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Drivers' information gathering pattern during transitions to manual control: a study about HMI design for autonomous vehicles

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Abstract

Cirino Gonçalves, Rafael; Quaresma, Maria Manuela Rupp (Advisor); Merat, Natasha (Co-advisor). **Drivers' information gathering pattern during transitions to manual control**: **A study about HMI design for autonomous vehicles.** Rio de Janeiro, 2018. 179p. Dissertação de Mestrado – Departamento de Artes & Design, Pontifícia Universidade Católica do Rio de Janeiro.

Highly automated vehicles (HAVs) are bringing new perspectives for the field of automotive ergonomics. By the time the driver is not constantly on the decision-making loop of the task, his/her performance for resuming control of the automation in safety-critical situations seems to be diminished. To mitigate this problem, many authors believe that by understanding drivers' information scanning patterns and decision-making process during transitions of control in vehicle automation it is possible to design tools better adapted to support them in this activity, by providing relevant information in appropriate times. Based on this issue, this research aimed to categorize driver's reliance on the different information provided by the system's HMI during transitions of control in different levels of automation. The research followed a driving simulator experimental approach, where drivers were exposed to different take-over scenarios and their gaze behaviour was measured to test the hypothesis that they generally rely on information on the road to gain situation awareness, and only access the information on the HMI in cases of transitions of control, to check the system status. The results suggest that driver's gaze behaviour patterns are susceptible to influence of two main factors: the level of automation and the task in hand. It was observed that the more information presented on the HMI, the more drivers will look at it. Active information about the road environment have enhanced drivers' performance during transitions of control, but it was not reflected in terms of perceived usability of the systems.

Keywords

Automotive Ergonomics; Human Factors and Ergonomics; Human-Automation Interaction; Human Machine Interface; Interface Design; Highly Automated Vehicles; Take-over request.

Resumo

Cirino Gonçalves, Rafael; Quaresma, Maria Manuela Rupp (Orientadora); Merat, Natasha (Co-orientadora). **Padrões de aquisição de informação durante transições para controle manual: Um estudo sobre design de interface para veículos autônomos**. Rio de Janeiro, 2018. 179p. Dissertação de Mestrado – Departamento de Artes & Design, Pontifícia Universidade Católica do Rio de Janeiro.

Veículos autônomos ou *Higly Automated Vehicles* (HAVs) vêm trazendo novos paradigmas para o campo da ergonomia automotiva. A partir do momento em que motoristas se encontram fora de um *loop* contínuo de tomada de decisão, suas capacidades de retomada de controle manual do veículo durante situações de emergência são comprometidas. Para mitigar este problema, muitos autores acreditam que um maior entendimento dos padrões de aquisição de informação durante retomadas de controle em automação veicular pode fornecer insumos para a concepção de ferramentas designadas a auxiliar o motorista nesta tarefa, ao fornecer informações relevantes em momentos de necessidade. Baseado nestas questões, esta pesquisa visou categorizar o acesso de motoristas a diferentes informações oferecidas em interfaces de veículos autônomos durante a retomada de controle em diferentes níveis de automação. A pesquisa abordou o problema por meio de experimentos em simuladores de condução, onde motoristas foram expostos a diferentes cenários de retomada de controle, e seu seus padrões de olhar foram avaliados, para se testar a hipótese de que eles geralmente acessam a informação presente na interface apenas durante a retomada de controle em si, para checar o estado do sistema. Os resultados sugerem que o olhar do motorista está sujeito a influência de dois fatores: nível de automação e tarefa desempenhada. Foi observado que uma maior a quantidade de informação oferecida na interface aumenta concentração de olhares do motorista nesta região. Informações ativas sobre o ambiente melhoraram o desempenho do motorista durante as retomadas, porém tal benefício não se refletiu em uma maior usabilidade percebida.

Palavras-chave

Ergonomia automotiva; Ergonomia e Fatores Humanos; Interação Humano-Automação; Interface Humano-Máquina; Design de interfaces; Veículos autônomos; Retomada de controle.

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Glossary

HAV – Highly Automated Vehicle.

LoA – Level of Automation.

