obstacles and preventing an accident (Radlmayr et al., 2014b). However, as Eriksson & Stanton (2017b) stated, reaction times and actions undertaken in "critical take-over situations", in which the drivers' failure to react in time lead to an accident, will not constitute the common take-over scenarios drivers will be called to manage. Although reaction times and drivers' capacity of coping with an unexpected situation are of great importance, they do not reflect or provide evidence of drivers' behaviour and performance in non-critical transitions, which are the most likely to occur. Prolonged exposure to HAD would impair drivers' ability to safely resume the driving task by itself and, even without unexpected occurrences, drivers might constitute a threat to other road users. Indeed, investigating drivers' performance without any "critical situation" might be more challenging, as the chances drivers might fail the driving task would be very little.

Nevertheless, during transitions, drivers and the ADS interact in order to achieve a safe and comfortable drive while the vehicle sees a shift of control inputs. The analysis of transitions, in which drivers and ADS' inputs are blended together, must not be limited to the study of the overall performance in terms of vehicle dynamics but needs to provide a deeper insight on the actual relationship taking place between control actions and drivers' behaviour. Nevertheless, salient vehicle dynamics variables such as yaw rate, lateral acceleration and position are key factors to consider as they provide a practical representation of the effectiveness of the adopted handover strategy. Although some metrics are closely related to the designed experiment and/or task, there are metrics that have been proven to be effective to analyse transitions of authority and shared control strategies.

1.5.1 Objective metrics

Mean Lateral Position (MLP) and its standard deviation have been proven effective to investigate drivers' engagement, namely the less engaged drivers are with the driving task (due to their involvement with other tasks), the larger will be the deviation of the vehicle from the lane centre and its "weaving" (Zeeb et al., 2016) and, as such, they have been used in order to assess the quality of the transition (Merat et al., 2014; Wada et al., 2016; Clark & Feng, 2017; Eriksson & Stanton, 2017a; Saito et al., 2018; Madigan et al., 2018). Within the framework of shared control, MLP jointly with SDLP have proven themselves as indicators of drivers' acceptance and compliance (Mars, Deroo, & Charron, 2014).

Yaw rate and lateral acceleration have been used to describe vehicle stability (Saito et al., 2018) and, during transition of authority, the smoothness of the transition itself (Zeeb et al., 2016). Adopting these, it has been proven that fading the ADS authority results in smoother transitions, mitigating the instabilities brought by drivers while taking over (Saito et al., 2018).

All the above is strictly related to the control exerted by drivers while re-engaging the driving task or, in the shared control framework, to the level of cooperation drivers and ADS achieve. Thus, considering just the lateral control, steering angle and related metrics have been broadly adopted to describe drivers' control performance. Steering angle has been used to analyse possible differences in steering behaviour induced by different TOR strategies after resuming manual control (Petermeijer, Bazilinskyy, et al., 2017; Eriksson & Stanton, 2017a). As yaw rate describes vehicle stability, the steering wheel angular velocity (as first derivative of steering wheel angular position) RMS has been effectively adopted to analyse steering stability (Wada et al., 2016; Saito et al., 2018). Steering Wheel Reversal Rate (SWRR), defined as the ratio between the number of changes of direction of the steering wheel rotation (i.e. the reversals) over a predefined time window, has been used as an indicator for drivers' distraction (Kountouriotis et al., 2016), task demand (Macdonald & Hoffmann, 1980) and cognitive load (Li et al., 2018). Within the shared control framework, SWRR has been effectively used to evaluate the optimal repartition of control between the machine and the driver and, hence, to what extent the control action is integrated into the sensori-motor control loop of the driver or the extent of conflicts between the automated system and the driver (Mars, Deroo, & Hoc, 2014). Mulder et al. (2012) adopted it to determine the level of control activity. In order to understand and differentiate the steering control components, the power of the high-frequency steering components (HFS) have been measured as a quantifier for the anticipatory steering actions, namely those used to stabilized the trajectory (Salvucci & Gray, 2004). After a transition of authority, these steering components indicated that drivers need more than 30s to stabilize the vehicle trajectory (Merat et al., 2014). Alongside HFS, Time To Lane Crossing (TTLC), defined as the available time interval before a vehicle crosses any lane boundary following a specified path direction (Cario et al., 2009) and measured in seconds, has been used to describe the quality of drivers' anticipatory steering actions (Godthelp, 1986). Van Der Wiel et al. (2015) adopted TTLC as an indicator of perceived task criticality since the lower the TTLC is, the shorter is the time drivers have to correct any lane deviation. From the latter, TTLC has been consequently defined also as a measure of perceived safety and, in this sense, it has been shown drivers are more comfortable when the TTLC is above the 3 seconds and, in turn, when drivers feel they have enough time to safely correct any lateral deviation. Steering components are strictly related to the physical control of the steering wheel and, thereof, to the steering effort drivers exert while pursuing the desired vehicle trajectory (Mars, Deroo, & Hoc, 2014). Steering effort is a measure of drivers' physical demand and has been used to assess the presence of conflicts of steering authority (de Nijs et al., 2014) and to evaluate the optimal amount of haptic feedback (Toffin et al., 2007). Steering effort has been adopted to evaluate the level of acceptance and compliance while testing haptic shared control (Mars, Deroo, & Hoc, 2014). During transitions of authority, while handing over the lateral control via haptic shared control, it has been adopted to identify drivers' intention to intervene (Nishimura et al., 2015; Wada et al., 2016; Saito et al., 2018; Kondo et al., 2019).

Vehicle handling is an essential aspect while transferring the authority back to the driver as it provide the first and clear picture of drivers' capacity of fulfilling the basic driving tasks. Nevertheless, drivers' capability of controlling the vehicle at an operational level is not enough to conclude anything concerning their engagement and awareness, aspects as important as control. Being engaged and aware of the surroundings are necessary elements without which the transition will likely lead to safety threats. Following Endsley's theoretical background, the first building block for awareness is perception, thus the collection of information from the surrounding (Endsley, 1988). Assuming drivers will be less prone to mind wondering while taking over, visual attentiveness towards relevant features and/or Area Of Interests (AOIs - as defined by Carsten et al. (2012)) would be a powerful indicator of drivers' visual engagement and information gathering. Louw & Merat (2017) have shown that drivers' visual engagement can be further subdivided into engagement with the ADS and engagement with the road by analysing the vertical and horizontal gaze dispersion respectively. While analysing drivers' gaze behaviour during transitions of authority, it is worth to bear in mind that attentiveness must be related to the task demand. Thereof, a generalized attentiveness towards the road, resulting in a large horizontal dispersion, might be a good indicator of drivers' visual re-engagement but, if drivers fail to capture salient information from the correct AOIs when they need to, they will likely fail to perform correctly any maneuver requiring a proper understanding of the current situation. The ability to re-direct attention towards the "correct" AOIs is a top-down approach based on knowledge and skills (Rasmussen, 1983). A good example has been provided by Salvucci et al. (2001), analysing drivers' gaze behaviour while changing lane. In this case, the metric adopted to accurately track attention repartition is gaze dwell ratio, which is defined as the ratio between the time spent looking toward a particular AOI (i.e. sum of the fixation durations) and the given time window. Nevertheless, Percentage towards Road Center (PRC), defined as the gaze dwell ration spent focusing on the road straight ahead, has been adopted as an indicator of visual engagement with the driving task, assuming no mind wondering and that the center of the current lane ahead is the most important section of the road (Merat et al., 2014).

1.5.2 Subjective metrics

Although the objective measurements seen so far are the most reliable due to their intrinsic objectiveness, whenever a driver-based experiment takes place subjective questionnaires are the most used tools to gather driver acknowledgment. Questionnaires are aimed at collecting information about different aspects: acceptance of the system, trust and perceived effectiveness are the most relevant within this framework. The questions are generally simple and the participants are asked to answer those questions by circling a number or a cell in order to define a "level of…". Hereafter, an example (Muslim et al., 2016):

Trust: to what extent do you think the system was trustworthy? (Not at all 0 ˜7 Absolutely);

Effectiveness: to what extent do you think the system was effective? (Not at all 0 ˜7 Absolutely);

Acceptance: to what extent do you think you would like to use the system in the real world? (Not at all 0 ˜7 Absolutely).

Figure 11: U-shape function representing the need for assistance according to the driver's workload and performance. Source: Flemisch et al. (2010).

Trust level of the driver on an ADS has been proven problematic because drivers fail to rely upon it appropriately. Inappropriate reliance associated with misuse (due to the violation of critical assumptions and inappropriate reliance) and disuse (due to the rejection of the capabilities of automation) depends, in part on how well trust matches the true capabilities of the automation (Parasuraman & Riley, 1997). Supporting appropriate trust is critical in avoiding over-trust (namely when trust exceeds system capabilities) and under-trust (namely when a large range of automation capabilities maps onto a small changes in trust) (Lee & See, 2004).

Another aspect questionnaires aim to investigate is drivers' workload. Now, before dealing with the review of the questionnaires used to capture it, it is better to explain the concept of workload and why is so meaningful in human-machine framework. First of all, there is no agreed definition of workload and consequently not one agreed method of assessing and modeling it; one definition describes workload as "the perceived relationship between the amount of mental processing capability or resources and the amount required by the task" (Hart & Staveland, 1988). Workload is affected by lots of different factors, some due to the driving task only (such as traffic condition, weather, drive duration and road type) and others due to introduced interactions with in-vehicle systems (such as type of feedback and level of automation) (Porter, 2011). It has been proven that both drivers' overload (i.e. too high workload) and underload (i.e. too low workload) negatively affect drivers' performance, therefore, workload needs to be kept under control: drivers' underload, perhaps due to over-reliance on the ADS, might push them to neglect some safety practices, whereas, drivers' overload might lead to performance decay while performing the primary task (i.e. the driving task) and it is an indicator of the drivers' need of assistance (see Figure 11) (de Waard, 1996; Flemisch et al., 2010).

The most known and used tools to collect data concerning perceived workload are the NASA-TLX questionnaire (Hart, 1986) and the RSME (Rating Scale of Mental Effort) (Zijlstra & van Doorn, 1985). The main issue whilst using off-experiment questionnaires is the possibility that participants could not report the actual perceived workload once the experiment is ended; for this reason, many authors adopt an online workload monitoring questionnaire with which report the perceived mental workload. Because of its structural complexity, the NASA-TLX questionnaire is not suited for this purpose and, in turn, the questionnaire used here is the RSME. The participant has only to be instructed to give a number each time a signal (auditory, tactile, vocal, etc.) is presented to him/her. The score is between 0 (Absolutely no effort) and 150 (Extreme effort). Similarly, the Continuous Rating Scale (CRS) follows the same process to collect workload and comfort in the form of a Numerical Response Scale (NRS) in range 1 (Very Low) and 10 (Very High) (Bourdel et al., 2014).

1.6 Summary, research gaps and assumptions

Although transitions of control in HAD have become an extensively studied topic, research have been mainly focused on the analysis of the take-over process, thus investigating how drivers re-engage the driving task once the ADS relinquish them control. Few studies have addressed the topic of how the take-over should be managed or, from the other perspective, how the ADS should hand over the control of the vehicle (Wada et al., 2016; Saito et al., 2018; Kondo et al., 2019). However, the OOTL phenomenon has not been considered properly, thus making questionable any conclusion drawn on the real effects that these handover strategies might have on drivers' take-over performances. The theoretical framework outlined by Walch et al. (2015) has never been implemented and therefore there is lack of evidence on how future handovers should be developed. The adoption of shared haptic control strategies have proven to be effective in supporting lateral vehicle handling and has been multiple times cited as a promising tool to provide seamless shifts of control authority (Flemisch et al., 2008; Mulder et al., 2012). Nevertheless, there is still little evidence of the potential benefits of shared haptic control during transition of control within HAD. Another topic that needs further understanding is concerning driver initiated transitions from HAD to lower Levels of Automation (LoA). Its assumed lower criticality w.r.t. automation initiated transitions has made this topic of little interest within the research community (Lu & de Winter, 2015). However, by definition, the OOTL phenomenon is due to the exposure to automation and, although it might become more critical whenever drivers are asked to take-over within a predefined amount of time, there are some aspects such as skills decay and loss of situational awareness that would affect them anyway.

Hence, there is the need to understand the human-machine interactions engraved with the handover problem as a mean to provide safe transitions of control to drivers affected by the OOTL phenomenon. Understanding the nature of these interactions and the transition-related factors that ignite them is the first step towards the development of a human-centered handover design, capable of minimizing drivers' poor control and of better reintroducing them to their role as drivers.

In synthesis, based on the discussion in Section 1.4.2, during the reported studies, the followings have been considered:

Constraints

- The ADS provides full longitudinal control, hence drivers have to care about lateral control only;

- The experiments have been simulated in motorways;
- Drivers have been deemed always in good mental state (no fatigue, drowsiness or stress);
- Driver OOTL state has been simulated through the introduction of a secondary task;
- Drivers have to press a button in order to declare their intentions of taking over to the ADS;
- The ADS does not present any faults or failure;
- The environmental changes have been presented so to not constitute source of discomfort (no sudden intervention required);

Assumptions

- OOTL state affects drivers' take-over, no matter who initiates the transition;
- Different handover strategies (as defined by Walch et al. (2015)) have different effects on drivers' take-over;
- Haptic Shared Control strategies might enhance drivers' re-engagement with the driving task;
- The way drivers perceive the ADS affects their willingness to relinquish control.

1.7 Research questions and thesis overview

The aim of this thesis is to investigate the effects on drivers' behaviour of handover strategies, which adopt haptic shared control, during transitions of control between HAD and longitudinally assisted driving. These handovers are thought to promote and fasten drivers' engagement with the driving task while safeguarding their actions throughout the handover process. In detail, this thesis tries to address the following research questions:

1. **How do different handover strategies affect drivers' behaviour during transitions of control?**

2. **How does varying the duration of the handover affect drivers' performance?**

3. **How do Driver-Initiated transitions differ from Automation-Initiated transitions?**

4. **To what extent steering conflicts can hasten drivers' re-engagement with the driving task?**

5. **Are drivers self aware of their own behaviour during transitions of control?**

The tested handover strategies were developed in order to vary the level of assistance and its duration. Drivers were exposed to assistance at both an operational and a tactical level so to able of drawing significant conclusion of their respective benefits/drawbacks during the transitions of control.

As outlined in Figure 12 and Figure 13, this thesis have been subdivided into 7 chapters:

- **Chapter two** analyses past taxonomies of transitions of control and discuss the colloquial use of two key terms: "takeover" and "handover". Moreover, proposes a new set of qualifiers to better adress transitions of control and facilitate the discussion of sub-tasks execution.

- **Chapter three** details a study that investigates drivers' behaviour during transition of control while being assisted by handover procedures. Drivers' behaviour is analysed depending on whether or not they were initiators. In opposition to system-initiated transitions, in user-initiated transitions, drivers were instructed to take over by themselves after completion of a NDRT. The presented handover procedures varied the granted steering authority at various stages of the transitions.

- **Chapter four** considers the same study of Chaper three and discusses the potential impact of lateral assistance systems during system-initiated transitions from HAD. The evolution over time of drivers' operational and tactical control are analysed within key segments of the transition. The DDT consisted of a lane-keeping task followed by a lane-change.

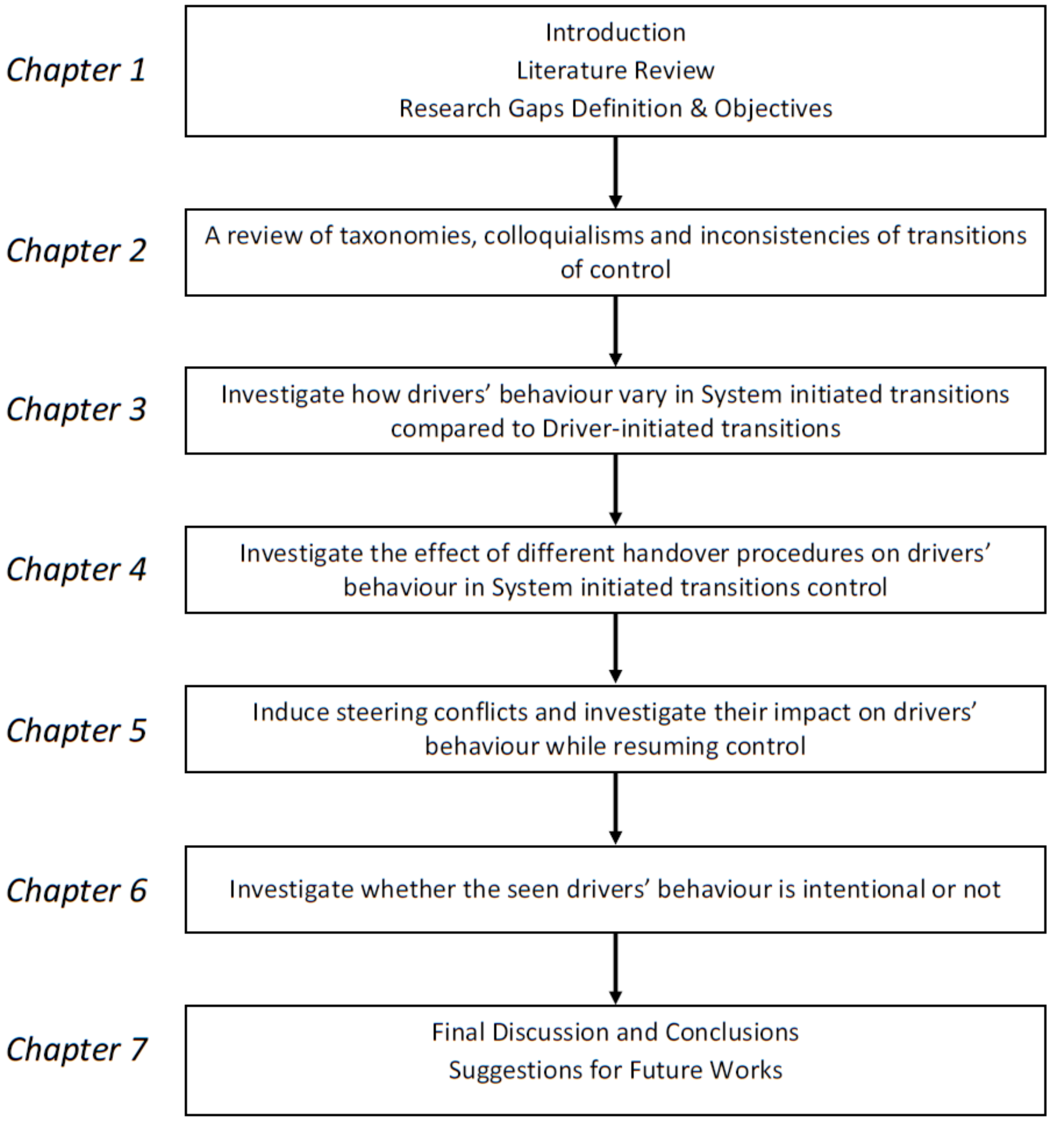

Figure 12: Thesis structure.

- **Chapter five** reports on a second study that sought to understand whether steering conflicts could be exploited to achieve a quicker drivers' re-engagement. To achieve steering conflicts, a inconsistent haptic guidance was provided within the first 10 seconds of the transitions.

- **Chapter six** reports findings from a online questionnaire. The survey aimed at understanding drivers' internal, or dispositional, motivations towards automated drivings and the use of ADAS during transitions of control. Drivers were proposed with motorways scenarios similar to those adopted in previous simulator experiments and asked to choose how they would expect the system to behave and whether or not they would like to be assisted.

- **Chapter seven** summarizes the presented works and provides a wider discussion, highlighting new research questions and suggesting directions for future works.

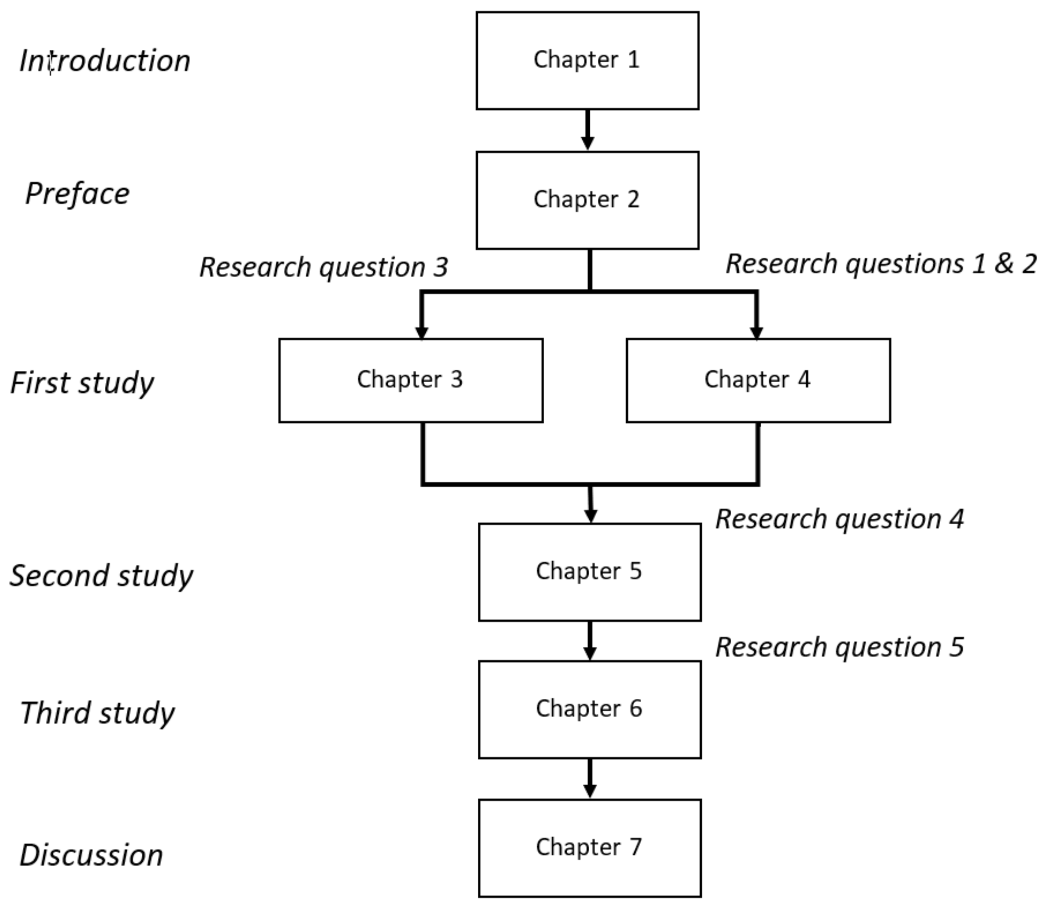

Figure 13: Sequential order of the thesis chapters and link to the outlined research questions.

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CHAPTER 2

When terminology hinders research: the colloquialisms of transitions of control in automated driving

ABSTRACT During the last 20 years, technological advancement and economic interests have motivated research on automated driving and on its impact on drivers' behaviour, especially after transitions of control. Indeed, once the Automated Driving System (ADS) reaches its operational limits, it is forced to request human intervention. However, the fast accumulation and massive quantity of produced studies and the gaps left behind by standards have led to an imprecise and colloquial use of terms which, as technology and research interest evolve, creates confusion. The scope of this survey is to compare how different taxonomies describe transitions of control, address the current use of widely adopted terms in the field of transition of control and explain how their use should be standardized to enhance future research. The first outcome of this analysis is a schematic representation of the correspondence among the elements of the reviewed taxonomies. Then, the definitions of "takeover" and "handover" are clarified as two parallel processes occurring in every transition of control. A second set of qualifiers, which are necessary to unequivocally define a transition of control and identify the agent requesting the transition and the agent receiving the request (ADS or the driver), is provided. The "initiator" is defined as the agent requesting the transition to take place, and the "receiver" is defined as the agent receiving that request.

2.1 Introduction

The past 20 years have seen the introduction and the commercialization of vehicles with growing degrees of automated capabilities. The introduction of increasingly enhanced automated systems has pushed research to produce taxonomies to categorize the levels of automation (LoA), also referred to as degrees of automation (DoA) (Sheridan & Verplank, 1978; Flemisch et al., 2008; Carsten & Nilsson, 2001). In parallel efforts, the German Federal Highway Research Institute (BASt), the National Highway Traffic Safety Administration (NHTSA) and the Society of Automotive Engineers (SAE) developed classifications of driving automation (Gasser & Westhoff, 2012; National Highway Traffic Safety Administration, 2013; SAE, 2014) to simplify the discussion and increase comparability of like systems. The SAE classification is the most widely adopted scheme, and research studies use it frequently to concisely describe the focus of the specific study and the limits of applicability of the obtained results. In the last six years, SAE has revised the original classification three times (SAE, 2016b, 2018, 2021) in line with the evolution of the technology and its most pressing implications.

By far, the most addressed implication of increasing DoA is the issue of transition of control authority. Transitions of control authority are made necessary by an immature technology, which cannot guarantee a safe management of the Dynamic Driving Task (DDT) at all times (SAE, 2014). Hence, in some cases, drivers must be ready to resume control to ensure the safety that the Automated Driving System (ADS) is unable to provide. Just as a classification was deemed necessary for DoA, classifications were developed for transitions as well. These classifications considered a transition either as a period in which the ADS changes from one DoA to another (Flemisch et al., 2008; Merat et al., 2014; Varotto et al., 2015) or as the moment when an activation/de-activation of a function of a specific DoA takes place (Pauwelussen & Feenstra, 2010; Gold et al., 2013; Miller et al., 2014; Nilsson et al., 2015). The derived classifications were generalized to be able to describe transitions in both directions (from driver to the ADS and vice versa) and considering who requested the transition (either the driver or the ADS) (Martens et al., 2007; Hoeger et al., 2011; Lu et al., 2016; McCall et al., 2016). For example, Lu et al. (2016) proposed a taxonomy of transitions of control based on three dimensions:

1. Who initiates the transition?

2. Who is in control after the transitions?

3. Is the transition optional or mandatory?

The proposed taxonomies failed to regulate the colloquial use of the take-over term and, similar to the reported standards, they have not been widely adopted in the research literature, which has been mainly focused on a very specific type of transition: the process in which ADS requests drivers' intervention and the drivers must resume control within a limited time. This transition was introduced first in Damböck et al. (2012), but reached the research community with Gold et al. (2013), and is termed "take-over" or, in Lu et al. (2016), Automation Initiation - Driver in Control (AIDC) mandatory transition.

Gold et al. (2013) addressed the "take-over" as the process in which drivers take over control. Thus, "take-over time" was defined as the time between a "Take-Over-Request (TOR)" and the deactivation of the ADS. Since publication, this paper has been cited 570 times, according to Google Scholar (accessed on 28/06/2021). The term "take-over", however, has lost consistency over time and has been, in some cases, been used with a different definition.

Another ambiguous term is complementary to take-over: handover. Within the field of transitions of control, it was defined by Miller et al. (2014) as the process in which the driver or the ADS hands back control to the other agent. During a system-initiated transition of control from automated to manual driving, the "take-over" concept would address the drivers' role while taking over control whereas the term "handover" would denote the actions/operations the ADS undergoes to support drivers' take-over.

Within a year from its first use, the term "take-over" was already widespread among human factors studies investigating drivers' behaviour while taking over control (Martens & Van Den Beukel, 2013; Bahram et al., 2014; Naujoks et al., 2014; Zimmermann et al., 2014; Körber & Bengler, 2014; Lorenz et al., 2014; Radlmayr et al., 2014; De Winter et al., 2014; Kerschbaum et al., 2014; Miller et al., 2014) and still retained its original meaning. However, various following studies distorted its meaning: some used it as equivalent to handover and others used it to identify transitions in general or transitions in which the driver takes back control from the ADS (Politis et al., 2015; Morgan et al., 2016; Hock et al., 2016; Schroeter & Steinberger, 2016; Russell et al., 2016; Van Der Heiden et al., 2017).

Hence, one goal of this survey was to collect information concerning the use of "take-over" and "handover". In particular, it was investigated whether there exists a consistent use of the "take-over" and "handover" terms depending on the specific focus of the paper. Another goal was to provide a simpler and more structured way of addressing a transition of control authority and the roles in this process of both the ADS and the driver.

2.2 Methodology

Starting from papers published in 2013, more than 300 papers were reviewed and 73 were selected. Most of the selected papers were published between 2013 and 2016 and they represent the root of the highlighted inconsistencies. Few recent papers (2017-2021) are cited since they have inherited the same inconsistencies. Used keywords were "take-over", "takeover", "take over", "handover", "hand over" and "hand-over".