ADAS – Advanced Driving Assistance System.

NHTSA – National Highway Traffic Safety Administration.

HSE – Health and Safety Executive.

SAE – Society of Automotive Engineers.

ANOVA – Analysis of Variance.

PRC – Percentage Road Centre.

CAD – Conditionally Automated Drive.

DAD – Partially Automated Drive.

UoLDS – University of Leeds Driving Simulator.

ITS – Institute for Transport Studies.

PUC – Pontifical Catholic University.

SUS – System Usability Scale.

TOR – Take Over Request.

HUD – Head-Up Display.

SA – Situation Awareness.

OotL – Out of The Loop.

OODA – Orientation Observation Decision Action.

HMI – Human-Machine Interface.

M – Mean.

SD – Standard Deviation.

N – Sample Size.

"The real problem is not whether machines *think, but whether men do. The mystery which surrounds a thinking machine already surrounds a thinking man"*

-B.F. Skinner, 1953

1
Introduction

This research has its fundamental theoretical basis grounded on the theme of Human-Automation Interaction, more specifically related to its application for the HMI (Human Machine Interface) design for autonomous vehicles. HAVs (Highly Automated Vehicles), or autonomous vehicles, are increasingly being used for driving assistance and gaining visibility due to its growth in the global market (BCG, 2016). Despite its notorious capabilities and promises, continuous usage of this technology can bring several impairments on drivers' performance (Young, 2012). According to Jones (1992), humans, after prolonged exposure to automation presented drastic reductions on their capabilities of supervising the task environment, which makes them vulnerable to a safety-critical situation, and driving is no exception to that rule. Parasuraman & Manzey (2010) also warn about the costs of automation, which may lead to induced complacency and automation bias. Once they are not in control of the driving task anymore, drivers are more likely to divert their attention away and unconsciously rely on automation to perform the task and grant safety.

Several empirical studies support the statements above. Carsten et al. (2012) stated based on driving simulator studies that drivers under highly automated driving conditions have a higher probability to engage in secondary tasks. Merat et al. (2014), Damböck et al. (2013) and Louw & Merat (2017) have also found that when driving HAVs, drivers have reduced the percentage of visual monitoring to the road centre. De Winter et al. (2014) have shown through a literature review that this reduction of visual attention to the road centre is a reliable indicator of drivers' low level of situation awareness, and even of a possible out of the loop state (Endsley, 1995a). In other words, as they divert their attention away, drivers lose track of fundamental information about the state of both the system and environment, which are generally required to re-establish control of the vehicle.

This issue would not be a problem if drivers were always able to re-establish situation awareness before assuming control of the vehicle and avoid one safety-critical situation, but that is not always the case. Endsley (2006) has proven during her work that resuming situation awareness is not an easy task, and is surrounded by several barriers. According to McKnight & Adams (1970), the driving task is composed of over 1700 simultaneous activities, and the driver is not always capable of controlling everything. Parallelly, Boer & Hoedemaeker (1998) stated that the driving task provides several sources of relevant information, but according to Wickens (1981), each one of them is processed procedurally, which might not give enough time for a proper transition. Parasuraman & Riley (1997) warn for the information overload of operators (in the case of this research, drivers) when trying to resume control of automation, after being removed from the decision-making loop. As complementary empirical evidence, Louw & Merat (2017) reported in their experiments that the more drivers are removed from the loop, more aggressive and dangerous is their transition of control.

Based on the arguments presented above, it can be assumed that to support such a complex task as the transition of control in vehicle automation, it is first necessary to understand the processes behind human decision-making and information scanning patterns during these scenarios. In their driving simulator studies, Louw & Merat (2017) have reported that drivers who successfully avoided safety-critical situations during transitions of control presented one same stable gaze-dispersion pattern during the experiment, as the ones who crashed presented a more erratic one. Based on this, it can be assumed that there must be one set of specific information required for a driver to safely resume control of autonomous vehicles. This assumption is also supported by Goodrich & Boer (2003), who believe that by understanding drivers' decision-making processes, it is possible to develop better-designed tools to help them in their activities.