2.2.1 Taxonomies

The structured analysis of a transition process reached the attention of the research community with Gold et al. (2013). In this manuscript the term take-over was adopted to identify the *take-over process* with which the driver takes over control from the ADS after receiving a TOR (see Figure 14). Within the same study, *TOR-time* or *Take-over time* were defined as the advance warning time, i.e. the time between TOR and critical event. Drivers' intervention, as the sum of performed actions after a TOR, was addressed as *reaction procedure*. The reaction procedure may consist of gaze reaction, hands on steering wheel, gaze fixations, steering/braking intervention and other actions drivers undertake while responding to the TOR. *Reaction time* was defined as the time between TOR and the first steering and/or braking intervention. De-activation of the ADS happened as soon as drivers' intervention was detected and not after the system reached its limits. The *remaining action time* was defined as the time between drivers' intervention and system limits. In a more recent version, the incongruities concerning system de-activation were corrected (Gold et al., 2018). Therefore, drivers' first intervention triggers system de-activation

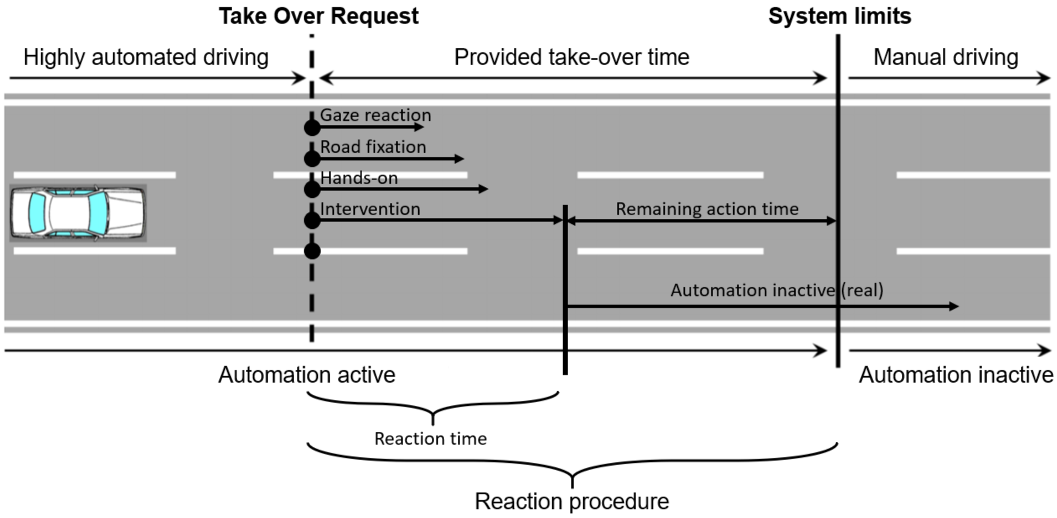

Figure 14: Schematic illustration of the sequence of a take-over process, adapted from Gold et al. (2013) and corrected based on Gold et al. (2018) to better define "Automation inactive (real)".

and the remaining action time is the period in which drivers' are in manual control and need to intervene before the system limits, which correspond to a critical event.

Seppelt & Victor (2016) expanded Gold et al.'s (2013) take-over process by considering also the control stabilization time, namely the period after the ADS has switched off and in which drivers could experience a degraded control.

The Human Factors Definitions for Automated Driving and Related Research Topics (SAE, 2016a) does not link the term "take-over" to any specific transition. Thus, *take-over response* is defined to address a *"...specific, measurable action taken by the human user or the system to partially or fully resume the DDT"* (SAE, 2016a, p. 17). Within the transition of control sequence from automated to manual driving (see Figure 15), the *take-over time* refers to the time interval between the TOR, here addressed to as *Request to Intervene (RtI)*, and the deactivation of the ADS (request phase), which coincides with drivers' take-over response. As in Gold et al. (2013), the take-over response coincides with the drivers grabbing the steering wheel or placing their feet on the pedals. Similarly to Gold et al. (2013), gaze reaction is not considered under the definition of measurable action. The transfer phase stands between the ADS deactivation and the initiation of the take-over response (i.e., hands-

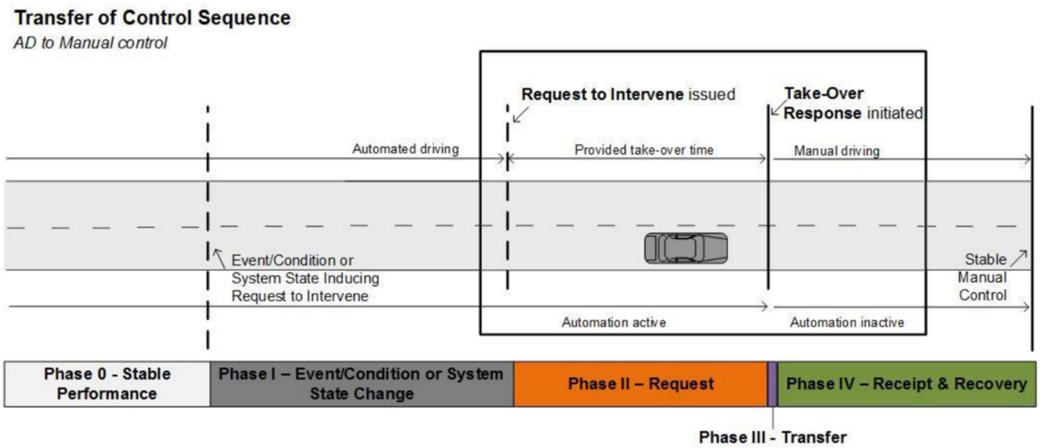

Figure 15: Schematic illustration of the sequence of a take-over process, taken from SAE (2016a). SAE adapted this figure from Seppelt & Victor (2016)

on wheel and/or feet on pedals) and is also referred to as *"the period of time when the transfer switches from one entity to the other (automation to user, or, user to automation) i.e., the moment of handover."* (SAE, 2016a, p. 15). The achievement of a stable DDT performance marks the end of the take-over response ("receipt and recovery" phase).

Wintersberger et al. (2017) provided a different taxonomy. *Handover* was used instead of take-over, hence *handover reaction time* corresponded to "take-over time" and *handover signal* referred to the TOR. *Sufficient handover* was coined to address what was defined in SAE (2016a) as "take-over response initiated" and thus denotes what in Gold et al. (2013) was the first measurable steering and/or braking intervention. *Complete handover* identified the end of the receipt and recovery phase. *Handback* was coined to address the drivers handing back control to the ADS as a substitute of what was more precisely defined as *"Transfer of DDT function sequence from manual control to automated driving"* (SAE, 2016a, p. 13).

In the most recent version of the ISO standards "Road vehicles - Human performance and state in the context of automated driving" (ISO/TR 21959-1:2020, 2020), a more detailed discussion of what was called "take-over process" in Gold et al. (2013) is provided. As in SAE (2016a), the standard keeps a distinction between driver/system initiated transition and its direction. Considering the take-over process, here addressed to as *"system initiated transition*

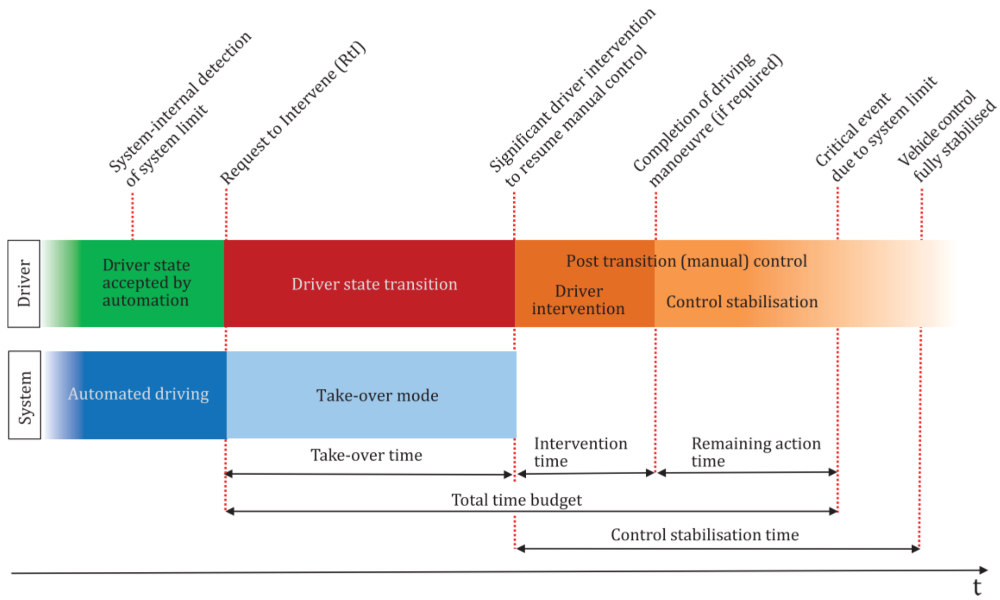

Figure 16: Schematic illustration of the sequence of a take-over process. Image taken from ISO/TR 21959-1:2020 (2020).

from automated to manual driving" (see Figure 16), the TOR is here addressed to as RtI, following SAE guidance (SAE, 2016a, 2018). *Take-over mode* refers to the ADS behaviour after the TOR, thus to the actions the ADS performs, which include, for example, minimal risks manoeuvres. *Driver state transition* is used to identify the *"process of transforming the actual driver state to a target driver state suitable to effectively take-over manual control"* (ISO/TR 21959-1:2020, 2020, p. 7) and indicates the sum of actions drivers undertake as a response to the TOR. Hence, it covers the elements of the reaction procedure described in Gold et al. (2013) before a braking/steering intervention. As in Gold et al. (2018), the TOR-time is here addressed as *total time budget* and the *take-over time* identifies what was defined as reaction time. The *intervention time* refers to the time interval required by drivers to handle the specific situation by performing an appropriate driving manoeuvre. Intervention time plus take-over time identifies the *driving recovery time*. The *remaining action time* represents the difference between the total time budget and the driving recovery time. Here, *system deactivation time* is defined as the time between the TOR and the full deactivation of automation functions (see Figure 16).

All these documents attempt to provide a common ground for future discussion, but the use of different terminology makes it harder to follow one guidance over the other. In the following, a critical discussion of the main differences between these taxonomies will be provided alongside their respective adoption within the reviewed papers.

2.3 A structured critique of the existing taxonomies

2.3.1 The introduction of a structured analysis of a take-over process

In Gold et al. (2013), the ADS deactivates before reaching the system limits, in particular as soon as a drivers' intervention is detected. Therefore, the "remaining action time" defines the difference between the provided take-over time and the "reaction time" (i.e. "time budget"). However, the *reaction procedure* is enclosed between the TOR and the end of the provided take-over time. The SAE report (SAE, 2016a) partially addresses this ambiguity, namely the fact that the term "reaction" has two different meanings in "reaction time" and in "reaction procedure". In the first, it indicates the first driver intervention (i.e., steering and/or braking) whereas, in the second, it defines the action drivers underwent from the TOR to the system limits. In Gold et al. (2013), Seppelt & Victor (2016) and SAE (2016a), the overall driver response starts when a driver places the hands on the steering wheel or feet on the pedals ("take-over response initiated") and, as Seppelt & Victor (2016), does not end until a stable manual control is achieved. Although system limits are not presented in Figure 15, the published taxonomy (SAE, 2016b) placed system limits as in Gold et al. (2018), thus after the "take-over response initiated". Between the "request" and the "receipt and recovery" phases stands a phase not considered in Gold et al. (2013): the "transfer" phase or the moment of handover. Within SAE (2016a), the transfer begins with the start of the release of automated control (e.g. TOR) until the "take-over response". This contradicts a definition of transfer provided earlier in the same document, which states that the transfer of DDT function sequence represents *"the period of time from when a transfer is initiated, either by the human user or the system, to when stable performance is (re-)established"* (SAE (2016a), p. 13). Standing between the "automation active" and "automation inactive" states, the transfer SAE (2016a) considered consists of an immediate automation deactivation,

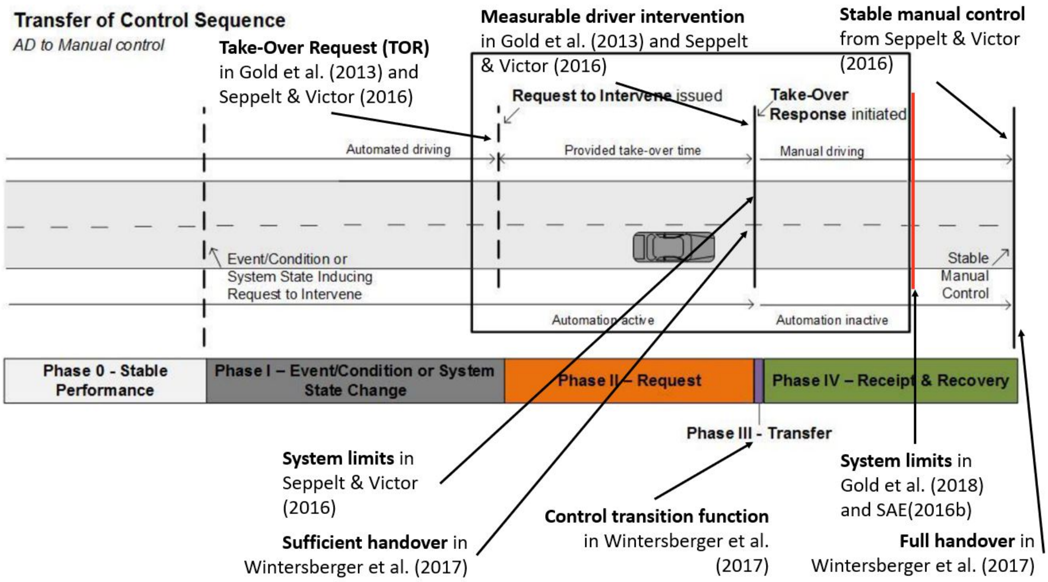

Figure 17: Transfer of DDT function sequence from automated to manual driving (system-initiated). Highlights of discrepancies among Gold et al. (2013, 2018), Seppelt & Victor (2016), SAE (2016a) and Wintersberger et al. (2017). This figure is adapted from SAE (2016a).

as in Gold et al. (2013). The transfer sequence is consistently used in SAE (2016a) when describing the transfer phase during transitions from manual to automated driving, in which the transfer ends once the ADS has achieved stable DDT performance. This again leaves ambiguities, as SAE (2016a) does not mention ADS limits (i.e. end of ODD). Is the transfer supposed to happen before the system limits or must the manual stable DDT be achieved before system limits? How can a "transfer" release longitudinal and lateral control to the drivers if it ends as soon as drivers place their hands on the steering wheel or feet on pedals?

The common ground between Gold et al. (2013), Seppelt & Victor (2016) and SAE (2016a) is the use of the term "take-over" to address the driver-centred aspect of the transition. SAE (2016a), with the description of the transfer phase, introduced also the term "handover", referred to the ADS or the driver releasing part of the DDT to the other agent. Nevertheless, it is imperative to acknowledge the importance that Gold et al. (2013) and Seppelt & Victor (2016) had in shaping the structured analysis of a transition of control.

2.3.2 Handover and handback in Wintersberger et al. (2017) taxonomy

Wintersberger et al. (2017) undoubtedly addressed some of the ambiguities found in the SAE report. The end of the transfer phase, as it was used to describe the automation to manual transition in SAE (2016a), was termed "sufficient handover", referring to the fact that the driver is ready (hands-on-wheel) and fit to intervene. The "full handover" ends as the "receipt and recovery" does, thus as soon as a stable manual control is reached. The sum of sufficient and full handover constitutes a handover. This revised taxonomy adopted "handover" to describe what in Gold et al. (2013) was termed as "reaction procedure" and in SAE (2016a) as "take-over response". The "control transition function" happening in the "transfer" phase overlap with the previous definitions of handover. In fact, previous works had already defined handover from automated to manual driving as a process starting as soon as a TOR (or RtI) is issued (Miller et al., 2014; Walch et al., 2015; McCall et al., 2016).

Wintersberger et al. (2017) underlined the inconsistency of the transfer phase as defined in SAE (2016a) and the need for a deeper investigation of control transition functions. However, this paper could have followed previous definitions and integrated them into the SAE (2016a) taxonomy. Thus, during transitions from automated to manual driving, a handover defines the ADS actions (i.e. the "control transition function") to hand back control to the drivers (ADS perspective). During transitions from manual to automated driving, a handover defines the drivers actions to hand back control to the ADS (drivers' perspective). Wintersberger et al. (2017), although using different terms, provided a clear correspondence between the provided taxonomy and SAE (2016a) taxonomy.

2.3.3 The ISO standard: does it bring any clarity?

Being the last published taxonomy, the ISO standards was supposed to condense the previous taxonomies more clearly, also accounting for their common use within the papers on the topic. However, this is not the case yet. The standard introduced a better picture of what a transition of control entails. It considered the transition as a period in which the ADS and the driver undergo

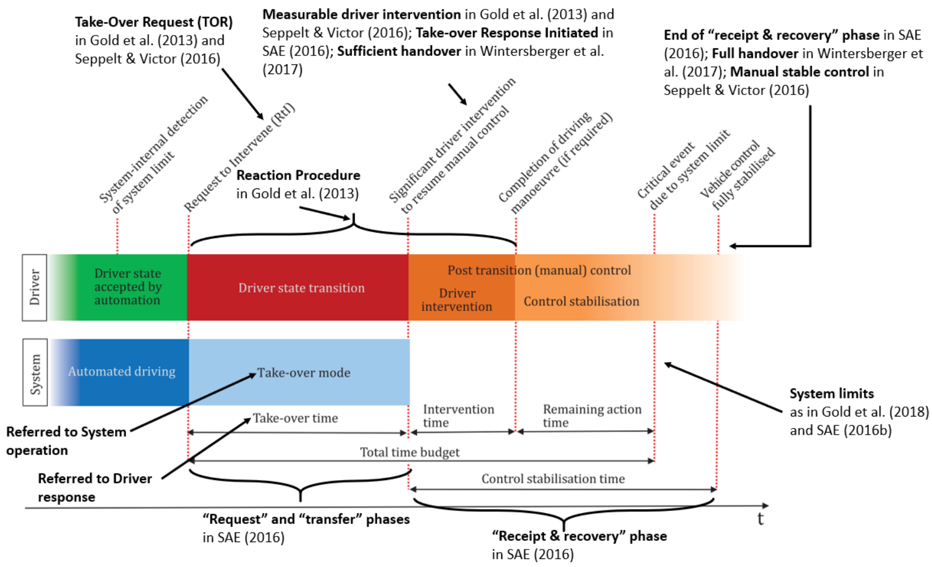

Figure 18: Transfer of DDT function sequence from automated to manual driving (system- initiated). Highlights of the found correspondence among Gold et al. (2013, 2018), Seppelt & Victor (2016), SAE (2016a), Wintersberger et al. (2017) and ISO/TR 21959-1:2020 (2020). This figure is adapted from ISO/TR 21959-1:2020 (2020).

different but complementary parallel processes.

There exist several re-defined terms, from the very beginning of the transition process (see Figure 18). RtI is used as in SAE (2016a) to address the TOR. The "driver state transition" could be considered as part of the "reaction procedure". However, in the ISO standard, it seems that the system deactivation takes place as soon a noticeable driver intervention is detected, hence is not representing all the actions drivers undertake to respond to a TOR, but only those up until their first intervention. Hence, a "sufficient handover" or initiation of the "take-over response", can be assumed within the "driver state transition", before a significant driver intervention. This because a significant driver intervention is defined as a clear request to deactivate the ADS, either using a button press or steering/braking above a threshold as opposed to the hands-on-wheel and/or feet-on-pedals events. After the RtI, in parallel with the driver state transition, the ADS switches to a "take-over mode". The choice of words seems strange and creates confusion when compared to "Take-over time" for example. The latter is explicitly defined as a human-centred term and identifies drivers' intervention time (or reaction time) but the second refers exclusively to the ADS state. This stage could represent part of the "control transition function" and surely falls within the "request" and "transfer" phases of the SAE taxonomy.

2.3.4 What does all this leave us with?

Based on this overview, to date, there is not a clear definition or a standardized use of "take-over" and "handover", since the standards themselves have failed to use them consistently. Gold et al. (2013) made clear that the term "take-over" always refers to the operation that drivers perform to take over the DDT. SAE (2016a) achieved the greatest consistency as it avoided linking the term to any specific transition but only to the operation that the agent, who is taking over the DDT, is performing. In Wintersberger et al. (2017) and ISO/TR 21959-1:2020 (2020), the distinction was not as clear.

Both the ISO standard and SAE reports reject the use of the term "take-over" (or "takeover") to address the whole transition process. On the contrary, in literature, it has been found that the term "take-over" has been used to identify the whole transition requiring a RtI (Gonçalves et al., 2015; Schwalk et al., 2015; Bahram et al., 2015; Melcher et al., 2015; Zeeb et al., 2016; Van Den Beukel et al., 2016; Wright et al., 2016; Körber et al., 2016; Petermeijer et al., 2017; Louw & Merat, 2017; Bazilinskyy & De Winter, 2017; Borojeni, Wallbaum, et al., 2017; Forster et al., 2017; Zeeb et al., 2017; Louw et al., 2017; Madigan et al., 2018; Van Dintel, 2019; Zhang et al., 2019; J. Clark et al., 2019; Kraus et al., 2020), as inherited from Gold et al. (2013).

The "handover" term has been used more consistently but it is still little used in comparison to its complementary "take-over". A number of papers have been using "handover" to define the ADS operation within a system-initiated transition from automated to manual driving (Walch et al., 2015; McCall et al., 2016; B. Clark et al., 2016; Hock et al., 2016; Johns et al., 2018; McCall et al., 2018; Naujoks et al., 2018; Mole et al., 2019). Nevertheless, even "handover" is not free from misuse and has been used as a synonym to "take-over" (Politis et al., 2015; Russell et al., 2016; Van Der Heiden et al., 2017; Schartmüller et al., 2018; Bronson et al., 2019; Chen et al., 2019; Drexler et al., 2019; Frison et al., 2019; White et al., 2019; Larsson et al., 2019), or to identify the transition from manual to automated driving (Miller et al., 2014; Borojeni, Meschtscherjakov, et al., 2017). Eventually, some of the reviewed papers used "handover" as, broadly speaking, the process of handing something to someone and specified the context of application to clarify their use (Miller et al., 2014; Kondo et al., 2019).

New research interests, such as transitions from manual to automated driving, driver assistance systems during transitions of control and user-initiated transitions, might be heavily affected by the current use of the "handover" and, especially, "take-over" terms.

Within the reviewed papers, no one adopted the described taxonomies and all have opted for the free use of one of the two terms, namely "handover" or "take-over". The vast majority of the reviewed documents adopted the latter to effectively drive the focus of the discussion to drivers' behaviour as the ADS role was that of providing a RtI (or TOR) as in Gold et al. (2013). On the other hand, "handover" has been adopted when the focus during the same transition was shifted from the driver to the ADS and the way it handed over the DDT to the driver as in Walch et al. (2015), which accounts for 143 citations according to Google Scholar.

2.4 Conclusions

There exist correspondences among the revised taxonomies, and their graphical representation has been provided in Figure 18. The highlighted correspondences are proposed to be helpful to researchers and ensure comparability. The basic control sequence during a system initiated transition of control from automated to manual driving starts with a RtI (i.e. TOR). The ADS waits for the drivers to react to the RtI, allowing a predefined time budget (i.e. *take-over time* or *provided take-over time*). Once the ADS measures a significant driver intervention (i.e. *take-over response initiated* or *sufficient handover*), the ADS switches off, and the drivers are in manual driving. Once in manual driving, drivers have a limited amount of time to handle the event (not necessarily critical but rather the edge of an ODD), which defines system limits. Once the borderline event has been handled, the transition will be considered finished when drivers manage to stabilize the vehicle trajectory (i.e. *manual stable control* or *full handover*). Taking a step back from the control sequence, and analysing how transitions of control are classified, the evidence here reported is that there are still several authors who use “take-over” and “handover” with no consistency and sometimes as synonyms. This is a result of inconsistent taxonomies that have either been misused or have not been accepted by the research community, which prefers a more colloquial terminology. However, these colloquial terms must be somehow clarified and their use standardized. According to their current and most recognized use, a possible clear distinction would see them as parallel processes. Indeed, during a transition, ADS and the driver will exchange partial or full control of the DDT; one will hand over something and the other one will take over it. Thus:

Definition 1. Take-over is the process with which one agent takes back control of part or all of the DDT;

Definition 2. Handover is the parallel process with which one agent relinquishes part or all of the DDT.

These definitions cannot be adopted to unequivocally define a transition as they fail to specify who is requesting a transition and who is called to provide some sort of handover. If one imagines a transition as a mediation process, there is always an agent requesting something and an agent this request is addressed to. Hence, there exists the necessity to define who is who. As Lu & De Winter (2015) already specified, the requester is the agent initiating the transition, hence a fitting term to identify this agent within a transition of control is “Initiator”. Identifying who is requesting the transition defines also the agent that should be listening to that request. A fitting term would be “Receiver”. The Receiver would be also responsible to provide a handover or preparing for a take-over but this does not imply that the receiver is also supposed to accommodate the request received from the Initiator. With smarter ADS and the increasing adoption of Drivers Monitoring Systems (DMS), when the driver is the Initiator, the ADS might decide whether to fulfil the initiator’s request or not. In these situations, the ADS is assumed to be mature and fully capable of both managing the DDT and detecting when drivers should not be allowed to take over. Today, the technology is not at that maturity level, thus it should not prevent drivers’ take-over. Drivers might be reacting to a silent failure. Similarly, drivers might decide not to respond to a RtI and the ADS will be forced to a minimal-risk manoeuvre. The direction of the transitions, either from automation to manual or vice-versa, determines who

Table 2: Transitions of control and relationship with the proposed terminology.

Transition of control	Initiator	Receiver	Handover	Takeover
System-initiated transition from automated driving	ADS	Driver	ADS	Driver
System-initiated transition from manual driving	ADS	Driver	Driver	ADS
User-initiated transition from manual driving	Driver	ADS	Driver	ADS
User-initaited transition from automated driving	Driver	ADS	ADS	Driver

between the Initiator and the Receiver is called to take over or to provide a handover. For example, in a system-initiated transition from automated to manual driving, the ADS is the Initiator and the one providing the handover, the driver would be the Receiver and the one taking over. The use of these 4 terms in a consistent manner would make the discussion clearer and would pave the road to a more structured research literature, which would otherwise require the introduction of more terms in an already dense glossary.

2.5 Further consideration and future challenges

Although this article revolves around the challenges that colloquialism introduced and tried to provide clear and simple definitions to address the transition processes, there is a pragmatic component that would affect the analysis of the transition process nevertheless: the way the start and end of these processes are defined and measured. This issue was already introduced by Liu & Green (2017), albeit only in forward collision warning. Relative to transitions of control, although providing longer take-over times allow for a higher situational awareness (Körber et al., 2016; Gold et al., 2016; H. Clark & Feng, 2017; Hadi et al., 2020), Zeeb et al. (2016) argued that drivers' response times are not representative of the quality of the take-over process.

Nevertheless, following the above definitions, depending on the adopted instrumentation and metric, the start and end of both take-over and handover processes are defined. This means that, for example, during a system-initiated transition, the handover is heavily influenced by what is considered as the Receiver's (i.e. the driver's) intervention. The majority of the revised studies adopt a physical interaction with the interfaces, namely a steering or braking action exceeding a predefined threshold (Gold et al., 2013; Radlmayr et al., 2014; Gold et al., 2015; Körber et al., 2016; Feldhütter et al., 2018). Thus, the handover starts as soon as these thresholds are exceeded. However, the take-over process starts in the moment in which the Receiver has already redirected their attention towards the road and are already preparing to physically take over. If only the physical interaction is considered, the handover would be delayed compared to the take-over process and the quality of the transitions (e.g. performance, stabilization time, comfort, workload, etc.) might be negatively affected, especially in challenging situations (Radlmayr et al., 2014; Gold et al., 2016; Dogan et al., 2021). In fact, a handover encompasses any action which an agent performs to ease the transfer of control, which could also be, perhaps, the activation of head-up notifications to redirect drivers' focus. Similarly, the definition of control stabilization time or "receipt and recovery phase" determines how long a handover would last. From the above examples, it is clear that the start and end of any transitions, and the related take-over and handover processes, exclusively rely on the metrics one chooses to measure (e.g., steering or braking actions above a threshold, gaze fixations, contact with the interface, etc.). What threshold to choose? Of what measure? What are the situations of applicability for each measure? How does one measure "control stabilization"? These are only some of the challenges research should tackle in the future.

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CHAPTER 3

Transitions between highly automated and longitudinally assisted driving: the role of initiator in the fight for authority

ABSTRACT A driving simulator study explored how drivers behaved depending on their initial role during transitions between Highly Automated Driving (HAD) and longitudinally assisted driving (via Adaptive Cruise Control). During HAD, drivers might issue a Take-Over Request (TOR), initiating a transition of control that was not planned. Understanding how drivers behave in this situation and, ultimately, the implications on roads safety is of paramount importance. 16 participants were recruited for this study and performed transitions of control between HAD and longitudinally assisted driving in a driving simulator. While comparing how drivers behaved depending on whether or not they were the initiators, different handover strategies were presented to analyze how drivers adapted to variations in the authority level they were granted at various stages of the transitions. Whenever they initiated the transition, drivers were more engaged with the driving task and less prone to follow the guidance of the proposed strategies. Moreover, initiating a transition and having the highest authority-share during the handover made the drivers more engaged with the driving task and attentive toward the road. Handover strategies that retained a larger authority share were more effective whenever the automation initiated the transition. Under driver initiated transitions, reducing drivers' authority was detrimental for both performance and comfort. As the operational design domain of automated vehicles (SAE Level 3/4) expands, the drivers might very well fight boredom by taking-over spontaneously, introducing safety issues so far not considered but very important nevertheless.