Several studies successfully attempted to relate drivers' visual scanning patterns with information processing and the acquisition of situation awareness (Chapman et al., 1998; Underwood et al., 2005; Crundall et al., 2003; Posner, 1980). Based on this, it is believed to be possible to model and identify what key information must be provided on the HMI of HAVs to enhance transitions of control. It has been proved that this is a key support item to improve driver's performance with automation (Schieben et al., 2014; Dziennus et al., 2017; Gonçalves, Quaresma & Mont'Alvão, 2017). Considering the arguments above, this research had as research object the drivers' information gathering behaviour during the resumption of control of autonomous vehicles.

Many authors have observed several factors that seem to influence on driver's visual scanning patterns (Chapman et al., 1998; Underwood et al., 2005; Crundall et al., 2003). Even so, most of these studies were based on manual vehicle control and did not consider factors such as levels of automation, nor HAVs' interfaces. Once established the relationship between eye-gaze patterns and transitions of control in vehicle automation, the following three research questions were purposed to compose the research problem:

- What information drivers need to acquire in order to regain situation awareness to decide how to act in different levels of driving automation?
- Which information sources do drivers rely on to acquire the information they need on take-over scenarios?
- What is the impact of different information provided on system’s HMI on its usability during transition of control?

Based on the questions above, this research had as the hypothesis that drivers generally rely on information on the road to gain situation awareness, and only access the information on the HMI in cases of transitions of control, to check the system status. Adding more information on the interface won’t necessarily increases the system's perceived usability.

The research's main goal was to categorize drivers' reliance on information provided by Highly Automated Vehicles' HMI based on their behaviour patterns during the transition of control. To do so, the following specific objectives were purposed:

- Understand the main factors that may interfere in the relationship between drivers and autonomous vehicles during transitions of control;
- Understand the priority given by drivers to each information present on the road/vehicle during take-over scenarios in different levels of automation;
- Identify which information source is accessed by drivers to acquire each specific information needed during take-over scenarios;
- Identify the sequence of drivers’ information attendance during takeover scenarios;

- Evaluate the impact of different HMI approaches on the system's usability during transition of control.

Each of the elements of the HMI for Human-HAV communication collaborates in different scales for shaping the way the user interacts with automation, leading to better or worse performance. Considering the role of the HMI designer for HAVS as responsible for the control of the interaction elements between the drivers and those systems, it is believed that this professional has a strong influence on the outcomes of this relationship, and consequently on the road safety. To better understand how to design interfaces for vehicle automation, it is first necessary to understand the human behind the steering wheel, and how to cater for their needs.

This research had one experimental and quantitative nature methodology, approaching the problem through empirical evidence of drivers' gaze behaviour on conditions that emulate a real take-over situation. The data is further discussed in light of literature review that surrounds the research problem. To answer the research questions and reach the proposed objectives, three techniques were applied:

- A systematic literature review regarding factors that may cause influence in the relationship between drivers and HAVs during transitions of control.
- *Post-hoc* gaze behaviour analysis of one experiment related to lane change on HAVS, where the metrics for eye tracking analysis were defined outside the initial experimental project.
- One driving simulator experiment focused on diver assessment of information on different HMI modalities during transitions of control.

The first technique was designated to reach the primary specific objective, in order to update knowledge about the state of the art in the area, and better develop the following steps of the research. Both experiments were part of the EU funded AdaptVe project which aims to provide a deeper understanding of drivers' decision making and vehicle control during transitions from automation to manual driving. All the two studies are focused on non-safety-critical driver-initiated transitions to manual. As literature suggests that limited time budget and the criticality of the situation might narrow drivers' field of view, which might create a bias on the research data (Gold et al., 2013, Louw & Merat, 2017; Crundall et al., 2003 Chapman et al., 1998). Drivers were given as much time as they wanted in order to simulate how would be one "ideal decision-making process".

On the table below, there are the objectives and content that will be present in each chapter of this dissertation:

Chapter	**Objective**	**Content**
1. Introduction	This dissertation's introduction provides to the reader a brief overview of the problem, and contextualization and the overall structure of the research.	- Theme and research problem; - Hypothesis and research object; - Main and secondary research goals; - Methodology; - Brief description of each chapter.
2. Vehicle automation: Definition, Perspectives and Failures	Present the main concepts of the Human-Automation Interaction. Present the concept of autonomous vehicles, and the state of the art of current technology. Relate the issues of the Human-Automation Interaction to the autonomous vehicles' topic, highlighting the challenges therein for this field of study.	- Foundations in Human-Automation Interaction; - Operational model of automated systems; - Levels of automation; - Automation fallibility and interaction issues; - Definition and classification of HAVs; - Current challenges for the studies in human factors for HAVs.
3. HAVs and the driver as a task supervisor	Present the challenges for the interaction between humans and HAVs, especially when it comes to the transition of control. Define the concept of take-over request, and explain the basis of situation awareness acquisition.	- Challenges in Human-Automation Interaction; - Definition and issues of TOR; - Definition and taxonomy of situation awareness; - Challenges for situation awareness acquisition and transition of control; - Satisficing decision making; - Situation awareness acquisition process; - Eye tracking measures and vehicle

	Explain the relationship between eye-movement patterns and information acquisition for resumption of control in vehicle automation. Highlight the value of interface design as a possible tool to aid drivers during transitions of control.	control.
4. Methodology	Stablish the margin and focus of this research, explaining the methodological approach for it. Describe and explain the research methods applied. Characterize the experimental design and data analysis for each method applied.	- Research structure; - Evaluation metrics and research variables; - Methodology structure; - Experimental design (s); - Data analysis processes for hypothesis verification.
5. Results	Present the overall results of each technique applied individually, with brief insights of their outcomes; Demonstrate how those results are related to the research problem;	- Data presentation of each experiment; - Statistical tests' results; - Overall data interpretation.
6. Discussion	Correlate the data found on the results with the core literature and discuss its implications to the field. Correlate the individual results together in order to understand how the whole picture answers the research questions and validates or not the hypothesis.	- Correlation of the overall findings with the core literature; - Answer of the research questions; - Hypothesis evaluation; - Overall implications of the findings
7. Conclusion	Summarize the whole structure of the research and arguments. Synthesize the key findings and overall implications. Ponder about the study limitations and future directions of the research.	- Research findings overview; - Key findings and implications for the state of art; - Limitations and future directions

References	All the references used on the whole dissertation.
Appendices	All the raw material produced and used on this research.
Annexes	Expanded figures and models extracted from the literature of this research.

2
Vehicle automation: definition, perspectives and failures

This chapter will focus on the base-theory needed for a more in-depth understanding of the issues that surround the research problem of this master's dissertation. As it deals directly with automation and automotive ergonomics, the first part of the chapter will deal with fundamental principles of the Human-Automation Interaction (HAI), while the second part will focus on the new trends and challenges on autonomous vehicles' technology.

2.1.
Principles of Human-Automation Interaction

The arrival of automation technology has brought new dilemmas for the field of the design, human factors, and ergonomics. Whenever automation is inserted in the task, the human role changes completely (Sheridan & Parasuraman, 2005). For this reason, it is necessary to understand how this human-automation relationship interferes with the different factors that affect the research problem.

2.1.1.
Automation definition and basic operation

Before beginning the reflexion purposed by this work, it is first necessary to define the concepts of automation and autonomous systems, in their different fields, and how it will be applied to this research. In previous research (Gonçalves & Quaresma, 2015), the term automation was defined as: "every system capable of performing certain task completely or partially without the need for direct human intervention in their processes" – a concept first established by Sheridan & Parasuraman (2005). According to the authors, the concept has four different meanings/applications: 1) mechanization of certain labour, and scanning of contextual variables; 2) data processing and computer-based decision-making; 3) mechanic action that applies force in a given environment/object; d) data scanning and processing to support human decision. For this dissertation, it will be considered a broader definition of the concept, first presented on this paragraph, mostly because it includes the four meanings mentioned above, in different scenarios task where the automation is inserted. In other words, the main point of the concept of autonomous systems, for the field of human factors and ergonomics, is the fact that the human labour is not necessary anymore to achieve the task's goals.