3.1 Introduction

Although automated driving is a reality, commercially available systems are still not completely autonomous. Those systems are classified as partial automation (SAE Level 2) and they require drivers' continuous engagement with all the aspects of the driving task. Even higher automation levels, such as Conditional (Level 3) and Highly Automated Driving (HAD - Level 4), can implement driverless motion of the vehicle only within predefined conditions and they still need human driver intervention (SAE, 2018). When not required to continuously monitor the operation of the Automated Driving System (ADS)(SAE Level 3/4), drivers will tend to engage in non-driving related tasks (Carsten et al., 2012; de Winter et al., 2014), which would have the effect of introducing new issues, uniquely addressed as the Out-Of-The-Loop issue (Endsley & Kiris, 1995; Merat et al., 2019). As obvious and ironic (Bainbridge, 1983) as it can be, if the drivers are no longer involved in the direct control of the vehicle, their capacity to properly control the vehicle will decline. In spite of the inevitable performance decay, the ADS will be forced to request drivers' intervention whenever it is about to exit its Operational Design Domain, defining the domain over which the automated vehicle can operate safely. This places the transition management at the very core of current research studies.

In research, transitions during Conditional and HAD have been mainly addressed in a unidirectional way: the ADS reaches the limit of its Operational Design Domain and, as automated driving is no longer possible, the system issues a Take-Over-Request (TOR) to unprepared drivers, who are supposed to take-over within a predefined amount of time (SAE Level 3). Many studies have shown how unprepared drivers are after periods of HAD, but they still retain the same transition process (Strauch, 2018). Drivers' behavior has been analyzed while varying different aspects around the TOR, including drivers' mental load before the TOR (Lu et al., 2017; Louw & Merat, 2017; Eriksson & Stanton, 2017a), demographics (Körber et al., 2016; Wright et al., 2016), TOR modality (Bahram et al., 2015; Petermeijer et al., 2017; Forster et al., 2017) and traffic conditions (Radlmayr et al., 2014; Gold et al., 2016). Eriksson & Stanton (2017b) pointed out that there exists a tremendous variability and, to a certain extent, loss of repeatability between these similar studies, whose main focus was reaction times in transitions. As they successfully underlined, with the increase in ADS reliability, the most common type of transition will likely be non-critical, i.e. free of any time-budget restriction; therefore, drivers' reaction-time will be of little importance. Indeed, some studies showed reaction times are not descriptive of drivers' take-over quality (Merat et al., 2014; Zeeb et al., 2016; Vogelpohl et al., 2018) and Gold et al. (2016) argued that longer take-over times might be indicative of a better reaction.

Moreover, there is a paucity of knowledge about how drivers would behave whenever they decide to take-over by themselves. In this scenario, drivers, as initiators, would not only self-pace the take-over, but they would also set the time instant in which the take-over would take place. This concept is not new in literature and it has been classified as Driver Initiation - Driver in Control by Lu & de Winter (2015), who described it as an "active transition" because the initiator (i.e. the driver) was supposed to be prepared to take-over afterwards. *"driver's preference of control"* and driver's acknowledgement of an *"automation failure"* were cited amongst the causes for this type of transition (Lu & de Winter (2015), p. 2514).

Assuming drivers are ready to intervene only because they have decided to intervene is not consistent with the aforementioned Out-Of-The-Loop issue, which has never been related to the transition itself but only to the prolonged exposure to automated driving. Recent studies made clear that drivers' readiness to intervene could be insufficient even when they judge themselves ready to take over (Wada et al., 2016; Saito et al., 2018), thereby underlying the importance of easing drivers' re-installment as operator.

Flemisch et al. (2008) postulated that a gradual passage from higher to lower automation levels will potentially facilitate the reintegration of the drivers into the driving task. In particular, haptic (i.e. via force feedback) shared control was presented as a viable instrument to provide this gradual control hand-over, which could be achieved by simply decreasing the amount of guiding torque acting on the steering wheel. Mars, Deroo, & Hoc (2014) showed that varying the level of haptic authority, while drivers and ADS are sharing the control, might however induce low acceptance and also conflicts on who is in charge of steering, which, in turn, could affect the induced workload. Indeed, these conflicts lead to an increase in interaction forces, i.e. forces applied on the shared interface (Griffiths & Gillespie, 2005; Forsyth & Maclean, 2006; Tsoi et al., 2010). In aviation, to increase the effectiveness of user-system interactions and reduce mental overload, the concept of adaptive automation was introduced (Rouse, 1976). Instead of providing “static” automation modes, an adaptive system could select its own automation level in response to variations in operating environment and driver performance. This strategy was designed to increase operators’ involvement while exploiting the benefits of automation (NADC, 1989).

Within the context of transitions of control, automation adaptation is constrained by the purpose of the transition itself (i.e. transferring control to the user). Nevertheless, the basic concept can be reused and adapted to the handover-design problem. Walch et al. (2015) provided a high-level classification of different type of hand-over strategies (Immediate, Stepwise, Driver-Monitored and System Monitored). Although no evidence on their respective advantages/disadvantages was presented, the Stepwise Handover formulation considered a gradual reintegration of control as a viable solution to reintroduce drivers to the driving task. However, the lack of evidence on drivers’ performance while experiencing any handover other than Immediate, left their design yet to be studied.

Indeed, to provide a gradual authority shift implies imposing a gradual reintegration of drivers’ authority. Drivers will be inevitably forced to follow a procedure before being in manual driving and this, in turn, might cause discomfort and even conflict. Past studies proved drivers need up to 15 s to stabilize the vehicle trajectory (Merat et al., 2014; Zeeb et al., 2016; Dogan et al., 2019), meaning that, after the take-over, drivers are far from being adequately in control. Whether a stepwise handover could help drivers to improve their performances after taking over is still to be verified. Moreover, how the gradualness with which these handovers are presented affects drivers, warrants further investigation to understand whether the above 15 s could be reduced or not. Therefore, although longer lead times have proven to produce better performance at both operational and tactical levels (Gold et al., 2013), the design of a proper handover process, in which the ADS actively helps drivers, could not only have beneficial effects in terms of performance after the transition, but also in terms of "reintegration" time. Irrespective of intra-individual differences, such a process could potentially ensure that the drivers have been properly reinstalled in their original role (i.e. operator) within a predefined amount of time. If this could be achieved, the transition planning strategies will be facilitated better and the transitions themselves will likely become more effective, and efficient, than how they have been addressed to date.

Given the above discussion and in collaboration with Nexteer Automotive, the purpose of this study was to investigate drivers' interaction with the ADS providing different "Stepwise" handovers. These handovers were tested both in common take-over scenarios, in which the ADS was issuing a TOR, and with the drivers initiating the transition by themselves. The main research questions of this study were:

1 - How long does it takes for drivers to take over when they initiate the transition themselves?

2 - How the take-over time could impact the safety of the transitions?

3 - Does the role of drivers as Initiators affect the way they interact with the ADS?

Following the findings of Eriksson & Stanton (2017b) and Walch et al. (2015), drivers' take-over time was expected to be longer whenever drivers were initiating the transition. Nevertheless, drivers were expected to exploit the delayed take-over by preparing themselves for the driving task, thus resembling the effects of a TOR with longer lead time as in Gold et al. (2013), leading to more attentive drivers and, therefore, safer transitions. Given the temporal demand related to automation-initiated transitions (Walch et al., 2015), drivers were expected to request the handover faster but without the necessary engagement with the driving task, preventing them from actively cooperating with the ADS. Therefore, a longer period of shared control would be required in order to promote drivers' full and safe engagement in driving. Nevertheless, the handovers relinquishing back control over a longer time span were thought to ease drivers' re-engagement irrespective of the initiation.

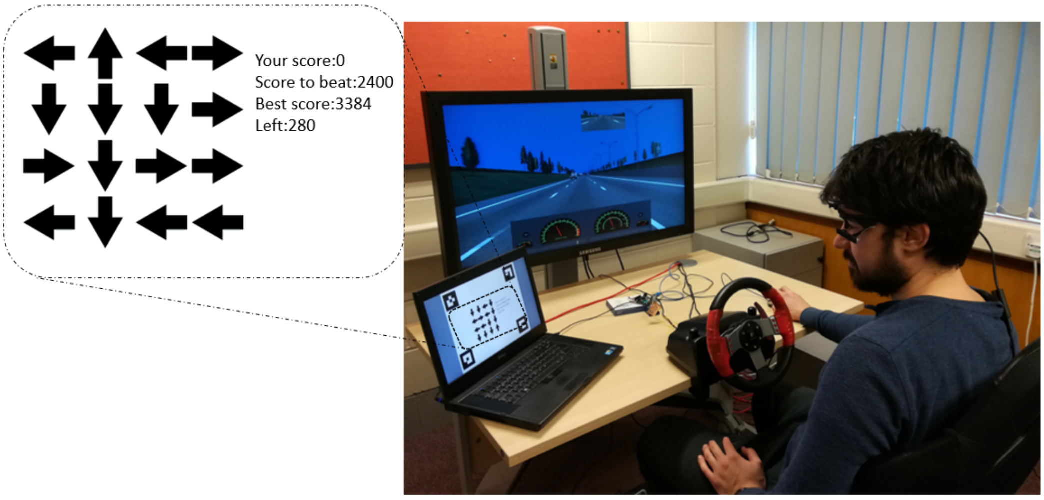

Figure 19: Experimental set-up. While in HAD, the laptop was used to present the arrow task.

3.2 Method

3.2.1 Participants

An ethics application was made for the project to the University of Leeds Research Ethics Committee and received approval on 8/02/2019. The application number was LTTRAN-099. Following approval, 16 participants (7 males) were recruited, ranging in age from 27 to 45 years (M = 33.1, SD = 5.3) via the driving simulator database. Participants had a valid driving license for more than 3 years and drove, on average, 8468 miles per year (SD = 2974). Participants were paid £20 each for taking part in a 2 hours study.

3.2.2 Equipment

For this study, the University of Leeds portable simulator was adopted (see Figure 30), which was operated on an HP Z400 workstation running Windows 7, using custom made software. The visual simulation was displayed on a Samsung 40" wide-screen 1920x1080 monitor, rendered at 60Hz. Vehicle control inputs were via a Logitech G25 dual-motor force feedback steering wheel and pedals. The portable simulator had been upgraded to provide a hands-detection signal, which, with a button depression, was used to trigger the handover. To record eye-tracking data, the Pupil Labs Core head-mounted eye-tracking device was used. Using a head-mounted set-up allowed tracking eyes movements even when the participants were not facing the monitor.

A laptop, placed on the side, was used to display the Arrow Task, a secondary task consisting on a manual-visual search of a “target” arrow (the one pointing upward) among a cluster of displayed arrows (Jamson & Merat, 2005). Following the participant’s selection of the target arrow, the successive search request started.

3.2.3 Experimental Design

A within-subject, repeated measures design was used, with all participants completing all conditions. The handover strategies varied the gradualness and authority of the haptic feedback and will be hereafter addressed as Immediate, Delayed, Delayed-Assisted and Assisted. Every trial was subdivided into sections, in which only a subset of Independent Variables was manipulated (see Figure 2). In Section 1 the Initiator (Driver Initiation - DI, Automation Initiation - AI); in Section 2 the type of Feedback (No feedback, Strong Lane-Keeping Assist (LKA), Lane Departure Assist (LDA)) and the Time Interval in which drivers experienced the above feedback (2, 7, 15 seconds); in Section 3 the presence of the Blind-Spot Assist (YES, NO); in Section 4 we analysed the aftereffects of the different strategies without any further manipulation. Every section was considered as a nested trial to study different aspects of the handover. A 4x3 counterbalanced design was adopted as the number of handover strategies times the number of Time Intervals. Initiators and Blind-Spot car were partially counterbalanced.

The experiment took place on a 3-lane motorway with a low traffic density and, throughout all the experiments, an Adaptive Cruise Control with a default target speed of 70 mph (112.7 km/h) as the maximum speed allowed on motorways in the UK, with a target headway fixed at 5 s, had been in charge of managing the longitudinal dynamics of the vehicle. The lateral controller acted, when active, as a LKA System and it maintained the vehicle in the centre of the occupied lane. HAD could be deactivated by requesting a handover. The transitions were not time-limited and drivers had to regain control of only the lateral dynamics of the vehicle; the Adaptive Cruise Control remained active. This approach was expected to reduce possible effects due to

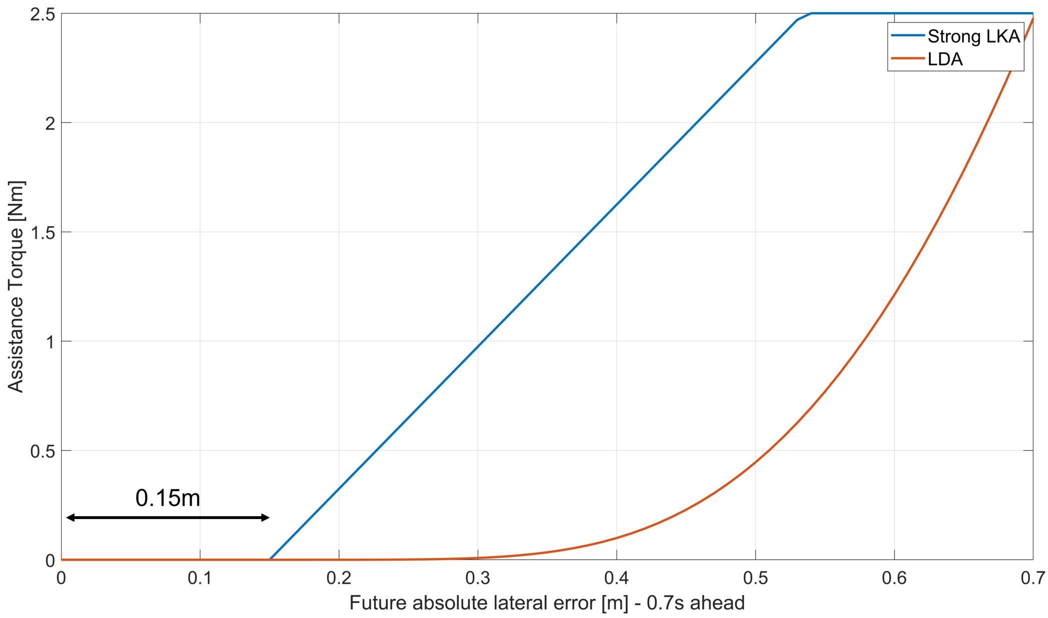

Figure 20: Illustration of the haptic lateral assistance systems. Both designed with a dead band of 0.15m around the reference position, i.e., the centre of the lane.

individual differences in speed selection. The reactivation of the ADS was fully automated: once the drivers removed their hands from the steering wheel the automation re-activated.

The handover strategies were designed to provide step-wise decreasing levels of assistance throughout the transitions (see Figure 21). In Section 2, the lateral assistance was in the form of a LKA with a strong steering authority for the Delayed and Delayed-Assisted strategies and a LDA for the Assisted (see Figure 20). In Section 3, Delayed-Assisted and Assisted provided an additional steering torque hindering drivers from steering when a vehicle was in the blind-spot.

3.2.4 Procedure

Before the experiment, all participants were briefed regarding the goal of the study, they were given the chance to read the Information Sheet and they signed a consent form. They were reminded that none of the transitions would be time-limited.

Hence, within the first 10 minutes, participants were given the chance to

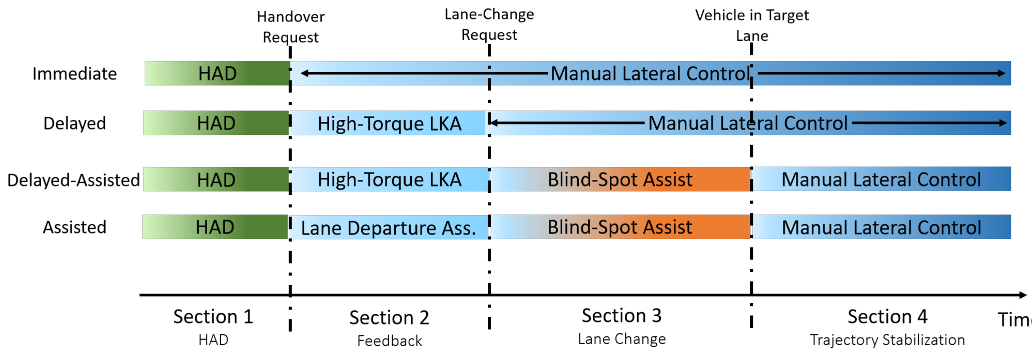

Figure 21: The handover strategies were designed so to have different authority levels during the handover as well as different supervisory roles afterwards. Every strategy varied the graduality with which the authority was relinquished back to the driver.

familiarize themselves with the simulator, the handover procedure and the arrow task. Following a short break after the familiarization, drivers started the experimental drive. The experimental drive consisted of 12 trials. Each trial started with 5 minutes of HAD while drivers were performing the arrow task. In AI cases, drivers were asked to take-over via the pre-recorded message: “Please, take over”. In DI cases, drivers were instructed during the familiarization that they had to take over by themselves once they completed 280 searches. The number of left arrow tasks was displayed but no take-over messages were prompted.

Once the handover had been requested (hands-on-wheel and button press), drivers experienced the different Feedback for 2, 7 or 15 s (according to the counterbalanced design). In Section 3, drivers had full lateral control with Immediate and Delayed handovers or Blind-Spot Assist with Delayed-Assisted and Assisted and were asked to change lane through a message displayed on the road. According to the counterbalanced design, while asking drivers to change lane, the simulation introduced a vehicle in the blind-spot of the target lane to test the effectiveness/vulnerability of the different strategies. Afterwards, they all had full lateral control and drove for 15 seconds before being asked to re-position the vehicle in the middle lane via a new visual signal. Once there, drivers were issued with a new acoustic signal informing them of HAD availability. Once drivers removed their hands from the steering wheel, they were asked to rate the experienced trial before reengaging with the arrow task so that a new trial could begin. Halfway through the experiment, drivers were asked whether they felt any discomfort and offered a short break before carrying on with the study.

The handovers were proposed so that each participant experienced the same strategy for three consecutive times (i.e. trials). This way it was possible to evaluate the learning trend and, through a post-condition set of questionnaires, investigate perceived workload, trust and acceptance of the single strategies.

3.2.5 Dependent Variables

The following metrics were collected for each condition per participant.

Re-engagement time was defined as the time elapsed between the issuing of TOR (for AI cases) or from the time instant drivers stopped performing the arrow tasks (for DI cases) and the handover request (hands-on-wheel and button press). Grab duration was defined as the elapsed time in which drivers were grabbing the steering wheel before requesting the handover.

Driving performance was measured by steering torque normalized over time, power of High-Frequency Steering Components (HFS) (see Figure 22 for raw data samples), Mean Lateral Position (MLP), defined as the distance of the ego vehicle Centre Of Gravity from the middle of the occupied lane, and its standard deviation (Standard Deviation of Lateral Position - SDLP). Increased steering torque is representative of steering conflicts between the driver and the ADS (Mars, Deroo, & Charron, 2014). Higher values of HFS (in band 0.3-0.6Hz) indicate a higher number of steering corrections (McLean & Hoffmann, 1973) and have been associate with an increase in task demand. Percentage towards Road Centre (PRC) was recorded as a measure of drivers' focus and measured as the percent dwell time spent focusing on the road ahead as defined in Carsten et al. (2012).

Continuous Subjective Ratings on a scale from 1 to 10 were collected after every trial to assess workload and comfort fluctuations (1 – Very Low to 10 – Very High). Every 3 trials, subjective workload scores were collected via

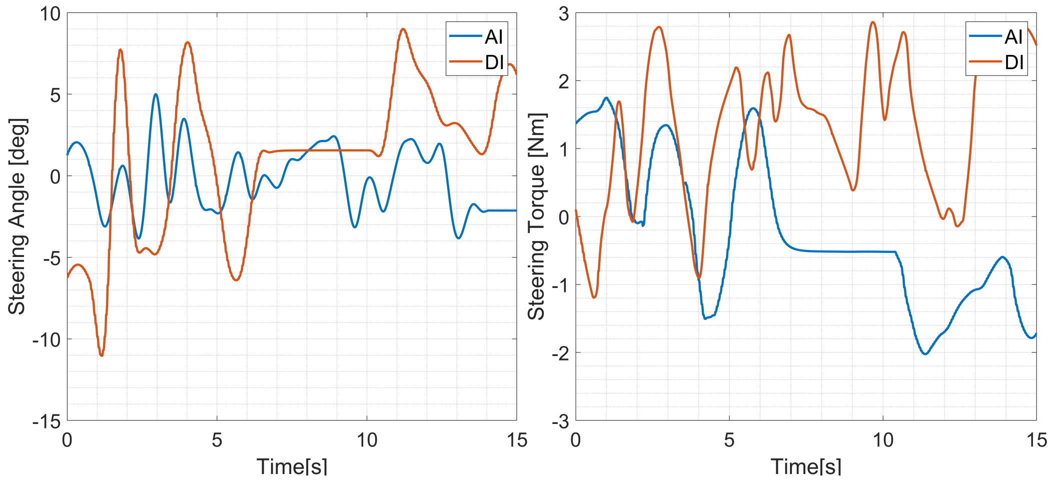

Figure 22: Data traces samples for steering angle (on the left) and steering torque (on the right) for Automation Initiated (AI) and Driver Initiated (DI) transitions.

the NASA-TLX subscales (Hart & Staveland, 1988) as well as trust (Jian et al., 2000) and acceptance (Laan et al., 1997). Moreover, drivers were asked to rate the perceived level of steering authority they had before the lane change request on a scale 1 (Not at all) to 7 (Absolutely).

3.2.6 Analysis

The data were compiled and metrics were calculated using MATLAB 2018a and analysed using IBM SPSS v24. Kolmogorov-Smirnov tests (Conover, 1999) were used to check for normality and, when necessary, non-parametric tests were adopted (Wilcoxon Signed Rank test instead of t-Tests) and effect sizes were calculated as $r = abs(Z/\sqrt{N})$ or transformations were made to perform parametric statistical tests (as ANOVA) and a partial eta-squared η_p^2 was computed as an effect size statistic (Fritz et al., 2012). To check and study possible interactions between independent variables and their relative effects on the dependent ones, repeated measures ANOVA was performed. An α-value of 0.05 was used as the criterion for statistical significance. Whenever Mauchly's test of sphericity was violated, degrees of freedom were Greenhouse-Geiser corrected. When relevant effects were found, pairwise comparisons (Bonferroni corrected) were performed as follow-up tests. Descriptive statistics and main results of the ANOVAs can be found in Table 10 and Table 4 respectively.

Table 3: Descriptive statistics and results of the conducted pairwise comparisons

Variable	DI case		AI case		t(df)	p	Cohen's d
	M	SD	M	SD			
Section 2							
Steering Torque - Strong LKA [Nm/s]	146.35	65.23	100.33	35.68	3.50(62)	< 0.01	2.43
Steering Torque - No feed/LDA [Nm/s]	92.39	29.65	87.14	38.87	0.61(62)	0.54	0.14
HFS	24.81	8.02	32.96	10.23	5.02(126)	< 0.01	0.88
PRC - Strong LKA [%]	73.65	20.61	64.83	20.93	1.70(62)	0.09	0.40
PRC - No feed /LDA [%]	69.81	17.96	70.24	21.71	0.08(62)	0.90	0.02
Section 4							
HFC	24.40	7.33	26.29	6.28	1.57(126)	0.049	0.28
MLP [m]	-0.12	0.25	-0.19	0.23	1.57(126)	0.08	0.29
SDLP [m]	0.34	0.09	0.36	0.15	0.74(126)	0.54	0.16
Questionnaires							
Continuous Subjective Ratings - Workload	4.80	1.84	4.42	1.92	1.15(126)	0.049	0.20
Continuous Subjective Ratings - Comfort	6.43	1.91	6.66	1.88	0.68(126)	0.21	0.12

Table 4: Main results of the conducted ANOVA tests.

Dependent Variable	F(df,Error)	p	η_p^2
Section 2 - Initiator effects			
Steering Torque	18.242(1, 15)	< 0.01	0.549
Power of High-Frequency Steering Components	50.096(1, 15)	< 0.01	0.770
Section 3 - Time Interval effect			
Crash-rate	9.750(2, 30)	< 0.01	0.394
Section 4 - Initiator effects			
Power of High-Frequency Steering Components	4.596(1, 15)	0.049	0.235
Mean Lateral Position	3.527(1, 15)	0.08	0.190
Standard Deviation of Lateral Position	0.391(1, 15)	0.54	0.025
Continuous Subjective Ratings - Initiator effects			
Perceived Workload	4.604(1, 15)	0.049	0.235
Perceived Comfort	1.743(1, 15)	0.207	0.104
Questionnaires - Handover Strategies effect			
Perceived Level of Control in Section 2	1.030(3,45)	0.388	0.064

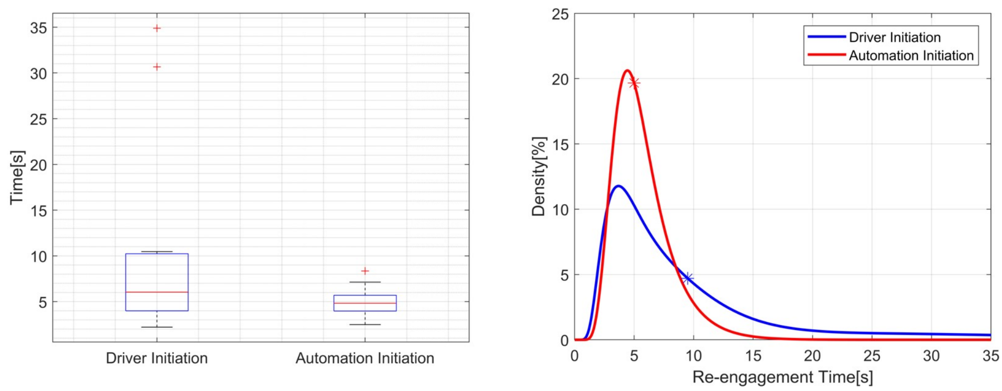

Figure 23: On the left, the re-engagement time (median line enclosed) and, on the right, its distribution (mean identified by the asterisks). Both differentiated by the type of initiation (DI and AI).

3.3 Results

A Wilcoxon Signed Rank test revealed (see Figure 23) a significant difference in re-engagement time between AI and DI cases ($Z = -1.965, p = 0.049, r = 0.49$). In DI cases, drivers took on average 9.51 ± 6.04 s to request the handover, whereas they took 4.98 ± 4.82 s in the AI cases (mean diff. $= 4.53$ s). In DI cases, on average, drivers spent 1.25 s longer with their hands on the steering wheel before requesting the handover ($t(15) = 2.332, p = 0.034$, Cohen's d $= 0.82$).

In Section 2, there was a significant interaction between Feedback and Initiator ($F(1,31) = 8.721, p < 0.01, \eta_p^2 = 0.220$). Drivers significantly reduced their efforts in AI cases (mean diff. $= 25.631$ Nm/s,$p < 0.01$). The steering torque was greater whenever drivers were initiators and the ADS was providing a strong LKA (mean diff. $= 46.02$ Nm/s,$p < 0.01$). Significant effects were also found on the HFS, which, overall, was significantly greater in AI cases (mean diff. $= 8.15, p < 0.01$). Trend-wise, PRC was 9.32% lower whenever the ADS was the initiator and retaining the largest authority share (see Figure 28).

Throughout Section 3, the Initiator did not significantly affect drivers' behavior. Follow-up tests revealed that, after Time Intervals of 15 s, the crash-rate, compared to the 2 s and 7 s cases, was reduced by 50% ($p < 0.01$) and

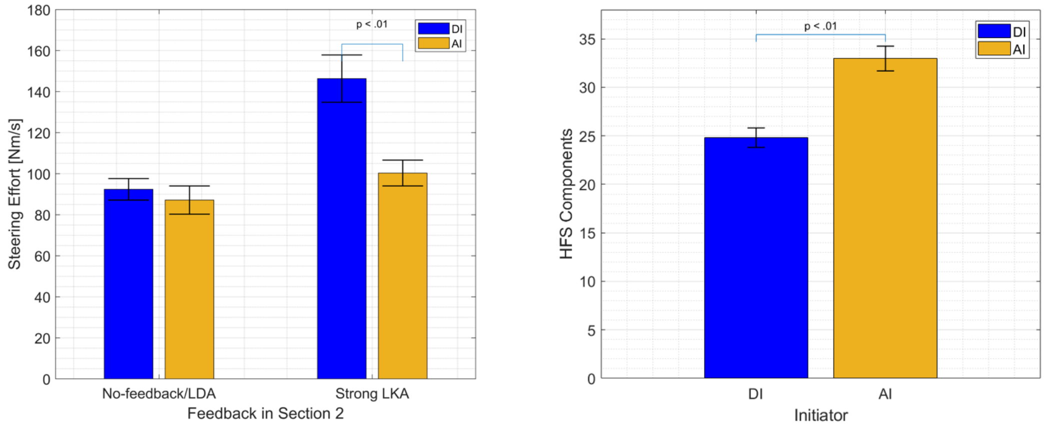

Figure 24: Section 2: on the left, the steering effort and, on the right, the HFS. Both are shown with the respective error bars (mean standard error) and the p-value from corresponding t-Tests.

32.5% ($p < 0.01$) respectively.

In Section 4, the HFS was significantly affected by the Initiator but the MLP and the SDLP did not show any significant effect. HFS was lower in DI cases (mean diff. $= 1.891, p = 0.049$) but drivers were better in keeping the vehicle closer to the lane centre. Moreover, SDLP was trend-wise lower, irrespective of the proposed strategy. On the other hand, in AI cases, 50% of participant showed higher SDLP values with the Delayed strategy.

The analysis of the Continuous Subjective Ratings for mental workload revealed the DI case was perceived more demanding (mean diff. $= 0.383, p = 0.049$). On the contrary, no significant effect was reported for the subjective comfort ratings. NASA-TLX ratings were not significantly affected by the different strategies and, moreover, none of them was significantly greater than the mid-scale point. Since the ratings were not statistically different from the mid-scale point, trust and acceptance questionnaires proved to be inconclusive. While experiencing different Feedback, drivers did not perceive any difference in their steering authority. Nevertheless, on average all the drivers reported themselves to be the agents with more authority (Mean $= 5.1094, SD = 1.323$), being the average value significantly greater than the mid-point (mean diff. $= 1.094, p < 0.01$).

3.4 Discussion

Drivers took between 2.73 s (5^{th} percentile) and 7.99 s (95^{th} percentile) (Mdn = 4.98 s) to re-engage the driving task after the prompt of a TOR (AI). In DI cases, although the 5^{th} percentile is close to that in AI cases (2.42 s), the 95^{th} is at 33.62 s and, on average, they took 9.51 s. 43% of drivers took longer than the 95^{th} percentile of the AI case and preferred to grab the steering wheel and wait, on average, 1.91 s before requesting the handover. A possible explanation is that drivers wanted to make sure they had proper contact with the interface before requesting the control. This suggests drivers, in DI cases, wanted to take time to make a subjective assessment of their own capabilities, which includes their awareness of the surrounding traffic and their capacity to keep the vehicle on a safe trajectory. The higher mental load reported after DI cases might be very well due to their commitment in taking over at the best of their capacities and supports Gold et al. (2016) argument. Knowing situation complexity (e.g. traffic condition) affects take-over time (Radlmayr et al., 2014; Gold et al., 2016), these results warrant further evidence: the increased complexity is expected to enhance the observed discrepancies between AI and DI cases but there is not enough evidence to back this hypothesis. Although artificial, the modality with which the DI transitions were triggered allowed a good level of controllability and, resembling the visual-manual surrogate reference task, was effective in ensuring drivers' dis-engagement with the driving task (Gold et al., 2013; Beller et al., 2013; Radlmayr et al., 2014; Lorenz et al., 2014).

Throughout Section 2, in AI cases, drivers reduced their steering torque of 46.02 Nm/s when the ADS was providing a strong LKA compared to DI cases. Under the same conditions, PRC was 8.82% lower, meaning drivers were actively diverting their attention from the centre of the current lane towards other areas, potentially increasing their knowledge of the surroundings and preparing themselves to step into a more pro-active behaviour. In AI cases, the lack of steering engagement led to an increase of the HFS (mean diff. = 8.15), due to the increasing number of correcting actions acted by the ADS while trying to mitigate drivers' poor control. Altogether, this might be indicative of drivers' engagement with the driving task or it might just suggest drivers thought steering authority lay in the initiator's hands. Accounting for the great capacity drivers have in adapting themselves to changes in haptic feedback (Russell et al., 2016), the discriminant factor for such behaviour seemed more likely to be the Initiator, hence the second hypothesis. Either way, drivers showed to be more engaged in DI cases and were less prone to be guided by the ADS.

The adopted simulator required drivers to rely on haptic feedback from the Blind-Spot assist. Although the obtained results might be affected by the visual impairment, from this study we saw drivers were able to understand the haptic feedback and hence, avoid the vehicle while changing lanes only when they had stayed in Section 2 longer. Although, at an operational level, drivers may show performance close to manual driving (Merat et al., 2014; Eriksson & Stanton, 2017a), at a tactical level they were still unprepared. This suggests, while designing handovers, control transition times should always be as long as possible. Of course, in AI transitions, this is a planning issue since the ADS will need to allow the most gradual shift of authority within the given time-budget. Due to the intrinsic nature of DI transitions, drivers might re-engage in conditions in which the ADS had not considered their interventions and this, in turn, might raise vulnerabilities on how the transition is handled and how an ADS could, or should, adapt itself to drivers' needs.

When it came to stabilizing the vehicle trajectory after the lane change, drivers' performance were the result of the engagement they showed in Section 2. In particular, in DI cases, the HFS was lower (mean diff. = 1.89), meaning drivers were using less corrective steering actions. Nevertheless, they were better in keeping the vehicle closer to the lane centre. Moreover, SDLP was trend-wise lower and not affected by the proposed handovers. In AI cases, the higher SDLP values with Delayed handover might be representative of the effects of a misunderstanding: drivers thought the ADS was in charge and, in turn, they let the ADS take care of the driving task but, once left in manual driving, unsupervised, some of them struggled to properly control the vehicle. Delayed-Assisted and Assisted handovers helped to mitigate the above providing further assistance and, in turn, increasing the gradualness of the authority shift. This, in turn, while supporting Flemisch et al. (2008) hypothesis, suggests that, especially in AI cases, handovers should make drivers more responsible for the vehicle motion to mitigate the effects of their reduced engagement. The level of responsibility seemed related to the actual authority allocation during the handover and, although drivers were very poor in assessing their own authority level (from questionnaires they reported they thought they always had the largest authority share), their behaviour showed otherwise. As already recognized (Mars, Deroo, & Charron, 2014), at a sensorimotor level, drivers were aware of their authority level and acted accordingly. Hence, as a result of the perceived higher steering authority, the reported mental demand increased.

3.5 Conclusion

This study found that drivers' behaviour throughout the transitions was heavily affected by their role as Initiator. Drivers' re-engagement time was not normally distributed, therefore car manufacturer should allow for a more flexible range of control transition times. Moreover, in DI cases, drivers stayed longer with their hands on the steering wheel and focused on the road ahead, which suggests drivers would be more perceptive towards Human-Machine Interfaces, leading their attention towards specific areas to raise their awareness.

Drivers increased their steering effort when they initiated the transition and the ADS was exerting a strong lateral control. Hence, proposing a handover with a strong steering authority should be limited to the AI cases only, since imposing it to drivers in DI cases turned out to be detrimental to both performance and driver' comfort. Nevertheless, in AI cases, handover designers should exploit drivers' visual engagement with the driving task, providing Human-Machine Interfaces to drivers who proved to be more prone to gaze wandering.

Results from the third section raised the importance of the supervisory role that the ADS should retain throughout every transition. Results showed drivers, even after 15 seconds, were struggling to understand the Blind-Spot assist. Hence, the ADS should make sure drivers receive contextual information in advance. Nevertheless, these results might have been heavily affected by the visual impairment due to the adopted simulator.

Results revealed that drivers' performance in stabilizing the vehicle trajectory were still linked to the perception of steering authority they had, and, in turn, to their initial role. Overall, drivers' performance benefitted from more gradual handovers. The sample size did not allow to test the effects of age and experience on re-engagement time and performance.

Since the transition time-budget is time-limited, future studies should investigate how to promote and hasten drivers' engagement with the driving task. Doing so in a handover should reduce the chances for unprepared drivers to be left unsupervised while they are not yet fully engaged.

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CHAPTER 4

Handing control back to drivers: exploring the effects of handover procedure during transitions from Highly Automated Driving

ABSTRACT The operational capabilities of automated driving features are limited and sometimes require drivers' intervention through a transition of control. Assistance at an operational level might be extremely beneficial during transitions but the literature lacks evidence on the topic. A simulator study was conducted to investigate the potential impacts that lateral assistance systems might have while the Automated Driving System (ADS) hands back control to the driver. Results showed that drivers benefitted from a strong Lane Keeping Assist during the first phase of the transfer, helping them to keep the lane centre. However, assisting the drivers at an operational level did not enhance their capability of addressing a more complex task, presented as a lane change. In fact, it was more task-specific assistance (Blind-spot assist) that allowed drivers to better cope with the tactical decision that the lane change required. Moreover, longer exposure to lane-keeping assist systems helped them in gaining awareness of the surrounding traffic and improved the way drivers interacted with the Blind-spot assist.

4.1 Introduction

Features enabling automated driving are classified as conditional or high automation (Society of Automotive Engineers, 2021), meaning that automation use is only safe within predefined conditions, usually referred to as an Operational Design Domain (ODD). As a vehicle in automated mode approaches these boundaries, a transition of control must take place and drivers' intervention is required. However, during automated driving, drivers are no longer involved in the direct control of the vehicle and their capacity to properly do so will deteriorate (Bainbridge, 1983; Flemisch et al., 2008; Kienle et al., 2009). This introduces safety threats for road users and poses the management of transition as a key factor to ensure safety on roads populated by autonomous and conventionally driven vehicles.

In literature, drivers' estrangement from the Dynamic Driving Task (DDT) has been addressed as the Out-Of-The-Loop (OOTL) phenomenon (Endsley & Kiris, 1995; Kaber & Endsley, 1997). The direct impact of being OOTL during transitions of control has been extensively studied (see Merat et al. (2019) for a comprehensive literature review), and the more concerning are deteriorated performance (Rose, 1989), loss of situational awareness (Endsley, 1988; Endsley & Kiris, 1995) and lack of readiness when prompted to respond (Martens & van den Beukel, 2013).

Research has been mainly focused on the investigation of the effects of warning signals, usually referred to as "Take-Over Requests (TORs)", during time-critical transitions, in which drivers are required to respond to a TOR within a limited amount of time (SAE Level 3). Drivers' behaviour has been analysed while varying different aspects around the TOR, including drivers' mental load before the TOR (Lu et al., 2017; Louw & Merat, 2017; Eriksson & Stanton, 2017a), demographics (Körber et al., 2016; Wright et al., 2016; Clark & Feng, 2017), TOR modality (Toffetti et al., 2009; Bahram et al., 2015; Naujoks et al., 2014; Lorenz et al., 2014; Telpaz et al., 2015; Petermeijer et al., 2017; Forster et al., 2017; Lu et al., 2019; Yun & Yang, 2020) and traffic conditions (Radlmayr et al., 2014; Gold et al., 2016).

Drivers have proven to benefit from multi-modal TORs, which better redirect their attention toward the impending hazard compared to the unimodal ones (i.e. audio, visual or tactile alone) (Toffetti et al., 2009; Naujoks et al., 2014; Petermeijer et al., 2017; Forster et al., 2017; Yun & Yang, 2020). Older drivers tend to benefit from longer take-over lead time (i.e. the time between the TOR and the de-activation of automation) (Körber et al., 2016; Clark & Feng, 2017) but, when requested to monitor the road, experienced drivers are better in anticipating hazards (Wright et al., 2016). Despite limited research, it has been demonstrated that taking over is compromised when an obstacle avoidance manoeuvre is required with increased traffic density (Radlmayr et al., 2014; Gold et al., 2016).

With SAE Level 4 automation, or Highly Automated Driving (HAD), drivers will not be required to take over after a limited amount of time as the ADS will be able to achieve a *minimal risk condition* (Society of Automotive Engineers, 2021). Indeed, granting longer take-over lead times improves drivers' behaviour and performance as drivers have more time to regain awareness and select the relevant actions to perform (Körber et al., 2016; Gold et al., 2016; Clark & Feng, 2017). However, this does not provide a solution to the loss of control skills (Zeeb et al., 2016; Eriksson & Stanton, 2017a; Vogelpohl et al., 2018). While taking over, drivers introduce instabilities (Kondo et al., 2019) and may require between 20 and 30 s to stabilize the vehicle trajectory (Merat et al., 2014; Pampel et al., 2019; Kim et al., 2021; Melnicuk et al., 2021). Further, driving assistance systems have been little investigated (Johns et al., 2018) despite their potential of easing the transition process (Walch et al., 2015). Driver assistance systems identifies automotive features that provides both momentary (e.g. LDA and Blind-Spot Assist) and sustained (e.g. continuous LKA) performance of part or all of the DDT (Shi et al., 2020).

In particular, Haptic Shared Control (HSC) has been proposed as an interesting solution (Flemisch et al., 2008). By acting directly on the control interface (i.e. the steering wheel), HSC could simultaneously provide both a lateral assistance and a gradual shift of control authority by just changing the amount of guiding torque. Lane Keeping Assist (LKA) and Lane Departure Assist (LDA) are Advanced Driver Assistance Systems (ADASs) providing haptic guidance, which have proven effective while helping drivers keep a safe trajectory in lower automation levels (de Nijs et al., 2014; Mars, Deroo, & Charron, 2014; Mars, Deroo, & Hoc, 2014; Nguyen et al., 2015; Nguyen et al., 2017). However, their impact during a handover of control is rather unexplored.

Summarizing the above, research lacks evidence concerning two fundamental aspects, which need to be examined: first, the importance of non-critical transitions, which in the future will likely constitute the most common transitions (Eriksson & Stanton, 2017b); second, the need for assistance at an operational and tactical level, to mitigate drivers' performance deterioration in the basic steering/braking operations. Past research showed that drivers take longer to resume control when no time pressure is imposed by the ADS (Eriksson & Stanton, 2017b), but giving drivers longer time windows to take over does not yield significant steering improvements at an operational level (Eriksson & Stanton, 2017a). The open question is whether drivers would be able or not to cope with a tactical decision right after the transition process. Assistance during a transition of control has been tested only within critical situations, in which a swift manoeuvre was required to avoid an obstacle or take an exit (Wada et al., 2016; Saito et al., 2018; Kondo et al., 2019). Whether the same assistance will yield the same results in non-critical situations is yet to be determined. Therefore, this study analysed the impact of different driver assistance systems during transitions between HAD and longitudinally assisted driving. The study aimed to answer the following research questions:

1. Does driver assistance improve drivers' performance during transitions of control?

2. Does assisting the drivers at an operational level (i.e. steering operation while keeping the lane) produce significant effects at a tactical level (i.e. the way drivers behave while changing lane)?

3. Does drivers' behaviour change depending on the period of exposure to lane-keeping assist systems?

Answering these questions would fill the outlined research gaps. First, it is important to determine whether drivers' loss of control skill can be mitigated by assisting them during transitions of control. The emphasis is on ensuring the safety of drivers even when they are exposed to automated driving for a long time, namely after periods in which drivers have not been actively involved with the DDT. Secondly, providing assistance at an operational level may not be sufficient. Drivers might need a more task-specific assistance to cope with tactical decisions (e.g. during a lane change or while taking an exit). As a final point, vehicles will not be able to handle every situation until some time in the future (TSC, 2017), and the assistance they can offer will be limited. Therefore, this study examined whether longer assistance enhances drivers' performance. This notion could be of great significance to the design of transitions of control, especially the definition of a suitable time budget.

4.2 Methodology

4.2.1 Participants

Following approval from the University of Leeds Research Ethics Committee, 16 participants (7 males) were recruited, ranging in age from 27 to 45 years (M = 33.1, SD = 5.3) via the driving simulator database. Participants were all familiar with the driving simulator. The number of participants for this study was decided after considering an α level of statistical significance of 0.05, a statistical power of 0.8 and an effect size estimate of 0.8 (large effect size). The magnitude of the effect size was chosen based on data collected during a pilot experiment. Participants had a valid driving license for more than 3 years and drove, on average, 8468 miles per year (SD = 2974). Participant reported they had prior knowledge of ADAS such as Adaptive Cruise Control (ACC) and Lane Keeping Assist (LKA) but hardly used them. Participants were paid £20 for taking part in a 2-hour study.

4.2.2 Apparatus

For this study, the University of Leeds portable simulator was adopted, which was operated on an HP Z400 workstation running Windows 7, using custom made software. The road ahead, the cluster and the rear mirror were displayed on a Samsung 40" wide-screen 1920x1080 monitor, rendered at 60Hz (see Figure 30). Steering control inputs and feedback were via a Logitech G25 dual-motor force feedback steering wheel (angular resolution 0.1 °, maximum torque 2.5 Nm). The rim of the steering wheel was upgraded to provide a hands-detection signal, which, with a button depression, was used to trigger the start of handovers, a "handover request". As opposed to high-fidelity simulators, where drivers tend to glance towards the road even if engaged with secondary tasks (Louw & Merat, 2017), the adopted desktop simulator forced

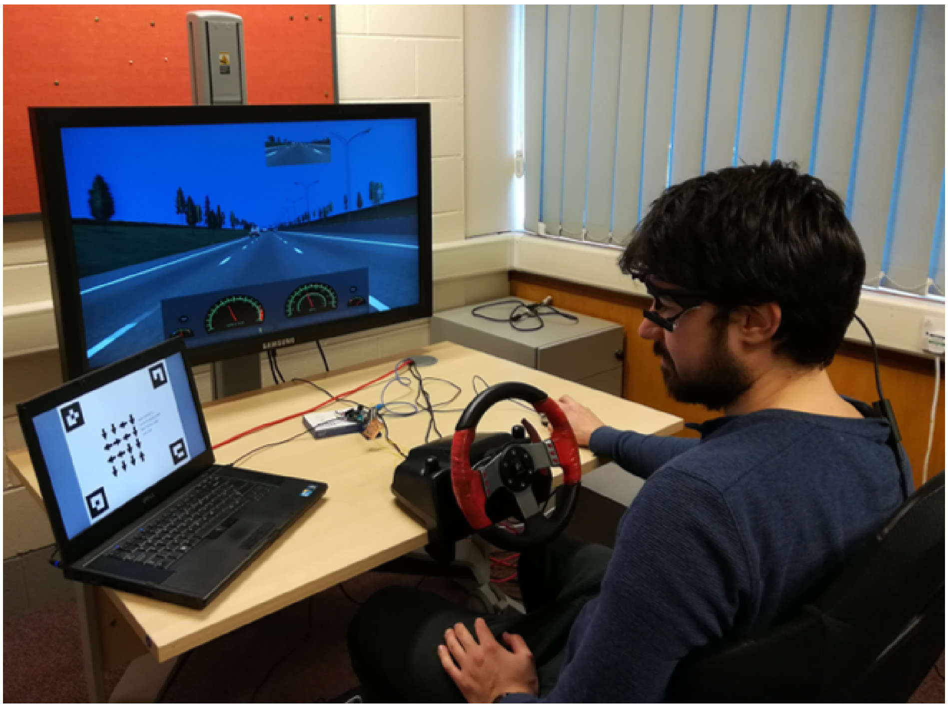

Figure 25: Experimental set-up. Samsung monitor (on the right) and laptop, with the displayed arrow-task (on the left).

participants to focus on another screen whenever automated driving was active. Secondly, the lack of visual cues (i.e. no side mirrors and no possibility to check above their shoulders) forced participants to exploit the provided haptic feedback. This was deemed ultimately beneficial as the main interest of this study was understanding the impact of haptic steering support. To record eye-tracking data, the Pupil Labs Core head-mounted eye-tracking device was used. Using a head-mounted set-up allowed tracking eyes movements even when the participants were not facing the monitor.

A laptop, placed on the left side, was used to display the Arrow Task, a secondary task consisting of a manual-visual search for a “target” arrow (the one pointing upward) among a cluster of displayed arrows. This task was previously adopted for past studies conducted within the University of Leeds Driving Simulator (Jamson & Merat, 2005; Merat et al., 2015; Kountouriotis et al., 2016). Following the participant’s selection of the target arrow, the successive search request started. To ensure consistency, pilot studies were made and a total of 280 searches was selected to ensure drivers did not finish the tasks in less than 5 minutes.

Pedals were not necessary because, throughout all the experiments, an ACC with a default target speed of 70 mph (112,7 km/h) and a target headway fixed at 5s, was in charge of managing the longitudinal dynamics of the vehicle. Lin et al. (2009) showed that, whenever the drivers are involved with secondary tasks with only ACC, headways of more than 2 seconds were beneficial to their perceived safety. Therefore, a larger headway was adopted to avoid participants feeling any discomfort caused by seeing a vehicle close by. The lateral controller acted, when active, as a Lane-Keeping System (LKS) and it maintained the vehicle in the centre of the occupied lane. HAD could be deactivated by requesting a handover (hands-on-wheel plus button press). The TOR consisted of a pre-recorded message ("Please, take over") and was provided such that the time the driver had, to stop playing the arrow task and request a handover, was not limited. Drivers had to manage the lateral control only since the ACC remained active. This approach was expected to reduce possible effects due to individual differences in speed selection (Gold et al., 2013; Radlmayr et al., 2014; Körber et al., 2016). Driver assistance was varied by changing the amount and type of guiding torque and the time interval drivers were exposed to these assistance. Steering support was expected to mitigate the safety risks related to the negative effects of long exposures to automated driving. These have shown to impair drivers' skills and reduce their capacity for controlling the vehicle (Bainbridge, 1983; Flemisch et al., 2008; Kienle et al., 2009). Indeed, drivers tend to introduce instabilities, which past studies have not related to any specific task (e.g. curve negotiation or evasive lane change). Furthermore, drivers' degraded control skills result in longer stabilization times (Merat et al., 2014; Pampel et al., 2019; Kim et al., 2021; Melnicuk et al., 2021).

4.2.3 Handover procedures

Hereafter, the set of assistances and their allocation during each trial will be referred to as handover procedures, identifying the way the ADS hands over control to drivers. Except for the baseline procedure (referred to as Immediate Handover), every other procedure consisted of two steps: the first aimed at providing drivers assistance in their lane-keeping task; the second aimed at helping drivers at a tactical level, specifically during a lane change.

Type 1 – Immediate Handover: representing the baseline condition, with this procedure, the lateral control was handed over as soon as the driver requested the handover through a fading function, which smoothly gave back the drivers full (lateral) authority in roughly a second. Following Kondo et al. (2019) findings, the fading function was necessary to avoid instabilities when transitioning from fully automated lateral control to no-assistance. In this case, the automation switched from SAE Level 4 to SAE Level 1 (with only ACC active).

Type 2 – Delayed Handover: the ADS retained the control of the vehicle for a predefined amount of time before releasing it to the driver. Hence, once drivers declared their intention to take over (by triggering the handover), the automation switched from SAE Level 4 (HAD) to SAE Level 2 (longitudinal assistance through ACC and a LKA that consisted of a lateral assistance with a high gain) first (step 1). The LKA provided a strong steering guidance but drivers had to place their hands on the steering wheel and re-engage with the steering task. After a predefined amount of time (discussed in the following section), the automation switched again from SAE Level 2 to SAE Level 1 (ACC only, step 2).

Type 3 – Delayed Handover with Blind-spot Assist: this procedure resembled the previous one but with an additional feature: a "Blind-spot Assist". Whenever the driver wanted to change lane and a vehicle in the blind-spot was present, the stiffness of the steering wheel increased so to hinder drivers' ability to steer toward the other lane. The amount of torque was limited so that drivers were able to overrule this assistance. As for the previous procedure, once the driver triggered the handover, the automation switched from SAE Level 4 (HAD) to SAE Level 2 (ACC and LKA- high gain) first (step 1). After a predefined amount of time, the automation switched to SAE Level 1 (ACC with Blind-spot Assist, step 2).

Type 4 – Assisted Handover: the last procedure consisted of an LDA, applied as soon as the driver requested the handover, and the same "Blind-spot Assist" as in the Type 3 procedure. Hence, once the driver triggered the handover, the automation switched from SAE Level 4

(HAD) to SAE Level 1 (longitudinal assistance through ACC and lateral assistance in the form of an LDA, step 1). Then, automation remained within SAE Level 1 (ACC and Blind-spot Assist, step 2). The Lane Departure Assist provided haptic feedback only when drivers were about to cross the lane markings but was not providing guidance as the LKA.

The re-activation of HAD was fully automated: once the drivers removed their hands from the steering wheel, HAD re-activated.

4.2.4 Procedure

Before the experiment, all participants were briefed regarding the goal of the study, they were given the chance to read the Information Sheet and they signed a consent form. To ensure drivers were fully aware of the experimental goals and procedure, they were reminded that none of the transitions would be time-limited and no critical occurrences would take place since, in case they delayed the take-over, the ADS would keep the vehicle on a safe trajectory within the current lane.

Within the first 10 minutes, participants were given the chance to familiarize themselves with the simulator, the handover request (i.e. hands-on and button press) and the arrow task, used as a secondary task to ensure a complete visual, mental and manual disengagement from the driving task while in automated driving. Gaze tracking data were checked to make sure drivers, while engaged with the arrow task, were not checking the road (i.e. Samsung monitor).

Following a short break after the familiarization, drivers started the experimental drive. The experimental drive consisted of 12 trials. Each trial started with 5 minutes of HAD while drivers performed the arrow task. After 5 minutes, a TOR was issued. After the TOR, drivers would stop performing the arrow task and request a handover without time restrictions.

Once the handover had been requested, drivers experienced different lane-keeping assistance, depending on the first step of the specific handover procedure. This assistance lasted for 2, 7 or 15 seconds (according to the counterbalanced design). After these time intervals, step 2 could take place. Hence, drivers had full lateral control with Type I and Type II handovers and assisted lateral control (via Blind-Spot Assist) with Type III and Type IV handovers

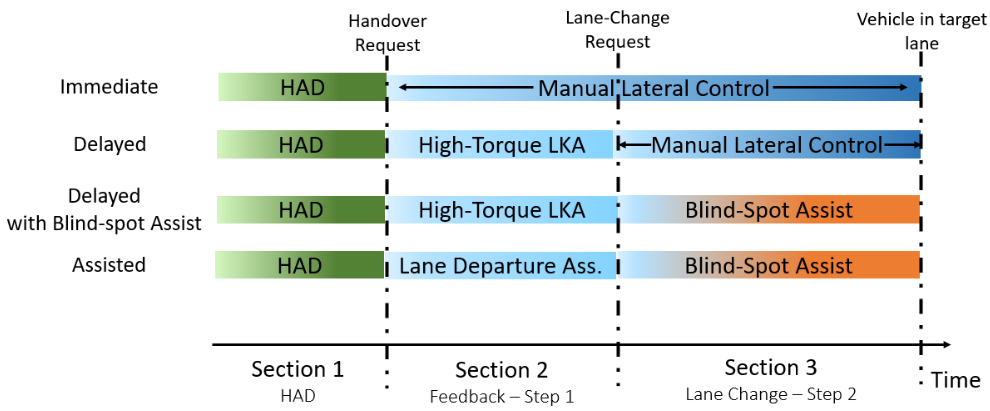

Figure 26: Subdivision of each trial (each experiment is composed of 12 trials).

and were asked to change lane through a message displayed on the road. In a randomized order, while asking drivers to change lane, the simulation introduced a vehicle in the blind-spot of the target lane (there were no side mirrors) to test drivers' capacity for cooperating with the ADS at a tactical level. After they changed lanes, they all had full lateral control and drove for 15 seconds before seeing a new visual signal informing them to re-position the vehicle in the middle lane. Once there, drivers were issued with a new acoustic signal asking them to remove their hands from the steering wheel. Once the drivers removed their hands from the steering wheel, they were asked to rate the experienced trial and, afterwards, to reengage with the arrow task so that a new trial could begin. Each trial lasted around 7 minutes, but it varied depending on drivers' take-over time, the duration of the assistance and the time drivers used to change lane.

Halfway through the experiment, drivers were offered a short break before carrying on with the study. The handover procedures were counterbalanced and drivers did not know which one was provided.

4.2.5 Experimental Design

A within-subject, repeated measures design was used to study the effects of different driver assistance with all participants completing all conditions. The independent variables were handover procedures (Type I, Type II, Type III, Type IV), Time Interval in which drivers experienced the above feedback, namely the time duration under step 1 (2, 7, 15 seconds) and initiation (driver-initiated or system-initiated). Within this framework, only system-initiated transition were considered. With driver initiated transitions, drivers did not receive any TOR but were given instructions to play the arrow task until they achieved a determined amount of searches. Then, they could request the handover by themselves (hands-on-wheel and button press). Driver initiated cases were not considered in the analysis because of the time variability with which participants decided to request the handover, which was significantly longer compared to the system-initiated cases. From past studies, this was unexpected. However, past studies have shown that giving more time to drivers affects their performance during the transitions (Gold et al., 2014; Körber et al., 2016; Gold et al., 2016; Clark & Feng, 2017) and, thus, a comparison was avoided. A counterbalanced design was adopted to reduce order effects.

For convenience, each run is subdivided into 3 sections (see Figure 26) to ease the discussion. In every section, there was only a subset of Independent Variables being manipulated. For the sake of clarity, these sections will hereafter be addressed to as:

First section: denoting the periods in which the vehicle was in automated driving and the drivers were engaged with the arrow task. This section ended when the driver, responding to a TOR, stopped performing the arrow task and requested a handover (hands-on-wheel and button press);

Second section: denoting the periods between the end of the first section and the start of the Lane Change Task (LCT), namely when the change lane request was prompted. Within this section, drivers experienced different haptic feedback according to the specific handover procedure (Step 1 of each procedure: No feedback, Strong LKA, LDA);

Third section: denoting the periods within which the lane change took place. In detail between the lane change request (i.e. end of the second section) and the moment in which the vehicle (all four wheels) was within the target lane. Depending on the handover procedure, drivers were assisted by the Blind-Spot Assist;

At the end of every trial, participants were asked to give ratings concerning the perceived comfort and workload.