In classic studies found on the base literature in field of human factors and ergonomics (Moraes & Mont'alvão, 2012; Chapanis, 1959; Proctor & Vu, 2006 Apud. Salvendi; Fitts, 1947) the task analysis was made based on the triad Human-Task-Machine. In this structure, the human, who possess the technique to perform the task, achieve his/her goals through manual/informational inputs on a certain machine – as can be seen on the model described by Proctor & Vu (2006) (figure 2.1).

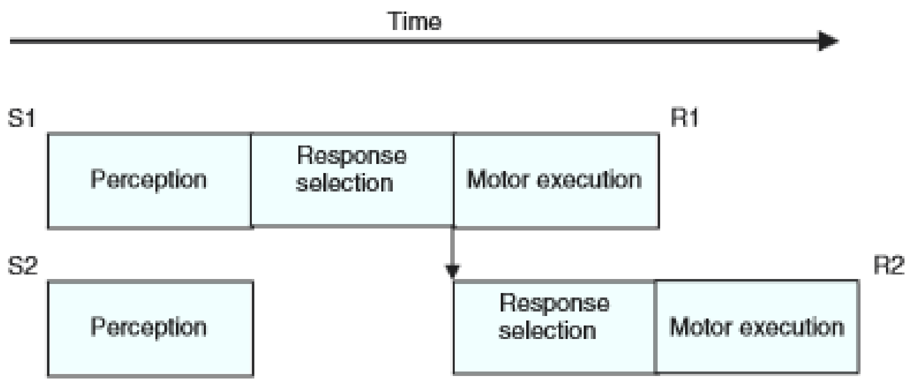

Figure 2.1 – Interaction model Human-Task-Machine. Source: Proctor & Vu (2006) (Expanded copy in annexes).

More recent studies on the field have established one new model to characterize the processes that occur during the Human-Automation Interaction, as the human moves away from the centre of the task, and delegates most of the labour to the machine. In this new conjuncture, the machine – or automated system - assumes the operational role of the task, performing the activities with precision and agility way higher than the human capability. Besides their superior physical abilities, according to Norman (2009) and Wickens et al. (2010), such systems lack decision-making skills once they are not capable to subjectively analyse and evaluate complex situations. In other words, automation systems base all their decision-making process in a limited amount of abstractions from numeric reads of sensors that are translated into a hypothetic assumption of the real world, that might or not be accurate with the reality, which may compromise the safety of the performed task, especially on emergency situations. In a similar line of thought, HSE (2003) states that automation is best suited to discrete/controlled environments, where the number of possible scenarios is limited and fully capable of prediction by sensor reads (E.G., industrial control processes, and other closed settings). Unfortunately, a significant proportion of automated systems are applied to complex and probabilistic scenarios – such as the driving environment, where not all the safety-critical situations can be modelled in a limited set of possibilities. On the other hand, the human/user/operator of the system, despite not having the same skills to perform the task itself with similar efficiency, possess plenty of capabilities for critical and strategic thinking. For that reason, he/she is responsible for identifying the task's goals; define the activities to be performed and observe the execution process, without the need for direct intervention, unless in case of a system failure.

Sheridan & Parasuraman (2005) and Dekker (2004) define this new interaction structure as supervisory control paradigm, which represents strictly the roles of each individual – human and automation – inside the task, based on their capabilities and limitations. From the perspective of the user, the supervisory control can be divided into five steps (Sheridan & Parasuraman, 2005; Dekker, 2004): 1) offline task planning; 2) programming and system orientation; 3) monitoring of automated system during task execution; 4) interference on the system workflow (in case of a malfunction or limitation); 5) learn with the experience. From the perspective of the automated system, as can be seen on figure 2.2, researchers (Young, 2012; Degani, 2004; HSE, 2003; Sheridan & Parasuramanan, 2005) defined similar steps for its operational workflow: 1) observation of certain variable through sensors; 2) orientation of this variable according to with the relevant thresholds; 3) decision of the optimal action according to the given scenario; 4) execution of the chosen activity.