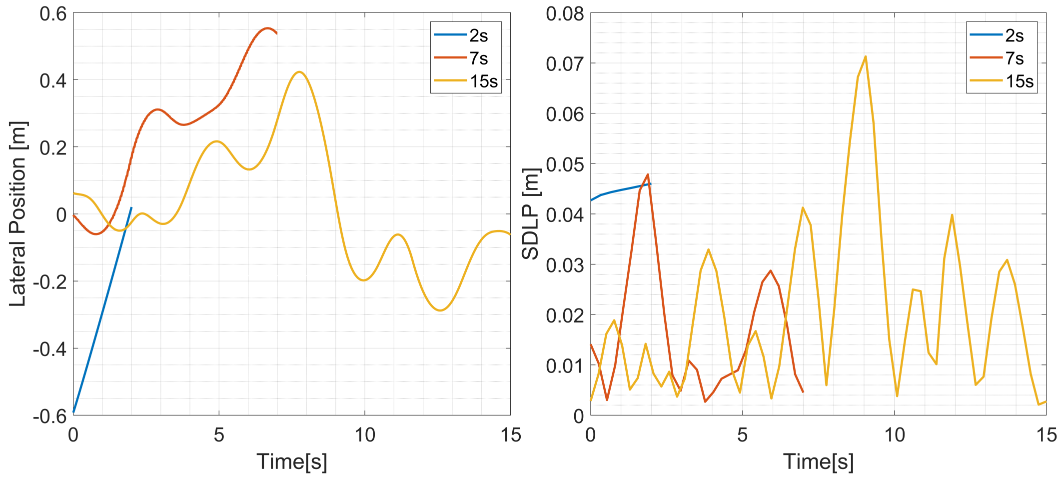

Figure 27: Sample traces over time of lateral position with respect to the lane centre (on the left) and SDLP (on the right) for the different time intervals (2s, 7s and 15s).

4.2.6 Dependent Variables

The following metrics were collected for each condition per participant. Mean values of each dependent variable were calculated for each section (as represented in Figure 26). Take-over time was defined as the time elapsed between the issues of TOR and the handover request (hands-on-wheel plus button press).

Driving performance was measured by steering torque normalized over time, power of High-Frequency Steering Components (HFS) and Standard Deviation of Lateral Position (SDLP). Within Section 2, SDLP was computed for the last 2 seconds for the sake of comparability. Given the mean lateral position is not expected to be zero (i.e., some drivers prefer staying closer to the left lane marking and some closer to the right one), the SDLP was expected to increase over time, thus resulting in larger values for longer handovers. Accounting for the last 2 seconds allowed the comparison of the effects of longer Time Intervals on vehicle stabilization (see Figure 27), removing the data duration dependency (Östlund et al., 2005). Percentage towards Road Centre (PRC) was recorded as a measure of drivers' focus as well as the frequency with which drivers' focus passed between Area-Of-Interests (AOI as defined in Carsten et al. (2012)). During assisted driving, conflicts between the driver and the ADS produce an increase of the steering torque (Mars, Deroo, & Charron, 2014), however, during transition of control, larger values might be indicative of a greater involvement in the steering control. A larger number of steering corrections results in higher values of HFS (in-band 0.3-0.6 Hz) (McLean & Hoffmann, 1973) and indicate a poor anticipatory control (Salvucci & Gray, 2004). Percentage towards Road Centre (PRC) was recorded as a measure of drivers' focus and measured as the percent dwell time spent focusing on the road ahead. Vehicle stability was monitored via Yaw Rate RMS (Wada et al., 2016).

During the lane change planning, thus before drivers initiated the lane change, Time-To-Lane-Crossing (TTLC) was measured as safety-performance metrics, in addition to the ones above. Although more commonly adopted as a performance metric (Gold et al., 2013; Radlmayr et al., 2014; Gold et al., 2016, 2018), Time-To-Collision (TTC) was not a suitable metric as the collision could happen while the drivers were changing lane and the blind-spot vehicle was in the blind spot. Similarly, the discrimination between braking and/or steering reaction could not be captured as the drivers were only able to steer. Given the absence of side mirrors, drivers could only rely on the haptic feedback provided from the Blind-spot assist or the assessment of the surrounding traffic they could make before the lane change request was issued. Therefore, taking longer before completing the manoeuvre, while keeping a safe distance from the lane markings, was adopted as an index of a better assessment of the blind-spot car location. Furthermore, the analysis of Percentage of gazes toward Rear Mirror (PRM) contributed to the study of gaze behaviour along with PRC and frequency of gaze movements. Crash events with the blind-spot vehicle and overall manoeuvre duration were also collected.

Workload and comfort subjective ratings on a scale from 1 to 10 were collected after every trial to assess workload and comfort fluctuations (1 – Very Low to 10 – Very High), resembling the Continuous Subjective Ratings (CSR) method (Teh et al., 2014).

4.2.7 Analysis

The data was compiled and metrics were calculated using MATLAB 2018a and analysed using IBM SPSS v24. Kolmogorov-Smirnov tests (Conover, 1999) were adopted to check for normality and, when necessary, non-parametric tests were adopted (Wilcoxon Signed Rank test instead of t-Tests) or transformations were made to perform parametric statistical tests. Effect sizes were calculated as $r = abs(Z/\sqrt{N})$(Fritz et al., 2012). Since only system-initiated cases were considered, 6 combinations of handover procedure and time intervals were missing (i.e., 96 out of 192 observations were analysed). In fact, all handover and time interval combinations were experienced by all participants. However, depending on the participant, half of these were experienced in the driver-initiated case only. Therefore, to check and study possible interactions between independent variables and their relative effects on the dependent ones, linear mixed models were used and an α-value of 0.05 was used as the criterion for statistical significance. The general form of a linear mixed model was adopted:

$$y = \mathbf{X}\beta + \mathbf{Z}u + \epsilon \tag{1}$$

where y is the observed measure, X is the vector of fixed effects, namely assistance of step 1 (Section 2) or step 2 (Section 3) of the handover procedures and time interval, Z is the vector of random effects (participants) and ϵ is the error. Covariance structures were tested (compound symmetry, unstructured, diagonal and Toeplitz) and compared using Akaike's Information Criterion (AIC). The lowest AIC values was achieved with a compound symmetry structure, which was then chosen for the marginal variance-covariance matrix, which assumes that the observations of the same subject have homogeneous variances and homogeneous covariances. Results of the models can be found in Table 5. R^2 was calculated as one minus the ratio between the sum of square of residuals and the total sum of squares and it considered the variance of both fixed and random effects. When relevant effects were found, pairwise comparisons (Bonferroni corrected) were performed as follow-up tests. Descriptive statistics can be found in Table 10.

Table 5: Parameter estimates and goodness of fit of the Linear Mixed Models.

Variable	Handover procedures				Time intervals				Fit
	Beta	SE	CI		Beta	SE	CI		(R^2)
			Min	Max			Min	Max	
Section 2									
Steering Torque [Nm/s]	7.21	4.19	-1.11	15.53	13.18	5.74	1.79	24.57	0.08
HFS	1.50	0.97	-0.44	3.44	-1.31	1.34	-3.98	1.34	0.04
SDLP[m]	-0.008	0.007	-0.21	0.006	-0.008	0.009	-0.027	0.011	0.02
PRC [%]	-0.46	1.91	-4.26	3.34	8.42	2.62	3.21	13.62	0.10
Gaze Feq. [AOI/s]	0.07	0.09	-0.11	0.26	-0.24	0.13	-0.49	0.02	0.04
Section 3									
TTLC [s]	0.09	0.06	-0.01	0.21	0.10	0.08	-0.05	0.25	0.05
SDLP [m]	-0.015	0.014	-0.04	0.013	0.46	0.02	0.01	0.08	0.07
Maneuver duration[s]	-0.71	0.91	-2.51	1.09	-0.54	1.25	-3.02	1.93	0.01
Crashes [%]	0.02	0.04	-0.05	0.10	-0.25	0.05	-0.34	-0.13	0.18
PRM [%]	-0.29	1.65	-3.57	2.98	-0.55	2.26	-5.04	3.93	0.01
Gaze Feq. [AOI/s]	-0.14	0.08	-0.29	0.015	-0.16	0.11	-0.38	0.05	0.06
Questionnaires									
CSR - Workload	-0.15	0.19	-0.53	0.22	-0.06	0.26	-0.57	0.45	0.01
CSR - Comfort	0.07	0.18	-0.29	0.44	0.09	0.25	-0.41	0.59	0.01

CI, Confidence Interval; SE, Standard Error.

Table 6: Descriptive statistics (Means (M) and Standard Error (SE)) and results of the linear mixed models (F-value, numerator degree of freedom - dN, denominator degrees of freedom - dD and p-value).

Variable	2 s		7 s		15 s		F(dN,dD)	$p-value$
	M	SD	M	SD	M	SD		
Section 2								
Steering Torque [Nm/s]	86.06	7.73	98.08	7.73	112.42	7.73	2.92(2,84)	0.06
HFS	30.26	1.70	35.60	1.7	27.62	1.70	5.68(2,84)	0.005
SDLP [m]	0.11	0.013	0.1	0.013	0.09	0.013	0.38(2,84)	0.69
PRC [%]	60.27	3.54	70.78	3.54	77.11	3.54	5.75(2,84)	0.005
Frequency of Gaze Movements [AOI/s]	1.70	0.17	1.51	0.17	1.23	0.17	1.93(2,84)	0.15
Section 3								
TTLC [s]	2.43	0.11	2.60	0.11	2.64	0.11	0.98(2,84)	0.38
SDLP [m]	0.52	0.027	0.58	0.027	0.61	0.027	3.16(2,84)	0.048
Maneuver duration[s]	9.38	1.77	12.05	1.77	8.30	1.77	1.19(2,84)	0.31
Crashes [%]	46.9	6.9	40.6	6.9	16.6	6.9	13.66(2,84)	< 0.001
PRM [%]	28.76	3.06	34.19	3.06	27.65	3.06	1.31(2,84)	0.27
Frequency of Gaze Movements [AOI/s]	1.77	0.15	1.49	0.15	1.44	0.15	1.33(2,84)	0.27
Questionnaires								
CSR - Workload	4.19	0.36	5.03	0.36	4.06	0.36	2.10(2,84)	0.13
CSR - Comfort	7.06	0.34	5.81	0.34	7.25	0.34	5.40(2,84)	0.006

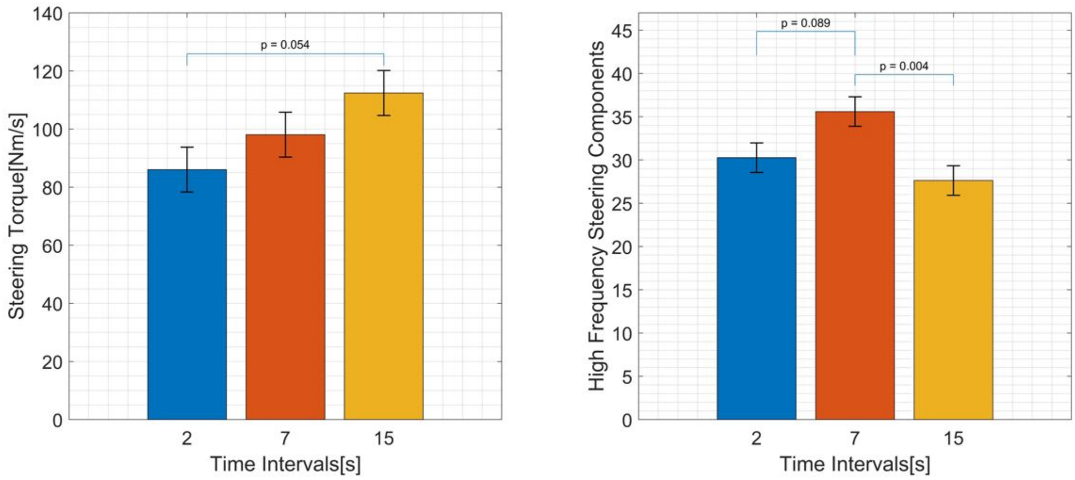

Figure 28: Section 2 - From the left, the steering torque and the High Frequency Steering Components (actual means). All represented with the respective error bars (mean standard error) and significance (Bonferroni-corrected). The reported means represent the means of the combined support modes (i.e. haptic feedback) for each Time Interval (2 s, 7 s and 15 s).

4.3 Results

In Section 1, drivers took between 2.94 s (10^{th} percentile) and 10.38 s (90^{th} percentile) to reach the steering wheel and request the handover with a few drivers taking up to 28 s. On average, drivers took 4.98 s ± 1.50 s to request the handover but the distribution was not normal. The 50^{th} percentile was 4.82 s whereas the reported mean value represents the 60^{th}.

In Section 2, significant effects of lateral assistance on vehicle yaw rate RMS ($F(3, 84) = 7.32, p < 0.01$) were found. A strong LKA kept vehicle yaw rate RMS to lower values compared to the No-feedback and LDA (mean diff.= 0.009 rad/s, $p < 0.01$). Within the last 2 seconds, SDLP also benefitted from a strong LKA and showed lower values compared to the no-feedback/LDA cases (mean diff.= 0.037 m, $p = 0.11$). The steering torque increased with longer Time Intervals and post hoc tests revealed the values reported with the 15 s interval were higher than the ones reported with the 7 s interval (mean diff. = 14.34 Nm/s, $p = 0.579$) and with the 2 s interval (mean diff. = 26.36 Nm/s, $p = 0.054$). Significant effects of Time Interval on HFS were found ($p < 0.01$). HFS values showed a minimum with the 15 s intervals, which follow-up tests revealed to be significantly different compared to the values at 7 s (mean diff. $= 7.97, p = 0.004$) (see Figure 28). In the last 2 seconds of Section 2, SDLP was lower with longer Time Intervals. Time

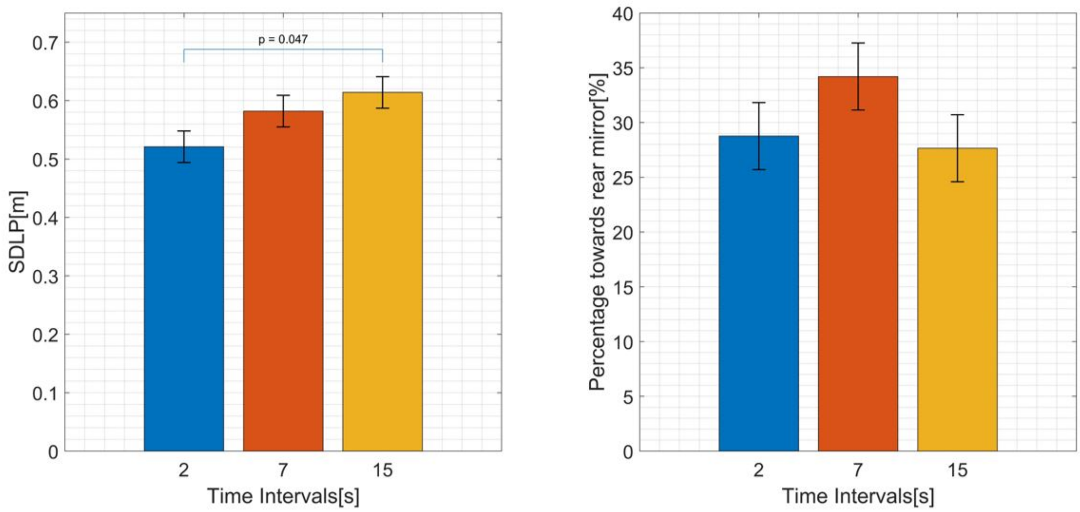

Figure 29: Section 3: Lane Change - From the left, the SDLP and the Percentage of gazes toward the rear mirror (actual means). All represented with the respective error bars (mean standard error) and significance (Bonferroni-corrected). The reported means represent the means of the combined support modes (i.e. haptic feedback) for each Time Interval (2 s, 7 s and 15 s).

intervals had significant effects on PRC ($p < 0.01$). Although PRC was greater with longer intervals, the frequency of gaze movements showed a different trend with higher values in the 2 s, and then decreasing with longer Time Intervals.

During the lane change planning, a significant effect of Time Interval on SDLP ($p = 0.048$) was found. After the 15 s time intervals, SDLP was significantly larger than the 2 s (mean diff. = 0.093 m, $p = 0.047$) ones. Trend-wise, TTLC increased with longer time intervals, reaching a peak after the 15 s intervals of 2.64 ± 0.11 s.

Drivers took longer to change lane after the 7 s intervals than the 2 s ones (mean diff. = 2.66 s, $p = 0.87$) and the 15 s (mean diff. = 3.74 s, $p = 0.41$). Although quicker in completing the lane change, the number of crashes with the blind-spot car were significantly fewer after the 15 s cases than the 2 s (mean diff. $= 30.3\%, p < 0.01$) and the 7 s ones (mean diff. $= 24\%, p < 0.01$). The frequency of the gaze movements decreased after longer time intervals. The rear mirror was checked more after the 7 s intervals with respect to the 2 s ones (mean diff. $= 5.43\%, p = 0.64$) and the 15 s ones (mean diff. $= 6.54\%, p = 0.40$) (see Figure 29).

Although comfort ratings were not significantly affected by the handover procedures, they were found to be significantly affected by the Time interval that drivers were exposed to the lane-keeping assistance ($p < 0.01$). In detail, drivers were less comfortable with the 7 s cases compared to the 2 s (mean diff. $= 1.25, p = 0.03$) and 15 s ones (mean diff. $= 1.44, p = 0.01$).

4.4 Discussion

We found drivers took between 2.94 s and 28 s to reach the steering wheel and request the handover. Albeit these might be considered outliers, the non-normality of drivers' re-engagement time, as highlighted by Eriksson & Stanton (2017b), enforces the importance of having driver monitoring systems, which could help the transition planning. Some solutions, based on the estimated drivers' readiness to intervene, have already been proposed (Zeeb et al., 2015; Mioch et al., 2017) and could be adopted to allow a longer transition time budget, able of accommodating the entire spectrum of re-engagement times.

In the second section, results showed that having a strong-LKA provided a more stable and smooth control initially. Over time, drivers increased the exerted steering torque from $86 Nm/s$ (2 s intervals) up to $112 Nm/s$ (15 s intervals) and the HFS significantly decreased, suggesting drivers were focusing more on their anticipatory steering. Consequently, the resulting SDLP values in the last 2 seconds were lower with longer Time Intervals. Considering the recorded discrete trend, drivers started engaging the driving task somewhere between 2 and 7 seconds. Results suggested that drivers, within the first seconds, were merely there, redirecting their mind-state to the new task at hand but not truly engaged with the vehicle control. In fact, drivers' inputs with 2 s intervals were very limited.

Drivers' visual engagement followed the same trend; PRC increased with longer intervals and its values plateaued around 74% with 7 s and 15 s, against 60% with the 2 s intervals. Although this result might be due to the short time window, the frequency of gaze movements showed drivers relaxed their visual scanning over time. This might suggest drivers sacrificed their operational control in favour of a first scan of the surrounding; once they believed they collected enough information, they started redirecting their mental resources from the visual scanning of the road to the physical control of the vehicle. Nevertheless, accounting for past studies (Radlmayr et al., 2014; Gold et al., 2016), this might change with task difficulty; in this case, the task was limited to a lane-keeping task in a low-density traffic scenario. The introduction of a more dense and changing traffic could push drivers to overlook their compensatory control in favour of a more attentive focus towards impending and potential threats.

Irrespective on the type of feedback drivers received within the second section, their capacity to effectively cooperate with the ADS at a tactical level in the third section was related only with the duration of the previous one (i.e. Time Intervals). In particular, the longer the time intervals, the greater the drivers' success rate in changing lane without crashing into the blind-spot vehicle. This suggests that giving the drivers the chance of self-regulating the transitions did not bring any benefit. As reported in past studies, drivers might show at an operational level, namely in the lane-keeping task, performance close to manual driving (Merat et al., 2014; Eriksson & Stanton, 2017a), but, at a tactical level, they were still unprepared. While planning the lane change after the 7 s time intervals, drivers kept the vehicle on a safer trajectory maintaining a higher TTLC (around 2.6 s) but increasing their "weaving" (i.e. SDLP) possibly with the intent of exploiting more of the displayed rear mirror, which was checked significantly more compared to after the 2 s and 15 s intervals. The number of crashes was 24% less after the 15 s intervals compared to the 7 s. These results support what was suggested in the second section: after 7 s drivers were still redirecting their resources from the visual scanning to the physical control of the vehicle but the lane change request possibly hindered this process and forced them to start scanning the environment once again.

Comfort ratings revealed drivers were significantly less comfortable after 7 seconds of lane-keeping assist. Given the past discussion, it might be possible this comfort drop was because drivers, after 7 seconds, were in the middle of their re-engagement process and they were not ready to take care of the lane change.

Answering the initial research questions, drivers definitely benefitted from assistance during the transition; a strong LKA reduced the instabilities drivers tend to introduce when taking over (Kondo et al., 2019). However, assisting the drivers at an operational level did not enhance their capability of addressing a more complex task, presented here as a lane change. Thus, drivers need a more task-specific assistance to better cope with the tactical decision a lane change requires.

Interestingly, drivers also evolved the way they interacted with assistance over time. From step 1 of lateral assistance, drivers' steering activity increased between 2 and 7 seconds before plateauing between 7 and 15 seconds. Drivers' visual scanning, on the contrary, followed an inverse trend, showing its peak in the first 2 seconds. The time drivers were exposed to a simple lane-keeping assistance also influenced their ability to interact with the Blind-spot assist. Drivers were more successful after longer exposure and comfort ratings suggested that interrupting lane-keeping assistance around 7 s was causing a comfort drop, potentially because the ADS interrupted their re-engagement process when it was at its peak.

The variance explained by the factors time interval and handover procedure was limited (low R^2 values). However, in certain cases, the factors has a significant impact on the dependent variable. Overall, this represents a good starting point as it provides the first piece of evidence that the provided handover procedures had an impact in shaping drivers' response. However, the outlined model needs further refinements.

4.5 Conclusion

This study presented evidence on the benefits of driver lateral assistance systems after non-critical transitions of control from HAD to longitudinally assisted driving. Drivers benefitted from lane-keeping assist only if the ADS was providing such support for more than 7 seconds after the handover request. Providing shorter lane-keeping assistance proved ineffective in reintroducing drivers to the driving task and made it harder for them to cope with the lane change. Drivers seemed to use the first seconds after they reached the steering wheel to scan the surrounding and assess the situation at hand. Only after this process ended, between 2 and 7 seconds after the handover request, drivers started to increase their steering activity. Assisting the drivers for 7 seconds, forced them to stop scanning the environment to take care of the lateral control. This made them report lower comfort ratings compared to the 2 and 15 seconds assistance, where the scanning process had barely started or was already completed.

While investigating the impact of lateral assistance during drivers' take-over, this study demonstrated that the use of haptic-shared control can enhance vehicle and steering stability during transitions of authority. Although promising, these enhancements in the first period of the transition were not sufficient to ensure drivers' re-engagement with the driving task. Evidence suggested that, for drivers to be engaged, the ADS should provide lateral assistance for at least 7 seconds. The penalty for shorter times would be either drivers' discomfort or lack of sufficient engagement with the driving task. Results pointed out some related issues, spanning from the transition time-budget to the Human-Machine-Interfaces (HMIs) that could improve drivers' interaction with the provided assistance. Providing assistance after the drivers have grabbed the steering wheel requires that the ADS is capable of doing that, namely that the time-budget includes a time interval long enough to be able to provide such assistance before leaving its ODD. The adoption of HMIs clarifying the state of the ADS and the type of assistance might ease drivers' reintegration.

Hence, while highlighting these issues, this study aimed to underline the importance of considering the transition of control as a feature, in which drivers' behaviour is as important as the assistance that the ADS provides to the drivers.

4.6 Limitations

The study has the following limitations. First, the adopted simulator did not allow participants to fully scan the environment as they normally would have. Participants were unable to visually check for vehicles in the blind spot, hence they were forced to rely on the haptic feedback provided by the ADS which possibly increased their "weaving" towards the target lane to exploit the rear mirror. It has been proven that the visual cues given by the side mirrors and the chance of looking over the shoulder are important information drivers use to plan a lane change manoeuvre (D. Salvucci et al., 2001; D. D. Salvucci & Liu, 2002; Doshi & Trivedi, 2009; Guo et al., 2014), hence it is certain that providing the drivers with such cues would influence the reported results.

The presented simulation consisted of a low-density traffic scenario. Research has proven that traffic density has a great impact on drivers' behaviour during a transition (Radlmayr et al., 2014; Gold et al., 2016), thus more dense traffic could have affected the obtained results. Similarly, ACC headway was chosen to be larger than what is currently available in fielded vehicles (1-3 seconds). Shorter headways, closer to the commercially available ones, might cause changes in drivers' safety perception (Lin et al., 2009) and post-transition behaviour (Louw et al., 2020).

The limited size of the sample did not allow further investigation of whether drivers' age, gender and experience could affect how drivers interact with the presented lateral assistance. Accordingly, it is necessary to expand upon the outlined model by including additional factors that could contribute to the explanation of the dependent variables. Factors such as age, gender, experience and attitude towards driving assistance systems and automated driving might produce a more effective model.

4.7 References

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CHAPTER 5

The effect of inconsistent steering guidance during transitions from Highly Automated Driving

ABSTRACT This driving simulator study investigated the effect of inconsistent steering guidance during system and user-initiated transitions from Highly Automated Driving (HAD). In particular, the aim of the study was to understand if steering conflicts could be achieved by adopting inconsistent steering guidance and whether these conflicts could be exploited to accelerate drivers' steering engagement within a limited time. Inconsistent steering guidance was generated by switching the guidance on and off at 3 different frequencies (0.1, 0.2 and 0.3 Hz). Results revealed that steering engagement has more to do with the initiation rather than the quality of the steering guidance. In fact, drivers were more engaged with the steering task when they initiated the transition themselves. Compared to system-initiated transitions, in user-initiated ones, drivers exerted stronger steering inputs throughout the transition, which allowed them to maintain larger Time To Lane Crossing (TTLC) values with fewer steering corrections. During system-initiated transitions, drivers started to actively engage with the steering activity only after more than 5 s from the start of the transition but were able to achieve a steering behaviour close to the one shown during user-initiated transitions at 10 s.

5.1 Introduction

The past decade has seen a fast shift from cars equipped with lower automated systems, introduced to assist drivers operation, to ones with higher automated systems aimed at substituting the role of the human driver for a significant part of the trip. In their new role, drivers become passengers as they will not be required to drive as often. Indeed, drivers will be required to step back into control only when the Automated Driving System (ADS) issues a direct request-to-intervene (RtI) or when they decide to resume control themselves, perhaps to satisfy their desire to drive once more, giving place to a system-initiated and user-initiated transition of control from automated to manual driving (ISO/TR 21959-1:2020, 2020).

Irrespective of the type of initiation, drivers, while resuming control, undergo four actions (Petermeijer et al., 2016):

1. shift their visual attention to the road;
2. gather information and grow awareness of the surrounding, developing a strategy (i.e. list of operations to be undertaken);
3. re-engage with the control interfaces (i.e. steering wheel and pedals);
4. perform the chosen strategy by acting on the interfaces.

To try and solve drivers' lack of control skills after prolonged exposure to HAD, some system designers decided to reintroduce drivers only at a tactical level. Therefore, the drivers are informed of the manoeuver to be taken and the ADS performs it (Walch et al., 2017, 2018). The intrinsic limitation of this strategy is that it is only feasible as long as some levels of automation are still available, otherwise drivers will also have to take back physical control of the vehicle.

Rather than trying to remove driver physical control, other studies have tackled the issue by considering the transition process as a source of cognitive load for drivers, which needs to be lightened. Considering a fixed driver mental capacity, the transition process imposes a load on drivers depending on the complexity of the scenario (Radlmayr et al., 2014; Gold et al., 2016) and on the time drivers are given to resume control and manage the situation (Bahram et al., 2015; Petermeijer et al., 2017; Forster et al., 2017). Therefore, Human-Machine Interfaces (HMI) have been proposed to hasten drivers' visual attention and facilitate the information gathering (Radlmayr et al., 2014; Bahram et al., 2015; Petermeijer et al., 2017; Gold et al., 2016; Körber et al., 2016; Wright et al., 2016; Eriksson & Stanton, 2017b; Forster et al., 2017; Lu et al., 2017; Louw & Merat, 2017; Eriksson & Stanton, 2017a).

Hardly any interest has been paid to aiding drivers' operational control.

Understanding drivers' behaviour in user-initiated transitions is important to ensure the safety and smoothness of the transitions and avoid that an unexpected ADS behaviour causes discomfort. However, user-initiated transitions will be mostly self-paced transitions, in which no sudden intervention is needed. On the contrary, during system-initiated transitions, drivers' steering and/or longitudinal control response (i.e., braking or accelerating) will usually be required within a limited amount of time. In fact, a RtI could be due to missing road markings, which would prevent the correct functioning of the automated drive, or to works in progress on the road. Assuming a mature technology, these cases will not require sudden interventions (SAE Lv. 4) but they will require drivers to have a good operational control to avoid these occurrences becoming threats to road safety.

This study investigated handover procedures designed to introduce steering conflicts during transitions of control. The goal was to exploit steering conflicts to instigate drivers' steering engagement. In a previous study, it was demonstrated that conflicts could be beneficial after a period of drivers' disengagement from the DDT but, after system-initiated transitions, drivers seemed prone to follow the steering guidance rather than engage themselves in the lateral control. Following the assumption that steering conflict could then be triggered by creating confusion over who, between the driver and the ADS, is in charge of steering (Mars, Deroo, & Hoc, 2014; Mars, Deroo, & Charron, 2014), the handover procedures used here provided an inconsistent haptic guidance, namely an haptic assist which was working only intermittently. Hence, this study tried to answer the following research questions:

1. Can steering conflicts be achieved by means of an inconsistent lateral guidance?

2. Do steering conflicts accelerate drivers' steering engagement after system-initiated transition and user-initiated ones?

3. Are 10 seconds of assistance sufficient to guarantee drivers' steering engagement?

Figure 30: Cab interior of the UoLDS with presented motorway scenario (left). The left side of the cluster was presenting the speedometer while the right side was used to display ADS status. When blank (as in the left picture) HAD was off. When drivers were in HAD, the cluster displayed the picture on the top-right corner. On the bottom-right corner, the presented arrows task displayed on a touch-screen tablet placed on the left side of the driver.

5.2 Materials and methods

5.2.1 Participants

Following approval from the University of Leeds Research Ethics Committee, 18 participants (10 males) were recruited, ranging in age from 26 to 50 years (M = 37.1, SD = 8.2) via the driving simulator database. Participants had a valid driving license for more than 5 years and drove, on average, 11305 miles per year (SD = 9703). Participants were paid £20 each for taking part in a 1 and a half hour study.

5.2.2 Apparatus

This study was carried out on the University of Leeds Driving Simulator (UoLDS) (see Figure 30). The UoLDS consists of a Jaguar S-type cab with all driver controls operational. The vehicle is housed within a 4 m diameter spherical projection dome and has a 300° field-of-view projection system. In order to provide a Hands-on-the-wheel signal, the vehicle was equipped with the Autoliv zForce steering wheel (Autoliv, 2016), equipped with a set of 64 infrared sensors on the rim. Hands-detection along with a pull of the left-side stalk were the means for the drivers to trigger the handover request.

A touch-screen monitor was provided to let drivers play the Arrows-Task

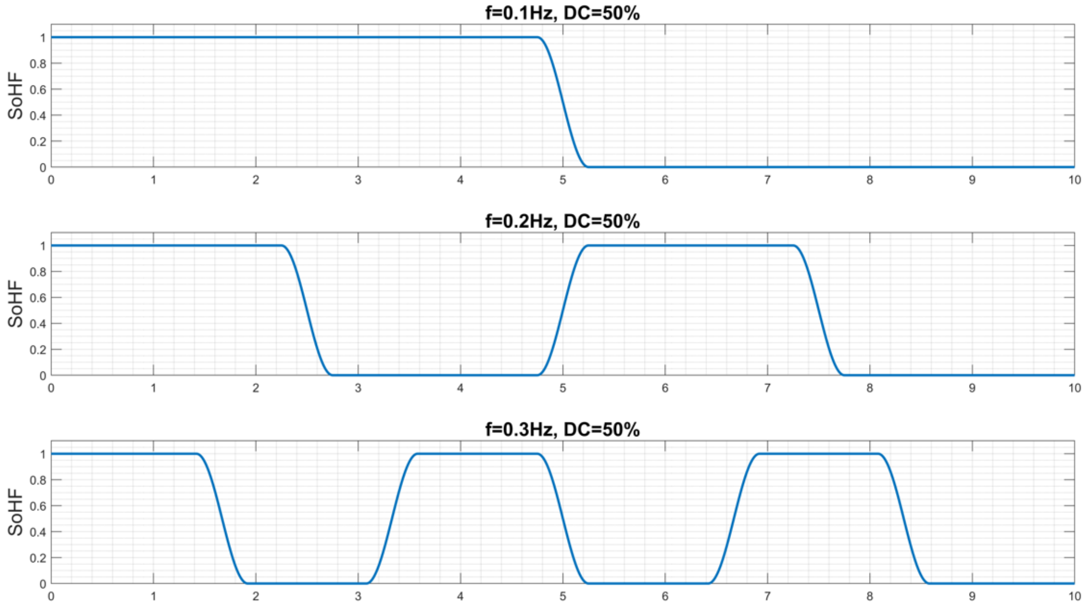

Figure 31: Varying frequencies strength of haptic feedback (normalised).

(Jamson & Merat, 2005) while in automated driving, to ensure a complete visual-mental-physical disengagement from the driving task.

Throughout all the experiments, an ACC with a default target speed of 70 mph (112,7 km/h) as the maximum speed allowed in motorways in UK, with a target headway fixed at 5s, was responsible for managing the longitudinal dynamics of the vehicle. When active, the lateral controller acted as a Lane Keeping System (LKS) and it maintained the vehicle in the centre of the occupied lane. HAD could be deactivated by requesting an handover (as described above). Transitions were designed such that the time the driver had to request the handover was not limited. Throughout the experiment, the ACC remained active. This approach was expected to reduce possible effects due to individual differences in speed selection. The reactivation of the ADS was fully automated: once the drivers removed their hands from the steering wheel, the automation activated.

The cluster displayed "Automation ON" whenever the vehicle was driving by itself. When drivers requested the handover, the writing faded away so that drivers could visually check that the handover request was successful and drivers were aware of the current ADS state.

Once the driver requested the handover (hands-on-wheel + pulled stalk), the handover procedure began. As discussed in the introduction, steering conflicts may rise from confusion regarding who, between driver and ADS, is in charge of steering (Mars, Deroo, & Hoc, 2014). Moreover, during a previous study, drivers who fought the steering guidance within the first period of the transition, were more engaged with the steering task after the transition (Maggi et al., 2020). Thus, to introduce confusion and instigate steering conflicts, a discontinuous steering assistance was designed. Therefore, during the handover procedure, the haptic feedback was tuned to follow 3 different frequencies (0.1, 0.2 and 0.3 Hz) but a fixed duty-cycle (50%). To avoid steering instabilities the Strength of Haptic Feedback (SoHF) (van Paassen et al., 2017), thus the strength of the feedback to deviations from the given path, was not decreased abruptly from 100% to 0% but rather a linear smoothing was adopted to accommodate the step within 1 s (see Figure 31). The percentage refers to the ratio of available torque (0% equals no torque and 100% equals all the available torque, i.e. 8 Nm) of the power steering system. The handover procedures were presented within a 10 s interval after the handover request (hands-on-wheel + pull-stalk). During the handover procedure the ACC remained active.

5.2.3 Procedure

Before the experiment, all participants were contacted via email and given all the necessary information regarding the goal of the study. They received an Information Sheet, a consent form, Covid19-mitigation instructions and a link to an online questionnaire in which drivers could agree to take part in the study. To ensure drivers were fully aware of the experimental goals and procedure, they were reminded that none of the transitions would be time-limited and no critical occurrences would take place. In case they delayed the take-over, the ADS would keep the vehicle on a safe trajectory within the current lane.

On the day of the experiment, within the first 10 minutes, participants were given a chance to familiarize themselves with the simulator, the handover procedure and the arrows task, used as a secondary task to ensure a complete visual, mental and manual disengagement with the driving task while in HAD. Therefore, the arrows task was adopted to keep the amount of attention paid to the road as low as possible across all the participants.

Following a short break after the familiarization, drivers started the experimental drive. The experimental drive consisted of 12 trials. Each trial started with 2 minutes of automated driving while drivers performed the arrow task. Drivers were asked to take over every time a pre-recorded message asked them to (system-initiated or automation initiated - AI) or whenever they had finished a predefined amount of arrow searches (user-initiated or driver initiated - DI). The amount of remaining searches was displayed on the side of the screen for their convenience but no further reminder was issued. Thus, drivers stopped playing the arrows task only when they realized they finished the searches. This artifice was necessary to ensure controllability but it is not a naturalistic triggering factor. However, in DI transitions, not having explicit TOR from the ADS removed the temporal demand usually associated with TOR (Walch et al., 2015; Eriksson & Stanton, 2017b).

Once the handover had been requested, drivers interacted with the different frequency haptic strategies (according to the counterbalanced design) for 10 s. After the handover procedure, a new acoustic signal informed them of HAD availability. Once the drivers removed their hands from the steering wheel, they were asked to rate the experienced trial and, afterwards, to reengage with the arrows task so that a new trial could begin. Halfway through the experiment, drivers were offered a short break before carrying on with the study.

The duty-cycles haptic strategies were provided so that each participant experienced the same strategy four consecutive times (i.e. trials). Workload and comfort ratings were collected after every trial.

The DI and AI cases as well as the order in which the handover procedures were presented to participants were counterbalanced to avoid order effects.

5.2.4 Experimental Design

A within-subject, repeated measures design was used, with all participants completing all conditions. The cyclic haptic strategies continuously varied the authority of the strength of the haptic feedback at different frequencies: Low (0.1Hz), Medium (0.2Hz) and High (0.3Hz). To provide a finer analysis of drivers' steering behaviour with respect to handover procedure and transition initiation (AI vs DI) over time, each handover procedure has been broken down into as a succession of 6 time windows (1.5 s each). The 1.5s bins were adopted after performing a comparison among bins of different length, from 0.5s to 2.5s. This bin length allowed to best capture the changes in steering behaviour. Adopting 1.5s, the last 0.5s of the 10s handovers were not considered. However, no significant changes were found in the last 0.5s, hence no important information were disregarded.

5.2.5 Dependent Variables

The following metrics were collected for each condition per participant.

Re-engagement time, defined as the time elapsed between the issue of TOR (AI cases) or the end of the arrow tasks (DI cases - when drivers stopped playing the arrows task) and the handover request (hands-on-wheel + pulled stalk).

While interacting with the haptic strategies, driving performance was measured by steering torque normalized over time, power of High-Frequency Steering Components (HFC), Standard Deviation of Lateral Position (SDLP) and Time-To-Lane-Crossing. Along with SDLP (i.e. the "weaving"), Time To Lane Crossing (TTLC), defined as the available time interval before a vehicle crosses any lane boundary following a specified path direction (Cario et al., 2009) and measured in seconds, was used to describe the quality of drivers' anticipatory steering actions (Godthelp, 1986) but has been also used in literature as a measure of perceived safety (v. d. Wiel et al., 2015). Vehicle and steering stability were monitored via Yaw Rate RMS and Steering Angular Speed RMS as in Wada et al. (2016). Steering torque was adopted as an indicator of steering conflicts between the driver and the ADS (Mars, Deroo, & Charron, 2014). HFC (in band 0.3-0.6 Hz) was adopted as an indicator of the quality of steering. A larger number of steering corrections results in higher values of HFC (i.e. higher ratio of HFC against all the steering components in range 0-3Hz) (McLean & Hoffmann, 1973) and indicate a poor anticipatory control (Salvucci & Gray, 2004).

Subjective ratings of workload and comfort, on a scale from 1 to 10 were collected after every trial to assess workload and comfort fluctuations (1 – Very Low to 10 – Very High).

5.2.6 Analysis

The data were compiled and metrics were calculated using MATLAB 2020a and analysed using IBM SPSS v26. Kolmogorov-Smirnov tests (Conover, 1999) were adopted to check for normality and, when necessary, non-parametric tests were adopted (Wilcoxon Signed Rank test instead of t-Tests) or transformations were made to perform parametric statistical tests (as ANOVA). Effect sizes were calculated as $r = abs(Z/\sqrt{N})$(Fritz et al., 2012). To check and study possible interactions between independent variables and their relative effects on the dependent ones, 3(Haptic strategies)x2(Initiator)x6(Time windows) repeated-measures ANOVAs were performed. An α-value of 0.05 was used as the criterion for statis-

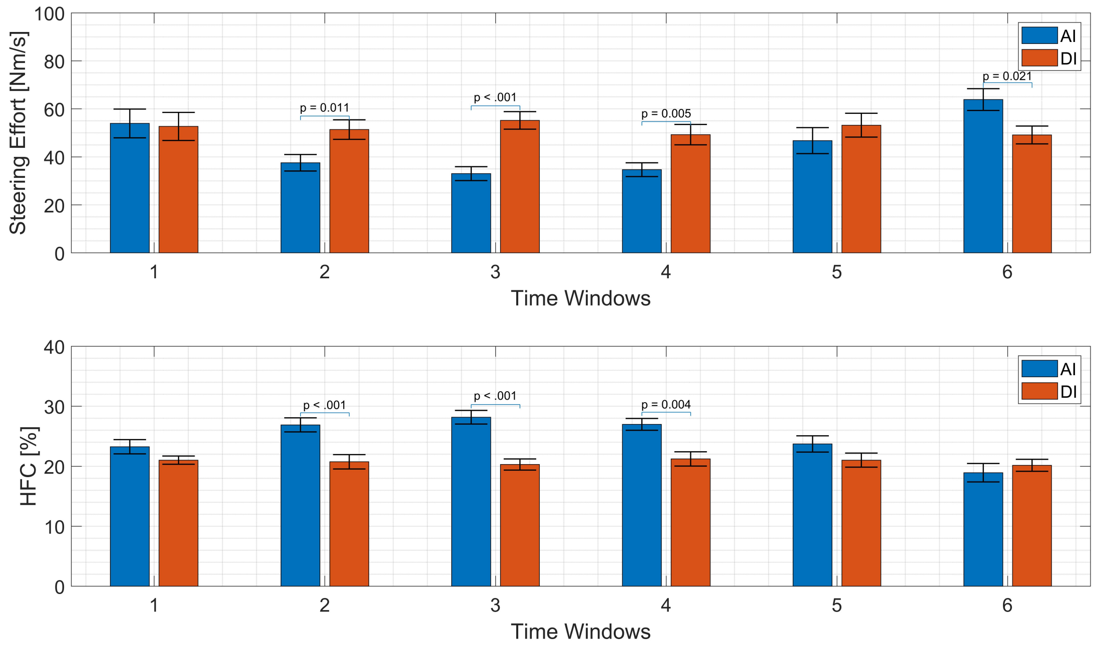

Figure 32: Steering effort and HFC, evolution over time. All represented with the respective error bars (mean standard error) and significance (Bonferroni-corrected).

tical significance, and a partial eta-squared η_p^2 computed as an effect size statistic. Whenever Mauchly's test of sphericity was violated, degrees of freedom were Greenhouse-Geiser corrected. When relevant effects were found, pairwise comparisons (Bonferroni corrected) were performed as follow-up tests. Descriptive statistics and main results of the ANOVAs can be found in Table 10.

5.3 Results

Drivers took on average 5.94 s ±3.74 s to request the handover. This time allowed drivers to interrupt performing the arrow task, reach out to the steering wheel and request the handover. No significant differences were found between user and system initiated transitions.

Drivers' steering behaviour during the handover procedure was not significantly affected by the different haptic strategies. However, more discontinued guidance (Medium and High), produced an increase of SDLP (mean diff.= 0.006 m, $p = 0.016$) and a reduction of TTLC. In detail, TTLC with Medium and High was shorter than TTLC with Low (respectively, mean diff.= 0.44 s, $p = 0.08$ and mean diff.= 0.60 s, $p = 0.003$). However, over time, being Initiator significantly affected drivers' steering behaviour. During DI transitions, drivers' HFC were significantly lower (mean diff.= 3.91%, $p < 0.01$) compared to those during AI

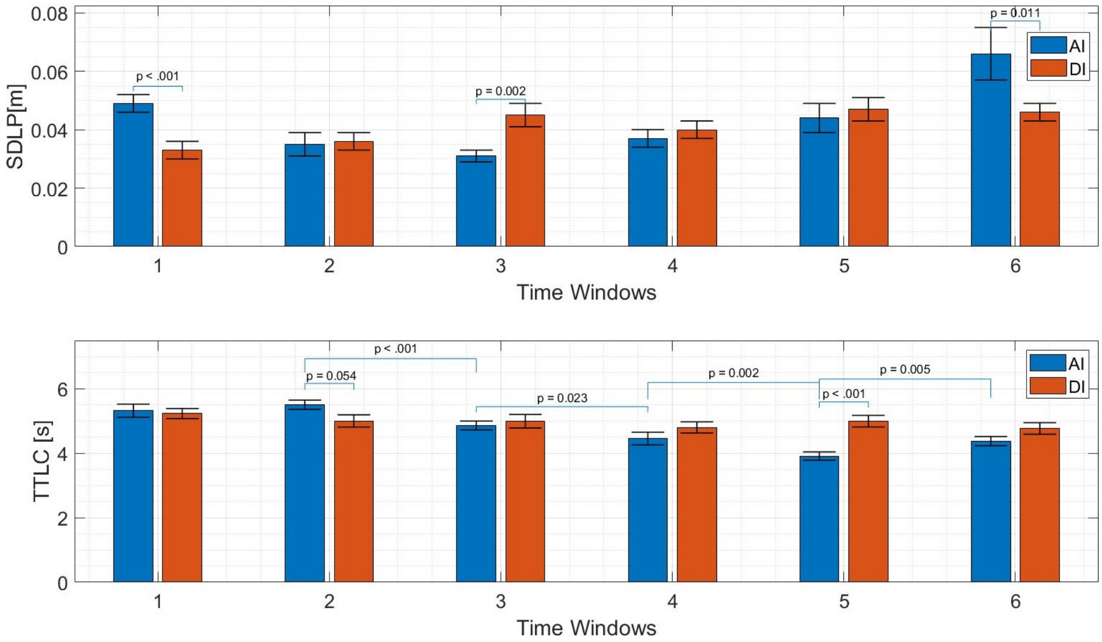

Figure 33: SDLP and TTLC, evolution over time. All represented with the respective error bars (mean standard error) and significance (Bonferroni-corrected).

ones. In particular, in the AI cases drivers increased the HFC between the second and the fourth Time windows (between 1.5 and 6 s) compared to DI cases (see Figure 32). Analysis of the steering effort revealed the more consistent steering shown in DI cases was achieved by imposing stronger steering inputs (mean diff.= 6.84 Nm/s, $p = 0.075$). A higher steering effort led to larger Yaw Rate RMS values compared to AI cases (mean diff. = 0.004 rad/s, $p < 0.01$). Over time, in DI cases, drivers exerted a stronger steering effort, in opposition to AI cases, in which steering effort significantly decreased between 1.5 and 6 s ($p < 0.01$). From 6 s onward, drivers started to increase their steering efforts, which allowed them, in the last 4 seconds of this section, to achieve a control close to DI cases (see Figure 32). SDLP and Yaw rate RMS reflected this evolution, showing in AI cases an exponential increase over time in opposition to a mostly flat trend in DI cases. Consequently, in AI cases, TTLC followed a specular trend, showing values decreasing from 5.32 ± 0.20s in the first Time windows to a minimum of 3.91 ± 0.13 s in the fifth. In DI cases, TTLC remained steady in a range 4.97 ± 0.13 s throughout the handover procedure (see Figure 33).

Comfort and workload ratings were not significantly affected. On average, drivers were comfortable in all the experienced conditions, rating the perceived comfort and workload 7.79 ± 0.50, 3.61 ± 0.80 respectively.

Table 7: Means (Standard Error) and ANOVA results over Time windows (I-VI)

Variable		I	II	III	IV	V	VI	F(df,Error)	η_p^2
Steering Effort [Nm/s]	DI	52.68(5.85)	51.37(4.07)	55.19(3.65)	49.26(4.25)	53.20(4.96)	49.13(3.72)	10.42(2.77, 47.06)**	0.38
	AI	53.92(5.99)	37.55(3.44)	33.02(2.89)	34.66(2.87)	46.78(5.41)	63.87(4.54)		
	mean diff.	1.24	13.82	22.17	14.6	6.42	14.74		
	p-value	$> .05$	*0.011*	$< .001$	*0.005*	$> .05$	*0.021*		
HFC	DI	21.02(0.68)	20.74(1.19)	20.29(0.93)	21.22(1.19)	21.02(1.17)	20.16(0.99)	5.94(5, 70)**	0.30
	AI	23.25(1.19)	26.90(1.17)	28.17(1.14)	26.98(0.98)	23.72(1.35)	18.92(1.54)		
	mean diff.	2.23	6.15	7.88	5.76	2.69	1.23		
	p-value	$> .05$	$< .001$	$< .001$	*0.004*	$> .05$	$> .05$		
Yaw Rate RMS [rad/s]	DI	0.014(0.001)	0.015(0.001)	0.016(0.001)	0.016(0.001)	0.016(0.001)	0.019(0.001)	14.24(2.39, 40.65)**	0.47
	AI	0.011(0.001)	0.006(0.001)	0.007(0.001)	0.009(0.001)	0.014(0.002)	0.026(0.002)		
	mean diff.	0.003	0.009	0.009	0.007	0.002	0.007		
	p-value	0.03	$< .001$	$< .001$	$< .001$	$> .05$	0.001		
Steering Anglular Velocity RMS [rad/s]	DI	0.014(0.002)	0.011(0.002)	0.011(0.001)	0.011(0.001)	0.009(0.001)	0.010(0.001)	1.19(1.99, 33.92)***	0.065
	AI	0.013(0.002)	0.011(0.002)	0.009(0.001)	0.011(0.001)	0.013(0.003)	0.012(0.001)		
	mean diff.	0.001	0.000	0.002	0.000	0.004	0.002		
	p-value	$> .05$	$> .05$	$> .05$	$> .05$	$> .05$	$> .05$		
SDLP [m]	DI	0.033(0.003)	0.036(0.003)	0.045(0.004)	0.040(0.003)	0.047(0.004)	0.046(0.003)	5.59(2.68, 45.61)**	0.25
	AI	0.049(0.003)	0.035(0.004)	0.031(0.002)	0.037(0.003)	0.044(0.005)	0.066(0.009)		
	mean diff.	0.016	0.001	0.014	0.003	0.003	0.020		
	p-value	$< .001$	$> .05$	0.002	$> .05$	$> .05$	0.011		
TTLC [s]	DI	5.23(0.15)	5.00(0.19)	4.99(0.21)	4.80(0.17)	4.99(0.18)	4.77(0.18)	6.14(2.87, 48.77)**	0.26
	AI	5.32(0.20)	5.51(0.14)	4.86(0.14)	4.45(0.20)	3.91(0.13)	4.38(0.14)		
	mean diff.	0.09	0.50	0.13	0.34	1.08	0.39		
	p-value	$> .05$	$> .05$	$> .05$	$> .05$	$< .001$	$> .05$		

* $p < .05$. **$p < .01$ ***$p > .05$

5.4 Discussion

Within the previous study, it was observed how drivers' re-engagement time depended on their role as initiators. In particular, drivers in AI cases were generally quicker in reaching out to the interface compared to DI cases (Maggi et al., 2020). In particular, re-engagement times in DI cases were, on average, 4.53 s longer compared to AI cases (mean re-engagement time = $4.98s$). Within this study, however, the two cases did not produce different outcomes and drivers' re-engagement times in DI initiations were close to the values showed in AI cases, namely around 5 s. This result might be due to the different simulator adopted. In this case, the driving simulator was more immersive and engaging as opposed to the one used during the first study (gaming steering wheel and LCD monitor). This might have pushed drivers to hasten their physical re-engagement with the DDT irrespective of who was initiating the transition.

In terms of the handover procedures, results showed that drivers' role as Initiator had significant effects on their steering behaviour. Although having discontinuous lateral assistance depleted drivers' ability to keep a steady trajectory, showing an overall increase of SDLP and shorter TTLC, the adopted handover procedures did not significantly affect drivers' steering behaviour. During DI transitions, drivers kept a steadier anticipatory control, maintaining HFC values of $20.54 \pm 0.70\%$ compared to $24.66 \pm 0.57\%$ during AI ones. HFC evolution over time, revealed how drivers start engaging with the steering task 5-6 seconds after the handover request. In the first 5 seconds, steering effort decreased over time and, as a result, the number of needed corrective actions increased. After 5 seconds, drivers' steering effort started to increase, revealing drivers' re-engagement with the steering task, and consequently, they started wielding a smoother anticipatory control, indicated by lower values of HFC.

During DI transitions, no such re-installment process took place. Instead, drivers kept from the very beginning a stronger steering activity, which resulted in a consistent anticipatory control throughout the handover procedure. Although the higher steering engagement led to larger Yaw Rate RMS values compared to AI cases, these remained within a small range (0.016 ± 0.001 rad/s). However, prioritizing the anticipatory control in DI cases, allowed drivers to keep, on average, a 227 ms longer TTLC, with a peak of 1.08 s within the fifth Time window (6-7.5 s).

From the obtained results it was not possible to conclusively answer the first research question. Steering conflicts, as an increase of interaction forces on the steering wheel, were witnessed but the results do not support the hypothesis of them being triggered by the proposed inconsistent guidance. In fact, the results suggest that the increase of interaction forces was mainly related to drivers' role as Initiators; hence any other lateral assistance could have produced similar results. However, it is important to consider that the adopted reference trajectory might have highlighted the discrepancies between DI and AI cases. In AI cases, drivers were mostly following the steering guidance, hence keeping a small lateral error. A small lateral error would have not produced any significant steering guidance and, in turn, no steering conflicts. On the contrary, in DI cases, driver were more engaged and tried to impose their own trajectory, thus increasing the lateral error and leading to steering conflicts. Therefore, it is unclear whether the adoption of a human-reference trajectory (van Paassen et al., 2017) would have led to different outcomes.

Higher interaction forces allowed drivers to keep a steadier and more consistent steering throughout the handover procedure in DI cases and a delayed but similar outcome could be seen in the AI cases as well. Answering the second question, steering conflicts instigated drivers' steering re-engagement but results did not provide enough evidence on the source of these conflicts. In the DI case, drivers might have learned to wield a steadier control as they were initiating the transition and they were supposed to be in charge of steering. The presented inconsistent guidance (Medium and High) made it harder for them to fulfill this task, resulting in larger SDLP and TTLC values, but they kept a constant steering engagement nevertheless. In the AI case, drivers were not as engaged with the steering task and they started showing a more active steering activity only after 5 seconds. Supporting findings from the previous study (Maggi et al., 2020), this behaviour could be affected from a number of factors. Providing drivers with RtI conveying a *level of urgency* has proven beneficial in triggering a faster drivers' reaction (Naujoks et al., 2014; Petermeijer et al., 2016; van den Beukel et al., 2016; van der Heiden et al., 2017). However, faster reaction times do not imply a faster steering re-engagement (Zeeb et al., 2016) and providing drivers RtI with false levels of urgency might lead to trust issues with the ADS (Sheridan, 2002; Pritchett, 2017). A more complex traffic scenario could trigger a faster steering re-engagement but could also worsen drivers' reaction (Gold et al., 2016; Zeeb et al., 2017). Nevertheless, the results provided evidence that drivers, after 10 seconds, including AI cases, were engaged with the steering task. To provide a more structured answer, in the DI cases drivers were showing steering engagement from the very beginning, whereas, in the AI cases, drivers' underwent a longer re-engagement process, which concluded right before the 10 s.

5.5 Conclusion

Indeed, in the DI transitions, drivers higher steering engagement suggests to adopt a constant and shorter handover procedure, which provides assistance for a short period rather than try to impose a steering guidance for longer or to trigger drivers' engagement. On the contrary, in AI transitions, longer transition time must be allowed to provide drivers enough time to re-engage in the driving task.

The results suggest also that steering effort is a good indicator to determine both the level of steering engagement and the presence of steering conflicts between the ADS and the driver. Therefore, steering effort could be used to tune the level of assistance to avoid steering conflicts during DI transitions, where drivers show steering engagement, and to stimulate drivers' steering engagement in AI transitions with auditory warnings, perhaps, whenever steering effort drops below a given threshold.

Further evidence is required to better understand how a more active steering behaviour could be exploited. This study failed to provide a comprehensive explanation for drivers' steering engagement. Future studies should focus on understanding the motivations behind the higher steering engagement shown in the DI cases. Why are drivers more engaged during DI transitions? Is it a mere mismatch between expected authority and the given one or is there anything more?

Future studies should also investigate how to hasten drivers' engagement in AI cases, particularly when the time-budget for the handover is less than 10 s. Would a multi-modal handover strategy be able to hasten drivers' engagement in AI cases? Would providing both a message conveying urgency followed by an inconsistent guidance hasten the re-engagement process? Evidence from the literature suggests that the process might be hastened. However, this method might affect drivers' comfort and trust in the ADS, which could ultimately affect acceptance and performance.

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CHAPTER 6

How will drivers behave during transitions of control in automated driving? A pilot investigation from the driver's perspective

ABSTRACT A pilot survey (26 respondents) investigated how drivers would behave during user and system initiated transitions of control from Highly Automated Driving (HAD). It is expected that HAD will soon be available in production vehicles and with it, transitions of control will grow common in everyday driving. The literature has investigated the implication of a period of exposure to HAD and how to most effectively bring drivers back in control. What literature lacks is the understanding of drivers' expectations about how the Automated Driving Systems (ADSs) would behave. A questionnaire was developed to understand (a) how drivers imagine they would communicate to the ADS that they want to, or are ready to take over, (b) how and if they would like to be assisted during the transition and, if yes, for how long. An online survey was adopted to present drivers with four transitions: system and user-initiated transitions with low or high traffic density. The results show that respondents who believe in today's driver assistance systems and who believe that HAD will be introduced in the future were keener in being assisted during the transition process and for longer periods.

6.1 Introduction

Vehicles can now assist drivers in almost every aspect of the Dynamic Driving Task (DDT). Adaptive Cruise Control (ACC) helps drivers by managing the longitudinal speed, Lane Keeping Assist (LKA) provides guidance on the steering wheel to maintain the vehicle in the centre of the occupied lane and Lane Departure Assist (LDA) provides guidance to avoid lane departure. The next step on the road towards fully automated driving is the introduction of conditional and highly automated driving (Force, 2017). The introduction of higher Levels of Automation (LoA) is expected to bring performance and comfort benefits, which will have a direct impact on road safety (Alessandrini et al., 2014; Fagnant & Kockelman, 2015). With higher LoA, drivers will have to resume manual control from time to time as the vehicle technology enabling automated driving is not yet fully mature. Automated Driving Systems (ADSs) will require drivers to take back control of the vehicle whenever they reach the boundaries of their Operational Design Domain (ODDs) (SAE, 2021).

The current literature provides empirical evidence on different aspects around the transition topic: the effect of different Non-Driving-Related-Tasks before the take-over (Lu et al., 2017; Louw & Merat, 2017; Eriksson & Stanton, 2017); the effects of different take-over-request (TOR) modalities (Toffetti et al., 2009; Bahram et al., 2015; Naujoks et al., 2014; Lorenz et al., 2014; Telpaz et al., 2015; Petermeijer et al., 2017; Forster et al., 2017; Yun & Yang, 2020); the impact of demographic (Körber et al., 2016; Wright et al., 2016; Clark & Feng, 2017) and the impact of traffic condition (Radlmayr et al., 2014; Gold et al., 2016).

Conducted surveys have been focused on collecting drivers' opinions on certain aspects of HAD such as acceptance and trust, sometimes relating them to system reliability. Körber et al. (2018) defined reliability in Conditional Automated Driving (CAD) based on the criticality of a Take-Over Request (TOR). Thus, an optional take-over defined the high-reliability system in opposition to the low-reliability one, which issued critical TORs that required mandatory takeovers. Following previous findings (Muir & Moray, 1996; Bagheri & Jamieson, 2004; Hergeth et al., 2016), results proved that drivers' perception of ADS reliability influences how much they monitor the environment while in CAD. Gaze behaviour was even used as an indicator for trust (Walker et al., 2019). The effectiveness of the provided feedback is also affecting trust and acceptance. Augmented reality led to higher acceptance and trust (Wintersberger et al., 2017) and female auditory warnings were presented as the most preferred feedback type for TORs (Bazilinskyy & De Winter, 2015). These studies provided valuable knowledge on *situational trust* and *learned trust*, namely trust based on either short or long term direct interaction with the ADS (Marsh & Dibben, 2003).

Other studies investigated instead drivers' *dispositional trust*, thus not the trust based on direct interaction but the one dependent on age, gender, knowledge, etc.. Data from recent surveys reported that people believe higher automated vehicles bring significant benefits in terms of safety and crash prevention (Eby et al., 2018; Hagl & Kouabenan, 2020). Nevertheless, people reported they would prefer to own vehicles with lower LoA (i.e. SAE Lv.1 and Lv.2) (Kim & Kelley-Baker, 2021). Irrespective of whether people trusted automation or not, the main reported concern was technology failure. Among those who distrusted automation, lack of or no control and over-reliance on automation were cited as other concerns. Following the classification of Marsh & Dibben (2003), even acceptance can be split into three temporal regions. Drivers can either accept the technology because they believe it will be useful to them (i.e. dispositional acceptance) or they will calibrate their acceptance levels based on direct interactions with these technologies (i.e. situational and learned acceptance).

Future users' dispositional trust and acceptance are related to the possessed mental model of these future technologies and, among drivers, the lack of accurate knowledge of these systems has already been documented (McDonald et al., 2018). A good understanding of the functions is of paramount importance for ADSs to meet the expected safety benefits. Gaspar et al. (2020) showed that people with a better ACC understanding, namely a stronger mental model, were able to properly use the technology and showed better performance when dealing with some of its limitations. A correct mental model, before any direct interaction with the system, may be even beneficial. Practice and exposure help drivers build stronger mental models (Piccinini et al., 2012; Beggiato & Krems, 2013; Singer, 2020) but even experienced users might fail to appreciate ADS capabilities and limitations (Beggiato & Krems, 2013; Piccinini et al., 2015; McDonald et al., 2018; DeGuzman & Donmez, 2021) incurring in abuse and/or misuse (Parasuraman & Riley, 1997).

The above delineates two main issues related to mental models in the context of driving automation:

1. the drivers need to understand the capabilities of the ADS;

2. the drivers need to recognize the ADS status.

An incorrect understanding of the system capabilities might lead to episodes of over-reliance, in which drivers fail to maintain the correct level of vigilance and control (Naujoks et al., 2016; Banks et al., 2018; Noble et al., 2021). This reported behaviour has led already to several road accidents (National Transportation Safety Board, 2020). A weak mental model might also lead to road accidents even with monitoring reminders (Victor et al., 2018). Further, failing to recognize the ADS status might lead to safety threats as drivers disengage from the driving task when they should not (Wilson et al., 2020). Mars et al. (2014) reported higher steering conflicts, in the form of higher interaction forces at the steering wheel, arising from ambiguities regarding who had authority over the steering task. Hence, a weak mental model, paired with an ineffective "mode awareness" can make ADASs ineffective in their attempt to reduce traffic accidents and increase drivers' comfort and safety.

During transitions of control from higher LoA, a weak mental model can cause drivers to retard their responses to TORs (Zeeb et al., 2015). Furthermore, drivers' post-transitions performance deteriorates and assistance may help ensure passengers' and road safety. However, during transitions of control, the LoA switches from HAD to lower LoA in a matter of seconds and drivers will need to be aware of these changes while ramping up their awareness and physical control, which may require up to 30 s (Merat et al., 2014; Pampel et al., 2019; Hyunsuk et al., 2021; Melnicuk et al., 2021). Even with lower LoA, this might undermine the intended safety purpose and even introduce conflicts between the ADS and the driver. Similarly to what was observed by Mars et al. (2014), Maggi et al. (2020) showed an increase of interaction forces and a comfort drop during user-initiated transitions from HAD when providing handover procedures with a strong LKA. As in Mars et al. (2014), the reason for the reported differences between drivers' behaviour during system and user-initiated transitions was not provided.

The proposed questionnaire was designed to investigate whether there exists a dispositional factor influencing drivers' behaviour. It was assumed that drivers, in driver initiated transitions, would deem themselves fit to take over and with no or little need for assistance. On the contrary, in system-initiated transitions, drivers would perhaps recognize their unfitness to drive and so expect assistance, even for long periods.

6.2 Methodology

6.2.1 Survey

Participants were recruited via posts circulated on Social Media platforms (LinkedIn, Facebook and Instagram). Data were collected via online questionnaires on Microsoft Form. The questionnaire was available in four languages (English, French, Spanish and Italian), each one checked and proofed by a native speaker. Interested participants were given the chance to choose the preferred language. The survey, as a pilot, did not target any specific group of individuals. The questionnaire consisted of 40 questions, which required approximately 10 minutes for completion. The first seven questions collected basic demographics information ("About you" section). Questions 8 to 13 aimed at collecting information concerning driving attitude and locus of control ("Your driving experience" section). Questions 14 to 20 aimed at assessing participants' knowledge and usage of 3 ADAS, namely ACC, LKA and LDA and their disposition towards automated driving ("Vehicle automation" section). Table 8 shows the questions of the first part of the survey as well as the corresponding coding.

The following five questions were repeated in 4 different cases (20 questions in total) and aimed to collect information concerning drivers' preference and expectations during transitions of control from HAD, namely how they thought they and the ADS would behave in the presented situations. All the situations were presented with the help of a short text description followed by a picture. The picture always represented a 3-lane motorway with the ego vehicle driving autonomously in the middle lane with varying traffic density, either light (code "A") or heavy (code "B") traffic (see Figure 34). By means of some text, drivers were asked to imagine they were seating in the driver seat and engaged with NDRTs. Depending on the study case, drivers were then asked to imagine either the system asking them to resume control (case "1") or them resuming control by themselves just because they felt like they wanted to (case "2"). For example, participants were introduced to a system-initiated transition as follows: "Take a good look at the image below: imagine you are in one of these autonomous vehicles, driving autonomously on a motorway while you're relaxing, reading, watching a movie or just chatting on the phone or with other passengers. At some point, the automated system asks you to take back control of the driving task (steering, accelerating and braking).

Table 8: Variable from the survey collecting participants' information

Question	Full question as reported in the survey	Answer coding
1.Age	Age	Positive integer value
2.Gender	Gender	1 = Male; 2 = Female; 3 = Prefer not to say
3.Occ	Occupation	Textual answer
4.DriveNat	Where do you usually drive (Nation)?	1 = Italy; 2= France; 3= Spain; 4= United Kingdom; 5=Switzerland; 6= Germany
5.km/year	Annual mileage (How much do you drive approximately?)	Numerical answer (converted in km)
6.LicYear	What year did you get your driving licence?	Numerical answer
7.DriveWeek	How many days a week do you drive? Range 0 (none) - 7 (every day)	Numerical answer
8.EnjoyD	Do you enjoy driving?	1=Yes; 2=No
9.SelfSkill	On a scale from 0 to 10, how would you score your driving skills and expertise? In other words, how good do you think you drive?	0= Very Bad; 10=Very Good
10.DriveAtt	On a scale from 0 to 10, how would you score your driving attitude?	0=Very Aggressive; 10=Very safety-oriented
11.NumCarAc	How many car accidents happened to you in the last 5 years?	0=0; 1=1; 2=2; 3=3; 4=4; 5= 5 or more
12.AccCau	What was the main cause of these accidents?	0=Not applicable - No accidents; 1=Yourself/your error; 2=Other drivers;3=Vehicle;4=Environment; 5=Fate/Bad Luck;6=Other causes
13.GenCau	In general, what do you think are the main causes of car accidents? Multiple answers allowed.	0=Not applicable - No accidents; 1=Yourself/your error; 2=Other drivers;3=Vehicle;4=Environment; 5=Fate/Bad Luck;6=Other causes
14.ADASfam	Are you familiar with Advanced Driver Assistance Systems such as Adaptive Cruise Control (ACC), Lane Keeping Assist (LKA) and Lane Departure Assist (LDA)? Multiple answers allowed.	1=Yes, all of them and more; 2=ACC; 3=LKA; 4=LDA
15.ADASown	Do you currently own a vehicle with any of the above systems? Multiple answers allowed.	1=No; 2= Yes, with ACC; 3=Yes, with LKA; 4=Yes, with LDA
16.ADASuse	Do you usually use any of the systems? Multiple answers allowed.	1=No; 2= Not applicable, I don't have any; 3= Yes, with ACC; 4=Yes, with LKA; 5=Yes, with LDA
17.ADASres	If you do not usually use them, what are the main reason? Multiple answers allowed.	1= Not applicable, I don't have any/ I use them regularly; 2=ACC feels odd; 3=LKA feels odd; 4=LDA feels odd; 5=I don't trust ACC; 6=I don't trust LKA; 7=I don't trust LDA;
18.ADAShelp	Do you think the above systems to be helpful?	1=Yes; 2=No
19.AUTOfut	Vehicle automation is more common every day. Do you believe that autonomous driving will be a thing in the coming years?	1=Yes; 2=No
20.AUTObuy	How likely would you buy a completely autonomous vehicle, capable of driving without any human intervention?	Range from 0 to 10; 0=Very Unlikely; 10=Very Likely

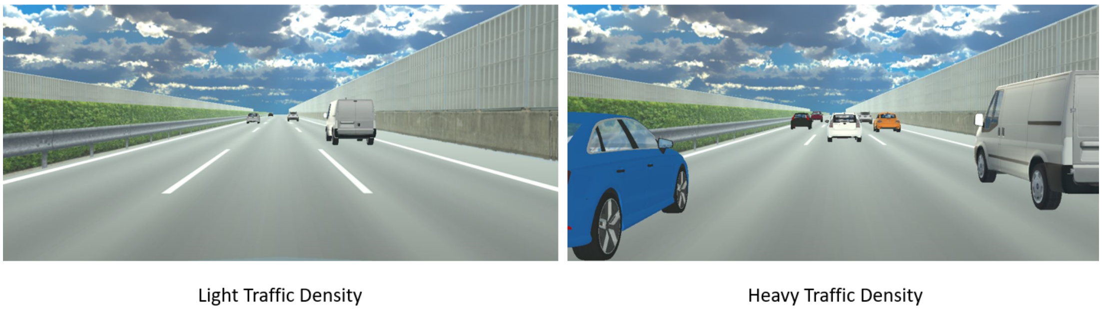

Figure 34: Presented light or heavy traffic conditions.

You have all the time you need to redirect your attention towards the road and grab the steering wheel and/or place your feet on pedals". Similarly, user-initiated transitions were presented as follows: "Take a good look at the image below: imagine again you are in one of these autonomous vehicles, driving autonomously on a motorway. It has been driving autonomously for so long that you feel you want to take back control and drive for a while". Following this description, 5 questions for each case were presented. Table 9 shows the questions of the second part of the survey with the corresponding coding.

Table 9: Variable from the survey collecting participants' preference and expectations in the presented cases.

Question	Full question as reported in the survey	Answer coding
21.ComPref	How would you like to communicate the system you want to take control of the vehicle?	1=I place my hands on the steering wheel and the system must understand that this is my way of saying that I'm ready to take over; 2=I would like to be able to grab the steering wheel for a while and communicate with some other means my readiness to take over (button press perhaps)
22.OOTLself	Do you think your capacity of controlling the vehicle is somehow reduced?	1 =Yes; 2 = No; 3 = Maybe
23.ADSexp	Now you've communicated the system you want to take over the full control of the vehicle. How do you expect the system to behave? Multiple answers allowed.	1=I expect the system to switch off and let me drive autonomously; 2=I expect the system to provide me some level of visual assistance, redirecting my attention towards close-by road users I must consider; 3=I expect the system to provide some level of supervision towards my driving, stopping any of my accelerating, braking or steering actions that would endanger my safety and the one of other road users; 4=I expect the system to provide some level of supervision towards my driving, providing guidance for my accelerating, braking or steering actions that would endanger my safety and the one of other road users but I don't want the system to cut me off
24.StateADS	Would you like the system to explicitly inform you of its actions during the transition? Displaying a message on the dashboard perhaps, telling you what is doing or not doing.	1 =Yes; 2= No
25.AssistTime	The system can provide a Lane Keeping Assist that guides your steering via forces on the steering wheel to help you maintain a safe trajectory within the current lane. How many seconds would you like the system to assist you?	1=less than 5 seconds; 2=between 5 and 10 seconds; 3=between 10 and 20 seconds; 4=between 20 and 30 seconds; 5=more than 30 seconds; 6=as long as I don't specifically ask the system to stop;7=I don't believe any assistance will be needed

Table 10: Descriptive statistics for the numerical survey items.

Variable	Mean	Median	SD	Skeweness	Min	Max
1.Age	36.6	28	15.8	1.3	24	72
2.Gender	1.5	2	0.5	-0.28	1	2
5.km/year	19043	10000	26855	2.38	1000	100000
6.LicYear	2002	2010	16.1	-1.33	1968	2015
7.DriveWeek	4.5	5	2.45	-0.38	1	7
8.EnjoyD	1.13	1	0.34	2.35	1	2
9.SelfSkill	8.4	8	1.1	-0.17	6	10
10.DriveAtt	6.7	7	2.1	-0.55	2	10
11.NumCarAcc	0.4	0	0.9	2.47	0	3
18.ADAShelp	1.13	1	0.34	2.35	1	2
19.AUTOfut	1.39	1	0.5	0.47	1	2
20.AUTObuy	4.2	3	3.1	0.22	0	10

Descriptive statistics were calculated for each variable. Skewness was calculated as the third central moment divided by the cube of the standard deviation (Wheeler, 2004). Due to the small sample, no inference or comparison was made. As a pilot, results should be regarded as quantitative indicators. Table 10 reports the descriptive statistics for all the numeric variables.

Data were collected following approval from the University of Leeds Research Ethics Committee.

6.3 Results

Twenty-three surveys were completed. Responses were gathered between August and September 2021. All the respondents matched the requirement; therefore all responses were used in the analysis.

6.3.1 ADAS knowledge & use

All respondents were familiar with at least one ADAS and 13 respondents (56%) reported they were familiar with the proposed ADAS and more. In total, 20 respondents (87%) were familiar with ACC, 19 with LKA (83%) and 18 (78%) with LDA (see Figure 35). However, ownership of vehicles equipped with ADAS was limited to 8 respondents. Six owned a vehicle with ACC, 4 with LKA, 1 with LDA and only one owned a vehicle with all these ADAS. Seven used ACC regu-

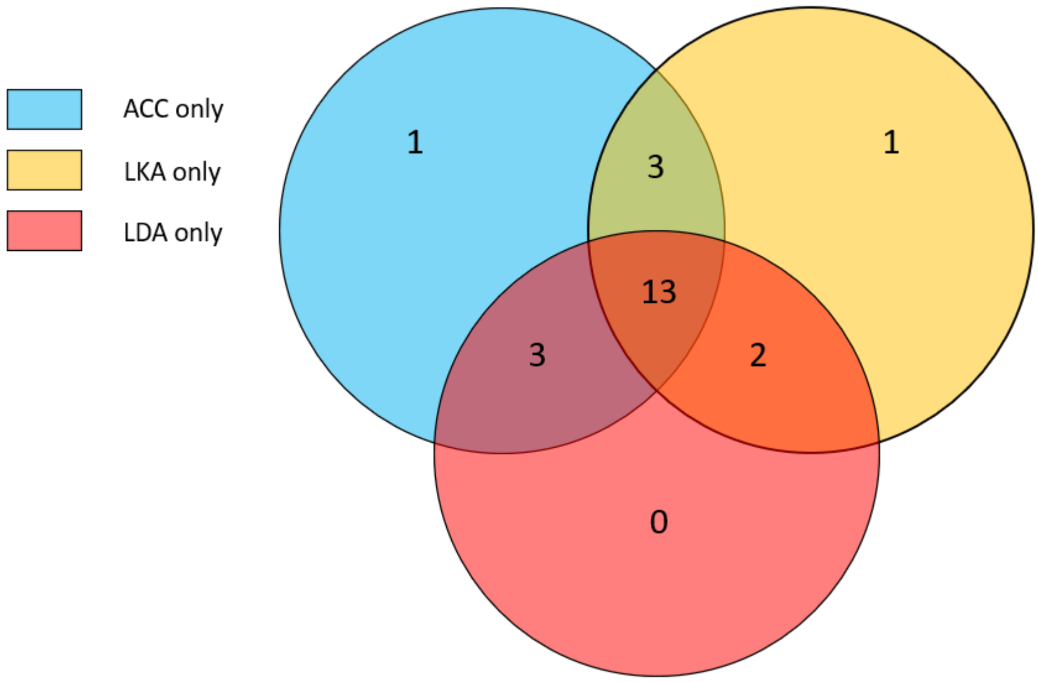

Figure 35: Drivers' familiarity and use of the most common ADAS.

larly, 4 used LKA regularly and only 1 used all the proposed systems regularly. Four respondents did not report any issue with the ADAS they regularly used, 1 reported that ACC felt odd, 3 that LKA felt odd. Two respondents reported they did not trust any of the ADAS. Twenty respondents (87%) thought the ADAS to be helpful. All the 3 respondents who thought otherwise previously indicated mistrust with some ADAS. Nine respondents did not think automated driving will deploy in the future and 5 of these were among those who reported using at least one of the ADAS regularly. When it comes to deciding whether they would buy a completely automated vehicle, respondents were split into three subgroups. Twelve respondents (52%) scored between 0 and 3, 3 respondents reported a score between 8 and 10 and the remainder were neutral.

6.3.2 Study cases

The preferred way of communicating to the ADS the wish to take over splits between participants and did not vary depending on the proposed study cases. Nine respondents wanted to just grab the steering wheel, while the rest preferred a two-step communication. When asked by the ADS to take over, 11 (low traffic) and 12 (heavy traffic) respondents thought their capacity to control the vehicle would be somehow reduced and the remainder were either not sure (6 in both

Table 11: Response frequencies subdivided by initiation and traffic density.

Variable		AI & Low traffic	AI & Heavy traffic	DI & Low traffic	DI & Heavy traffic
	Code	Frequencies			
21.ComPref	1	10	9	11	9
	2	13	14	12	14
22.OOTLself	1	11	12	7	8
	2	6	5	9	6
	3	6	6	7	9
23.ADSexp	1	8	7	12	10
	2	3	4	6	4
	3	6	5	2	3
	4	6	7	3	6
24.StateADS	1	16	16	15	16
	2	7	7	8	7
25.AssistTime	1	6	6	7	6
	2	6	5	4	6
	3	3	2	1	2
	4	0	2	0	0
	5	0	0	0	0
	6	6	6	6	6
	7	2	2	5	3

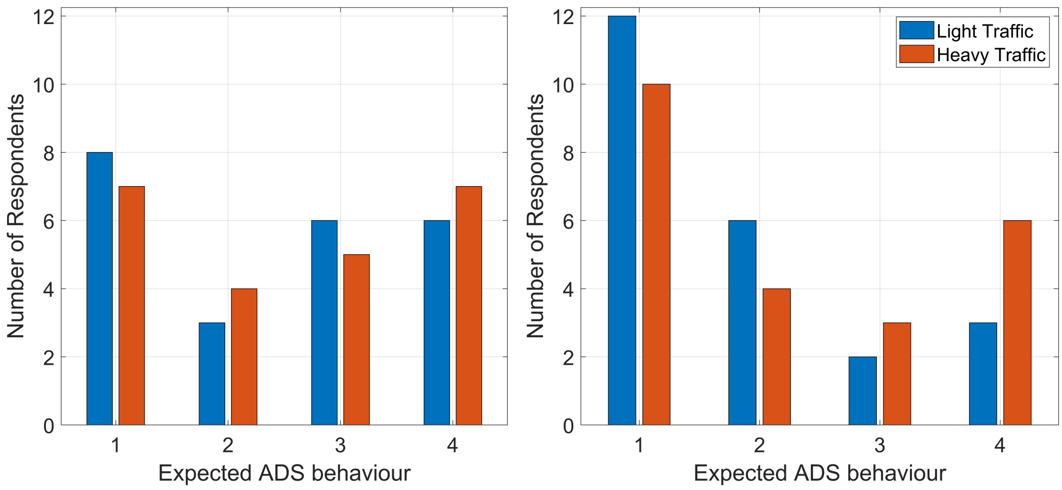

Figure 36: ADS expected behaviour (System-initiated cases on the left and driver-initiated ones on the right).

traffic conditions) or they did not believe it would have been the case (6 and 5, respectively). When asked to imagine a driver-initiated transition, 7 (low-traffic) and 8 (heavy traffic) respondents opted for “Yes”, 9 (low traffic) and 6 (heavy traffic) for “No” and 7 (low traffic) and 9 (heavy traffic) for “Maybe”.

Figure 36 summarizes the ADS expected behaviour when respondents were presented with the study cases. In any condition, most respondents expected the ADS to switch off, especially in driver-initiated transitions. In system-initiated transitions, on average, half of the respondents expected the ADS to switch off (options 1) and provide visual assistance (option 2). The other half expected to be supervised by the system (options 3) or even be guided by the ADS (option 4). In driver-initiated transitions, traffic density pushed 4 respondents’ expectations. With light traffic 12 were expecting option 1 and 6 option 2 but, with heavy traffic, 4 expected the ADS to provide either option 3 or 4 instead.

Figure 37 shows that the period in which respondents would like to be assisted by a LKA after the transitions is very diverse. In system-initiated transitions, 2 respondents always chose that assistance was not needed at all and 6 respondents always wanted the assistance as long as they do not specifically ask the ADS to stop. Heavy traffic pushed 2 respondents to select longer assistance than the one they chose with the light traffic case. In driver-initiated and light traffic, 7 respondents wanted the LKA active for less than 5 seconds, 5 did not think it was necessary and 6 wanted to decide when to stop the LKA. Only 6 respondents opted for a longer (between 5 and 20 seconds) assistance. With heavy traffic, 2

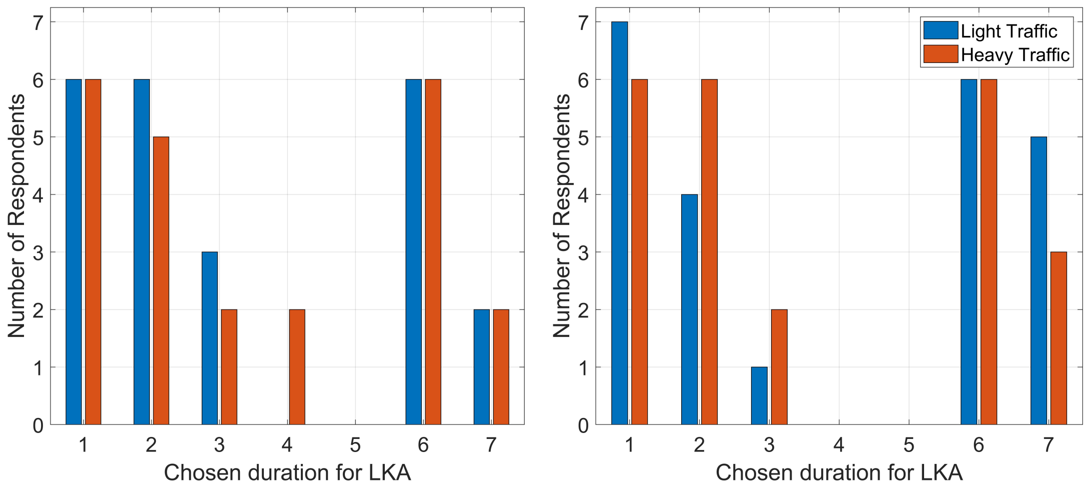

Figure 37: Desired time duration of the LKA (System-initiated cases on the left and driver-initiated ones on the right).

respondents changed their mind and, from option 7 (i.e., no need at all) to option 2 (between 5 and 10 seconds) and 1 respondent switched from less than 5 seconds (light traffic) to LKA between 10 and 20 seconds (heavy traffic).

6.4 Discussion

The presented pilot survey aimed at understanding whether a relationship exists between how drivers' behave during transitions of control and their expectations of the ADS behaviour. Moreover, it was investigated whether drivers' background and experience influence those expectations. The respondents who participated in the survey were presented with 2 different sets of questions. The first set aimed at collecting information about demographics, respondents' driving experience, knowledge and use of ADAS currently made available from most car manufacturers. The second set of questions proposed to them different study cases and collected information concerning respondents' preferences and expectations.

From the first set of questions it emerged that, although most of the respondents knew about ADASs, only a few owned a vehicle equipped with one. Although the sample was limited and can not be used as a reference, this finding has already been reported in past surveys (Trübswetter & Bengler, 2013). It is however important to consider that the survey did not test the extent of respondents' knowledge. Past studies have shown that being aware of ADASs does not imply understanding how they function and what are their limits (Mc-

Donald et al., 2017; Noble et al., 2019). Irrespective of their actual knowledge, most respondents believed ADASs to be helpful. This underlines how there exists an important dispositional factor influencing drivers' attitude and expectations towards these technologies and their willingness to buy a vehicle equipped with them. In this sense, this survey is in line with previous findings and only 9 respondents (39%) scored their willingness to buy a fully automated vehicle above the midpoint of the proposed scale (i.e., ≥ 6) (Schoettle & Sivak, 2014; Kyriakidis et al., 2015; Bansal et al., 2016; Regan et al., 2017; Cunningham et al., 2019).

Older and more experienced drivers expect the ADS to let them drive as soon as they reach for the steering wheel, even though the majority of respondents think ADAS to be helpful (87%). Those who own a vehicle equipped with at least one ADAS tended to acknowledge that their capacity might be reduced. However, given the low number of respondents who own a vehicle equipped with ADAS (35%), it was not possible to assess whether a correlation between OOTLself and ADSexp exists. In other words, it was not possible to understand if drivers with experience using ADAS had also a better idea of their effects after extensive use. If a correlation was found with a larger data-set, it would support the idea that a strong mental model of a system favours its proper use (Gaspar et al., 2020).

Respondents who believe in automated driving and its future introduction in commercial vehicles were more willing to be supervised or assisted after a transition for as long as they see fit. Similar results were found for respondents driving a few kilometres a year and who deemed themselves safety-oriented drivers. In spite of the limited extent of the survey, this relation may be seen as utilitarianism and may lead to misuse, especially if unsupported by a strong mental model. Experiencing currently available ADAS seems to have a beneficial impact on the development of users' mental models and on users' understanding of the impact that these systems may have on drivers' behaviour.

This survey also highlights how the dispositional factor will likely play an important role in the future as well. Respondents with high expectations toward future ADS capabilities will more likely rely more on its assistance during difficult situations (as transitions). As past studies have pointed out (Muir & Moray, 1996; Bagheri & Jamieson, 2004; Hergeth et al., 2016; Körber et al., 2018), users' dispositional acceptance and trust of future systems will be dependent on the situational and learned trust users are developing with the currently available ADASs.

6.5 Conclusions

The conducted pilot survey was aimed to gather some inputs from today's drivers and the potential dispositional factor that could influence their interaction with HAD during transitions of control.

A first takeaway is that the presented pictures of the different traffic densities might be insufficient to immerse the respondents into the presented scenarios. Only a few respondents changed their responses based on the presented traffic densities. Although in driver-initiated cases, most respondents expected the ADS to switch off or provide only visual cues, no correlation was found between expected assistance and initiation.

What can be drawn from these few responses is that a dispositional factor influencing drivers' expectations exists. In particular, respondents that believe in ADASs helpfulness and that HAD will truly become a reality were more prone to be assisted during transitions and for longer.

However, this study, as a pilot, was not able to draw a full picture of what parts of respondents' knowledge pushed them to have a more positive attitude towards ADAS and HAD. Future studies should try to test drivers' true knowledge of current ADASs and test whether their positive attitude is more due to a blind trust or due to some inconsistency between their knowledge and the true functionalities of ADASs.

To better understand what drivers' expect from future technologies is of great importance since their dispositional acceptance and trust will influence the capacity of these new technologies to reach their intended and predicted benefits.

This pilot survey failed to capture the real knowledge that respondents had on ADAS and automated driving. Future surveys should investigate deeper this aspect without constraining respondents answers to a set of predefined choices but, rather, let them express their answers freely. This would allow for a better understanding. Secondly, providing images supported by a textual introduction was not a viable method to capture any respondent reaction. Future studies should consider a hybrid survey. The first part of the survey can be designed as a regular survey, aimed at capturing respondents' knowledge and experience. However, the second part, aimed at investigating drivers' reaction to a set of study cases, should be supported by a direct experience, perhaps in a driving simulator. This will allow respondents to better understand the presented scenarios and will potentially make their responses more significant.

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CHAPTER 8

FINAL DISCUSSION AND CONCLUSION

7.1 Summary

The project titled "Safe and Seamless Transfer of Control Authority" was funded by Nexteer Automotive, a steering and driveline business delivering electric and hydraulic steering systems, steering columns and driveline systems, as well as ADAS and automated driving technologies for OEMs around the world. The project aimed to understand the limit of applicability and effectiveness of shared control during transitions of control authority, in particular with SAE Lv.4 automated vehicles.

Given the need to guide drivers in transitions out of and into automation, haptic shared control has been chosen to investigate the impact of its use during transitions of control. Haptic shared control was chosen over mixed shared control for two main reasons:

1. The literature provides sufficient knowledge on haptic shared control and its use with lower LoA. Therefore, hypothesis and research questions could be outlined accounting for past findings, giving them a more specific focus. Worldwide, mixed shared control accounts for a limited number of studies, thus a limited knowledge even with lower LoA.

2. Results obtained while investigating mixed shared control can not be easily transposed to haptic shared control. Vice versa, results from haptic shared control studies can be used to better develop design principles for the mixed one.

Contrarily from the concept of transition as a requirement, this thesis considered and investigated transitions as features, which can be activated and deactivated as the features found with lower LoA, perhaps a LKA or an ACC.

To investigate these two aspects, experiments were designed and conducted using driving simulators. The experimental design was driven, on one hand, by the desire to answer practical questions regarding the impact and effectiveness of adopting haptic shared control during transitions of control and, on the other hand, to deepen the understanding of drivers' behaviour during driver-initiated transitions, which is a topic hardly investigated so far.

The obtained results have allowed us to draw practical conclusions concerning the effects of lateral assistance during transitions of control on drivers' behaviour and performance and their relation with other factors of the transition such as the initiator and the adopted haptic strategy. These conclusions broaden the knowledge about drivers' behaviour during transitions of control and provide practical design implications for future studies.

A notable outcome of this thesis is also represented by the number of unanswered questions, which highlight the necessity of further investigation on both the topic of drivers' assistance and self-initiated transitions.

The work in Chapter 2 provides a detailed discussion concerning the world of transitions of control and the evolution of taxonomies and interests around related topics. Within the scope of this thesis, this chapter is the preface, highlighting inconsistencies and the colloquial use of two terms that constitute two complementary aspects of any transition of control: "takeover" and "handover". Without this basic distinction this thesis would have become hard to follow as the majority of the published works failed to use them consistently. Along with a concise definition of these two terms, Chapter 2 introduces a second set of qualifiers: "initiator" and "receiver". If one assume that every transition needs to be triggered by someone via a message, then these two terms become self-explanatory. Bear in mind that a message does not have to be strictly verbal but it could be any kind of functional interaction between the two agents partaking the transition process, namely the driver and the ADS. Then, whoever is sending such a message is initiating the transition. On the other side, an agent will receive this message and decide what to do next. It is important to notice that the choice of wording is not casual. The other agent could have been addressed as the "giver" or "provider", since it will be called to give back control or provide some sort of help. Instead, we decided to use "receiver" to underline the non-causality of the two events; receiving a message asking for something does not imply that something must be given. It is a simple concept but nevertheless important if we want to consider that technology keeps on improving and is getting closer and closer to generate smarter and safer ADS.

7.2 Answers to the research questions

Within the first chapter, we identified 5 research questions for filling the knowledge of self-initiated transitions of control and handover strategies. The studies reported in this thesis provide the following answers.

1. **How do different handover strategies affect drivers' behaviour during transitions of control?**
2. **How does varying the duration of the handover affect drivers' performance?**

Past studies have been mainly focused on addressing how drivers react to critical events, requiring their swift intervention within a limited time, usually between 4 and 7 seconds (Eriksson & Stanton, 2017; Zhang et al., 2019). Little interest has been given to self-paced transitions, namely transitions of control in which the driver is setting the duration of the transition and not the ADS (Eriksson & Stanton, 2017), or to assisted transitions, namely transitions in which the ADS actively helps drivers in regaining operational control (Walch et al., 2015). These gaps provided a good starting point to address the topic of handover of control.

Given our interest in investigating the impact of haptic shared control, a first crucial challenge regarded whether to implement an open or closed-loop interaction. In an open-loop interaction the haptic feedback does not take into consideration drivers' direct actions (e.g. SWRR, TTLC, SDLP, etc.) or state (gaze focus, workload, etc.); thus the heuristics ruling the interaction do not try to optimize, minimize or maximize any of these. The haptic guidance is tuned only over some vehicle performance and/or safety metrics among which the most common is lateral position. Here, the haptic guidance is proportional to the error between the desired lateral position and the current one. Therefore, the larger the deviation, the stronger the haptic feedback becomes. On the other hand, a closed-loop interaction adapts depending on drivers' direct inputs. The main issue with a closed-loop system is the need for profound knowledge on how the system behaves in an open loop. Otherwise, it is almost impossible to evaluate the resulting interaction as there would be no chance to distinguish behavioural variations due to the interaction alone or to the way the interaction evolves as a response to the closed-loop architecture. Given the lack of knowledge on how drivers behave when assisted during transitions of control, we opted for an open-loop configuration to have a direct link between the provided inputs (i.e. haptic feedback, experimental design, etc.) and the recorded output (drivers' behaviour and performance).

Overall, findings reported in Chapter 3 and Chapter 4 suggest that having a strong LKA within the first 5 seconds is beneficial and helps drivers to keep a safe trajectory while promoting the scanning of the surrounding. According to previous findings (Saito et al., 2018; Kondo et al., 2019), strong guidance hindered drivers from introducing steering instabilities when grabbing the steering wheel. Therefore, this result was expected; during a transition of control, sub-tasks are transferred back to the drivers, who need to cope simultaneously with all of them. Therefore, they need to take over the operational control of the vehicle and, meanwhile, scan the environment for impending threats. A gradual release of the above sub-tasks was expected to reduce the cognitive and physical load of controlling the vehicle, providing spare cognitive capacity to engage with other sub-tasks. Providing no haptic feedback or momentary assistance (via LDA) did not bring any benefit; drivers had to sacrifice the scanning of the surroundings and focus on their steering activity. It is necessary to underline how this conclusion is heavily interconnected with the proposed experimental scenario. Traffic was limited and slow-changing, hence the drivers could have felt less worried about the surroundings and decided to focus more on their steering operation as it was the most pressing task at hand. More complex traffic scenarios may yield different outcomes.

Furthermore, the chosen experimental design allowed for further considerations on the relationship between operational and tactical ability. If the first part of the take-over situation required drivers to mainly focus on operational control, the second part forced them to face an operational-tactical challenge. The proposed lane change task was made even harder by the lack of visual cues. This allowed for a set of considerations regarding the scanning strategy in the first part of the transitions and on the real impact of providing longer lateral assistance. First, it was noted that providing assistance for longer yields better outcomes in terms of lane change negotiations and crash avoidance. Drivers were more aware of the surroundings and more successful in exploiting the Blind-Spot Assist. This suggests that a fast reaction is a dangerous parameter to consider while designing handover strategies. As past studies have suggested (Zeeb et al., 2016), reaction time is not reflective of the overall drivers' performance during transitions. A specific reaction may not be appropriate. Indeed, results suggest that drivers need more time to regain the necessary control and awareness to perform tactical decisions (as a lane change). Granting drivers 15 seconds to grasp the situation around them proved to enhance the way they manoeuvred and improved drivers' capacity to interact with the haptic feedback and understand the scope of the blind-spot assist. This, in turn, significantly decreased the number of occurred crashes compared to the cases where only 2 or 7 seconds were granted. Repeated exposure to these blind-spot events did not have an impact on how drivers approached the lane change. Although overall beneficial, the blind-spot assist was the most effective when drivers had 15 seconds of lane-keeping task, irrespective of the assistance received within. This allowed for the conclusion that assisting at an operational level is not sufficient to ensure drivers' ability to cope with tactical decisions and, thus, their safety.

3. **How do Driver-Initiated transitions differ from Automation-Initiated transitions?**

The third research question was mainly postulated based on a couple of sentences found in Lu & de Winter (2015), which state that Driver-Initiated transitions can be triggered because of *"drivers' preference of control"* or also *"automation failure"*. However, by digging in the research literature, little was found addressing the topic. Thus, one of the objectives of this thesis was to provide the first piece of evidence concerning Driver-Initiated transitions and the impact that these transitions have on drivers' behaviour and road safety.

How to trigger and recreate a Driver-Initiated transition was the fundamental obstacle. System-initiated transitions are easy to implement since drivers' reaction is triggered by the system and drivers need to respond to it. Asking drivers to take over autonomously when they want to would have been the ideal situation and could have provided several interesting results. How many minutes do drivers spend in automated driving before requesting to take over? What NDRTs keep them OOTL for longer? Are drivers checking the traffic condition now and then and deciding to take over based on some related heuristics? Does the presence of passengers influence the above?

These are only some of the questions that could be answered from naturalistic-alike simulations but, for our purposes, this strategy was not ideal. Giving drivers absolute freedom to take over would have had a direct impact on comparability since the variance would have been too great. For the same reason, we needed a NDRT to ensure the same pre-transition treatment. The absence of references in the literature made the task of finding a suitable method even harder. Therefore, we decided to adopt the arrow task as the NDRT. The arrow task provided a monotonous task that would both ensure drivers' disengagement and, thanks to an artifice, could be used to trigger a Driver-Initiated transition. The artifice consisted of asking the drivers to reach a predefined set of arrow searches before autonomously requesting the ADS to hand the control over. Therefore, during Driver-Initiated transitions, drivers did not receive any input from the simulation asking for their intervention but they had to intervene themselves. This, in turn, implied that they needed to realize they had completed the searches. The number of completed searches was displayed on the same screen on which drivers were playing the arrow task but, due to the monotonous nature of the task, drivers, especially within the first study, performed more searches than necessary before realizing it. This constituted another point that needed to be carefully addressed. What time instant do we need to consider as the start of the transition? The time of completion of the searches or something else? Time of completion of the searches would have been by far the easiest to implement but not suitable for comparisons with system-initiated transitions. For the sake of comparability the time instant that was considered as equivalent to the TOR in system-initiated transitions, was the time instant when drivers stopped playing the arrow task. This happened only if and when drivers realized they completed the searches and is robust against drivers missing the completion of the searches.

Results reported in Chapter 3 and Chapter 5 address the third research question. The findings indicate that drivers do not behave the same during DI and system-initiated transitions. In particular, it was found that the proposed lateral assistance did not yield the same effects in both transitions. In Chapter 3, it was highlighted how drivers tended to keep a firmer steering control during DI transitions. This made drivers increase the steering torque when exposed to a strong LKA. The larger steering effort proved to be ultimately beneficial since drivers were able to maintain a steadier drive in the last phase of the transitions (i.e. during longitudinally assisted driving). During system-initiated transitions, drivers reduced their steering engagement in favour of a more attentive behaviour towards the road ahead. However, their steering control was poorer in the last phase of the transition compared to DI cases.

This first study raised the importance of understanding how drivers behave during DI transitions. In particular, it was noted that providing assistance during DI transitions seemed to be somehow detrimental in terms of both performance and comfort. In fact, not only did drivers exert stronger steering, but they also reported a higher mental load during DI transitions compared to the system-initiated ones. Thus, it seemed that assisting drivers who were already engaged with the DDT was not necessary. On the other hand, during system-initiated transitions, drivers did not exhibit any of these traits. Instead, they followed the provided guidance and performed poorly in comparison. Assisting drivers, in this case, is of paramount importance as they seemed not engaged with the DDT, at least not at a physical level.

This allowed for some practical conclusions concerning handover design. First, during DI transitions it is better to supervise drivers' operations rather than provide strong guidance as this could introduce steering conflicts. Steering conflicts could push drivers to disable the assistance during transitions, which would negate the benefits the assistance was designed to provide. On the contrary, during system-initiated transitions, drivers greatly benefit from strong guidance as their steering engagement is not enough to provide steady control of the vehicle trajectory. Given drivers' visual engagement with the road, HMI should be exploited to redirect drivers' attention towards salient AOIs while the steering assistance helps them to keep a steady drive.

The results presented in Chapter 3 and Chapter 5 allows for a more detailed analysis of the reaction procedure drivers underwent during the presented studies. Past works tried to model the reaction procedure and performances taking into consideration many different aspects (Gold, 2016; Zhang et al., 2019). Traffic density and the time budget available for taking over vehicle control played a major role when modelling take-over performance in driving simulator studies. In our experiments, we removed time-budget from the list of possible predictors because in SAE Lv.4, albeit a time-budget can be specified, there are not any time limits. Furthermore, in user-initiated transitions, time-budget itself is likely to become a function of the same predictors used for the evaluation of take-over performance, namely traffic density, repetition, drivers' age, etc. In the presented studies, instead, two different driving simulators were adopted. With a low-immersive driving simulator, the reaction procedure in user-initiated transitions took longer. Drivers spent more time looking at the road ahead, while grabbing the steering wheel before requesting the handover. On the contrary, with an immersive driving simulator, drivers in both system and user-initiated transitions hasten the reaction procedure and requested the handover in a matter of a few seconds. What was not affected by the driving simulator was the steering engagement, which was mainly dependent on initiation. Past studies have shown that, during system-initiated transitions, drivers' reaction time is generally shorter during on-road experiments compared to simulation (Eriksson et al., 2017). Nevertheless, both reaction times were on average below 7 seconds. As in the presented works, the impact of risk perception must be accounted for (Flach et al., 2008; Carsten & Jamson, 2011; Underwood et al., 2011; De Winter et al., 2012). However, it needs also to be considered that risk perception, as trust, might evolve with repetition (i.e. usage) (Manchon et al., 2021).

The above discussion allows for a couple of takeaways. First, assistance during a transition needs to consider initiation as a factor to tune the provided assistance. Second, initiation affects also the needed time budget. Indeed, the transition time-budget is a key element to consider during the design of a transition process. In DI cases, drivers have shown to engage the DDT instantly, hence 10 seconds seem enough but, with system-initiated transitions, drivers' engagement with the DDT is not as quick and drivers may constitute a threat to road safety if they have not been properly re-engaged with the DDT. This consideration led to the design of the second experiment, reported in Chapter 5. The goal was to understand whether instigating steering conflicts, as the one seen in DI cases, could be used to hasten drivers' re-engagement with the DDT in system-initiated transitions.

4. **To what extent do steering conflicts can hasten drivers' re-engagement with the driving task?**

Results presented in Chapter 5 support the findings presented in previous chapters: drivers in DI transitions are more engaged with the steering task and tend to fight strong steering assistance. In opposition, during system-initiated transitions, drivers start to engage the steering task only after 5-6 seconds from requesting the handover. Inconsistent steering guidance was provided in the hope of triggering steering conflicts. Following past findings (Mars et al., 2014), it was postulated that creating confusion over who is in charge of steering would indeed trigger such steering conflicts. These in turn, would hasten drivers' steering engagement, especially during system-initiated transitions. Although steering conflicts were present, it was not possible to conclude whether the provided feedback was the triggering factor. It was very clear that, during system-initiated transitions, drivers underwent a slower re-engagement process. It was also found that this process completed right before the given 10 seconds, which still constitutes a relevant outcome. Results did not make it possible to conclude anything concerning the usefulness of having discontinued steering assistance during system-initiated transitions.

The lack of evidence on the topic does not allow any inference about what triggers driver' engagement after a TOR. Although urgent RtIs produce quicker responses (Naujoks et al., 2014; Petermeijer et al., 2016; van den Beukel et al., 2016; van der Heiden et al., 2017), they might fail to trigger drivers' engagement with the steering task. Urgent RtIs must be used with parsimony and only when strictly necessary, otherwise drivers could loose trust in the ADS (Sheridan, 2002; Pritchett, 2017). Given drivers reactions, what drives these different responses is still unknown. Why do drivers display greater steering engagement during DI transitions? Are they doing it consciously? Is the little engagement displayed during system-initiated transitions related to drivers over-trust on the ADS or on the simulation? These are the questions that brought on the creation of an online questionnaire reported in Chapter 6.

5. **Are drivers self aware of their own behaviour during transition of control?**

Past studies have investigated the effects of mental models and the use of new ADASs. Practice and exposure help drivers build a mental model (Piccinini et al., 2012; Beggiato & Krems, 2013; Singer, 2020) but HAD is not a feature current vehicles can provide and thus drivers have not yet been exposed to transitions of control. Their behaviour during transitions was supposed to be due either to some dispositional factor or due to the mental model drivers build based on their knowledge and/or experience with lower LoA or simply on their expectations on how a ADS should behave on such occasions. Given how drivers behaved differently in system and user-initiated transitions, it was hard to infer the root cause of their diverse reactions. On one hand, drivers could have deemed themselves fit to take over during user-initiated transitions, thus fighting any system imposing guidance. On the other hand, drivers might have expected the ADS to do something different from what the ADS did. The latter case is not new in research. Aviation has faced a similar issue when automated systems were introduced to help pilots (Sarter et al., 1997). Hence, a pilot survey was developed to investigate drivers' expectations and preferences during transitions of control from HAD. The results detailed in Chapter 6, although limited by the small sample size, suggest that drivers have different expectations towards ADS behaviour during transitions of control. The survey, however, failed to correlate these expectations to drivers' role as initiators. The presented stories, adopted to introduce respondents to the different transition situations, were not enough to trigger any significant response. Hence, it was not possible to understand whether drivers are self-aware of their different behaviours between driver and system-initiated transitions. Instead, drivers' preferences and expectations were correlated with their disposition towards automated driving. In particular, respondents who believed in ADAS helpfulness expected to be assisted and for longer. On the contrary, older and more experienced drivers expected the ADS to switch off and let them drive manually. Moreover, current ADAS users were more aware of the impact that HAD could have on their capacity for driving. Nevertheless, most respondents did not believe their capacity of controlling the vehicle to be reduced. This finding suggests that drivers are mostly unaware of the challenges implied by automated driving, the OOTL phenomenon in particular. In aviation, this has been already documented among pilots. Without a strong mental model of what the automated system is doing and what are the limitations of these automated systems, pilots took more risks than they would usually do, causing serious accidents (Sarter & Woods, 1995). The blind introduction of automated systems made it for some pilots difficult to decide whose authority was the one to be relied upon between their own and that of the system. Ultimately, learning and training proved to be extremely beneficial when interacting with automated systems (Casner & Hutchins, 2019). If then a lesson must be learned from the past, it is that the increasing introduction of more advanced ADS has led drivers to believe automated driving means benefits without costs. Although this is the ultimate end of automation, the road ahead before reaching that goal is still far and, meanwhile, drivers are becoming more similar to aeroplanes pilots, asked every new year to cope with technology advancements they can not entirely understand.

7.3 Thesis contribution and future research

The main theme, interconnecting the chapters and the presented works, is transition of control in HAD. The presented work tried to introduce the concept of transitions as features. Although not a new concept with lower LoA, the conducted literature search showed that it is not the case with CAD, nor HAD.

Transitions were here considered as functions drivers can call and rely upon. A handover procedure, as a set of operations the ADS performs to aid the transition process, is the maximum expression of this idea. A handover procedure is the feature helping the drivers in the process and can be called by both the driver and the ADS. As already pointed out throughout the thesis, handover procedures are functions that are yet to be fully investigated and understood. But it is my belief that will be a key element in future fleets of automated vehicles. Another key contribution swirls around the concept of initiation. Drivers can start transitions of control and the ADS needs to be taught how to handle every specific situation to ensure road safety. A driver initiating a transition during HAD is one of the situations that might occur and this thesis provided evidence that here drivers require a different kind of assistance. Indeed, drivers' behaviour during system-initiated transitions is not suited to be generalized and used to design handover procedures for both cases. The OOTL phenomenon is still something only researchers appreciate and drivers' lack of awareness might introduce dangers as it has done in aviation. The final contribution of this thesis is the outline of possible future research.

Reconsidering the closed-loop configuration in light of the presented findings, two different closed-loop control strategies should be adopted in the two AI and DI cases. During the first 5 seconds of AI transitions, the closed-loop configuration should be based on lateral position and try to keep the vehicle within a safe trajectory with a strong steering guidance. After the first 5 seconds, the closed-loop should be tuned differently. The strong steering guidance should be replaced with a lane departure assist, thus allowing for more freedom within safety margins. During DI transitions, the closed loop configuration should behave as a supervisor, allowing the drivers to move freely within safety margins while tailoring these margins to reduce the error between the controller reference trajectory and drivers' chosen trajectory. This will allow to reduce steering conflicts and provide a more consistent support.

It is yet unclear whether a more complex scenario would push drivers to extend the re-engagement time or to decrease their steering engagement. In the first case, drivers would allow for a more thorough scan of the surrounding, thus splitting the required sub-tasks (control and monitoring) into two subsequent steps. The first, while still in automated driving, aimed at collecting information and, according to SA theories, at predicting traffic near future states. The second, after re-engaging the steering wheel, aimed at maintaining a proper steering control while shrinking their visual focus only towards pre-selected regions of interest. Both these two speculations, somehow assume that drivers are aware of the OOTL phenomenon and have embraced automated driving consciously and are aware of its limits. As aviation research reminds us, this process takes training and learning, aspects that have been notoriously neglected since the introduction of the first ADASs in commercially available vehicles.

The chosen strategy to study Driver-Initiated transitions was not ideal. We hope that the presented method and results will help future studies to further investigate the topic, which has still been little investigated. There are several unanswered questions, some of which have been already highlighted in the past chapters. Of course, the adopted methodology has its flaws and needs refinements. The triggering factor in user-initiated transition was far away from naturalistic. As it was explained, this was a necessity for the sake of controllability and reproducibility. Extensive research should investigate what could be the triggering factors. Several factors could push drivers to take back control by themselves and the ADS will need to plan a handover strategy from that moment onward. Since time-budget might still be an issue in the future, providing means to the ADS to understand when it should expect a handover request to happen. Future research questions should identify internal and external factors triggering a transition. Internal factors could be boredom from being in HAD for too long, anxiety from the ADS driving within legal speed limits or a sudden desire for adrenaline or even a very common need to stop for a toilet. Understanding which of these factors might trigger a user-initiated transition is also important to deal with the moral and legal obligations a ADS should abide to. Namely, it is not always a good idea, or legal, to grant drivers the right to take over control. On the other side, external factors could be related to traffic density, weather, road type and conformation or even interest in something along the road (national park or other touristic attractions, restaurants, malls, etc.). These, however, deal only with the trigger factors for user-initiated transitions and do not dig into how or why drivers showed different behaviours during the transitions.

To give a better insight around the motivational needs during the transition process a metaphor shall be presented. Let's consider the metaphor of a father trying to help his child to ride a bike. At the very beginning, the father is standing behind while holding the bicycle so to avoid the child from losing equilibrium and falling. As the child starts pushing the pedals, erratically steering left and right, the father is still keeping an hold of the bike while trying to help the child the handlebar steady. At some point, the child starts to achieve a better control over the basics of biking. Therefore, the father starts to reduce his inputs and gradually let the bike, and the child, free. This metaphor allows for some considerations, embracing not only drivers' motivational needs (the child's needs), but also the needs of the ADS (the father). Indeed, for every drivers' internal or external need, the ADS might have its own motivational needs. These, in turn, are likely to be different from drivers' and this difference could sometimes negate the benefits a handover strategy is supposed to provide. For example, let's assume the ADS issues a TOR and the driver is supposed to respond. Drivers' needs in this case are somehow irrelevant as they are called to respond to a TOR. If they fail to respond, the vehicle (SAE Lv.4) will perform a minimal risk manoeuvre and abort the trip. This would clash with drivers basic need of getting somewhere. Hence, drivers' only option to fulfill their need of getting someplace is to respond to the TOR and take back control of the DDT. In this framework, drivers' need becomes taking over control to be able of continuing their trip. Meanwhile, the ADS needs to reduce its authority over the DDT because it is getting closed to its ODD while ensuring a safe handover of control. This is not a trivial needs and it requires the ADS to carefully plan the transition time budget to allow for drivers' take over while being able to provide assistance during the transition. Coming back to the presented metaphor, the father needs to decide carefully where to start teaching the child how to ride. If the road ahead is not free for long enough, the child will not have time to get confident! Hence, as the ADS, the father needs to plan the handover with a certain time budget to ensure the safety of the child. The child's safety represents the motivational needs for the father as well as the driver's safety for the ADS. While safety is, of course, a primary need, there is also another that is engraved with the transition process: to grant back control to the driver. The father as well, is with the child for safety but the main goal is to teach the child to ride alone. These two needs could sometimes collide with each other. If driver wants to take over to speed up, driver's need will clash with the legal obligation of the ADS. If the driver wants to stop or take a detour from the previously planned trip, then the ADS would need to provide assistance and make sure the driver regain control skills and is able of making safe decisions. Similarly, if the child new found confidence pushes him/her to speed up, the father will slow the child down as it would deem the child not ready yet. Nevertheless, the child may keep trying to follow a different path from what planned by the father, who will be still following and helping the child. While the training (i.e., the transition) continues, the motivational needs evolves as both the father and the child are learning and adjusting to each other. The child will start to hunch how to use the handlebar and the basics of equilibrium while the father will try to help the child based on the perceived child's control. The same way, the ADS will try to help the drivers while considering, as the father, that, on one hand, too much help will make harder for the drivers to regain the necessary control skills (and for the child to get the basics of riding) and, on the other, too little help will likely results in safety risks (and for the child, the risk of falling off the bike). Hence, the child and the father might, at times, have opposing needs based on their own perception of the needs of the other. If the child deems to be able to ride alone, needing more freedom, but the father deems the opposite, the learning process will become harder and will potentially take longer. Similarly during a transition of control, understanding the needs of the driver might facilitate the process.

From the very beginning of a transition, it is still not clear why drivers, in system-initiated transitions, rushed to the interface and requested the handover while then showing little steering engagement. Similarly, it is not clear why drivers behaved the opposite in driver-initiated transitions. Chapter 6 showed that dispositional factors may exist and impact the way drivers interact with the ADS at an individual level. However, the behaviour seen during the presented simulator experiments was heavily dependent on drivers' role as initiators. Thus, we still do not know the reasons. On the other hand, it might also be that the reason has not been found because of the limited sample size and collected information. In both the presented experiments, participants age was, on average, around 35 years old. A larger data set might highlight a correlation between age and drivers' different behaviour in user and system-initiated transitions. Again, this might be the most important takeaway from this thesis: there is still much unknown around transitions of control and this thesis highlighted that user-initiated transitions with HAD and handover strategies are new topics that need to be further investigated.

However, this thesis is mainly focused on the operational aspects tied to drivers' take-over, namely how drivers re-engage the lateral control of the vehicle. It is important to remember that this is only one aspect of the take-over and does not describe the whole process. The struggle in regaining control over the ADS during our simulator studies is evidence that the different sub-tasks must be handed over to drivers at different stages during the transition. In the conducted studies, drivers' SA was never investigated but only inferred based on drivers' tactical decisions during the lane changes. We concluded that drivers, during user-initiated transitions, prioritized the operational control and started to scan the surrounding only once they deemed that their steering control was good enough. On the contrary, in system-initiated transitions, drivers sacrificed the operational control to scan the surroundings. None of these behaviour is to be considered optimal; handover procedures should be designed to allow drivers to focus on a single sub-task at a time. Hence, future handover procedures should provide contextual information concerning the status of the ADS and the surrounding traffic while retaining the longitudinal and lateral control. Drivers need time to allocate mental resources and comprehend what is happening around them. Only after some time, which is still to be defined, the ADS should start to hand over the longitudinal and lateral control.

7.4 References

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