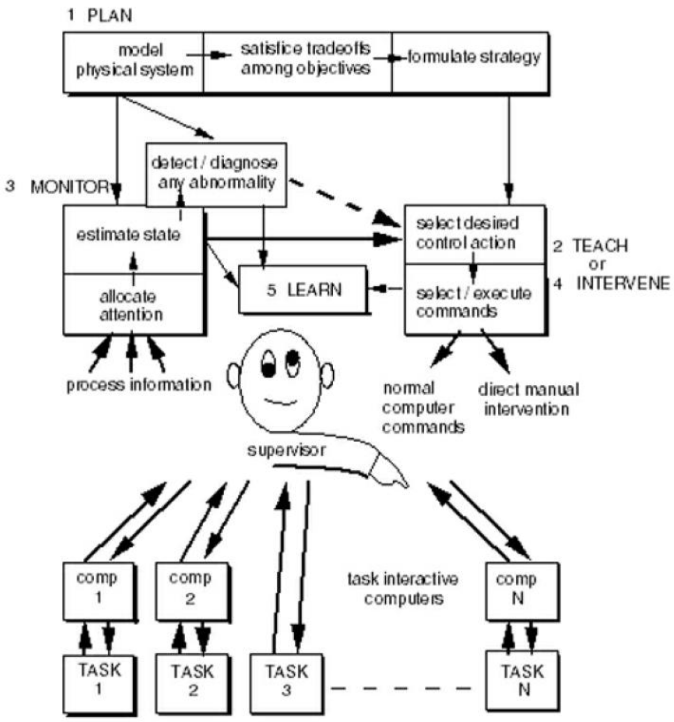

Figure 2.2 – Model for the supervisory control paradigm. Source: Sheridan & Parasuraman (2005) (Expanded copy in annexes).

In summary, it can be assumed that automation removed the human being from the operational role of the task, reallocating them to a vigilant function. As already said by Parasuraman et al. (2000), the insertion of automation on the human labour does not just change the way the task is done, but alters its context in a way it cannot be seen in the same way. Issues such as biomechanics, muscular stress and technical skill for task execution ends up losing their importance in favour of new variables, such as monitoring apathy, situation awareness and human trust in autonomous systems. In the same line of thought, it is not efficient to think about human and machine activities separately. By observing the processes that compose the supervisory control paradigm, it is evident that all the steps of both sides – human and system - are deeply related, in a way that failure on any part of the process may severely jeopardize the whole task. In case an automated system presents one malfunction and its operator is unable to perceive it, the entire task is compromised. Norman (2009) defends that every automated system is prone to error, and is most of the time unable to perceive its failures, needing a human intervention in critical moments. Authors such as Dekker (2004) argues that effective interactions between human and autonomous systems are less focused in the division of roles ("who does what") and more focused in the Human-System coordination ("how can we work together"), defending a human-centered automation design approach.

2.1.2. Automation taxonomy and levels

When studying the impact of automation on a given task, one must understand that this process does not necessarily apply to the whole task. In many cases, automation is inserted in a specific minor activity that composes a major task – such as driving a vehicle, and in other cases, the automation does not have full authority over the processes that form the task. One example to be observed in driver assistant system is the cruise control, responsible for the maintenance of longitudinal control and average speed of the vehicle, without the need for the driver to interact with the pedals. Even during the system actuation, the driver is still responsible for part of the activities that compose the driving task. Within those it can be cited the lateral control of the vehicle (keep it on the same lane regularly); route control; vehicle's conditions monitoring; external environment monitoring, and at last, the automated system's status monitoring. Even on more advanced cars, where the driver is excluded from the cycle of operations that composes the driving task, the level of his/her intervention and the nature of their activities can vary within a scale, depending on the complexity of the automated system in hand.

Regarding the automated system authority and the level of its intervention on the task, publications of SAE (2014) and Parasuraman et al. (2000) defined scales that classifies the different possible approaches for this kind of system. The human role in the interaction with autonomous system can be understood in two different aspects: 1) actuation of the automated system (how much intervention the user needs to apply to the system in order to achieve the task's goals); 2) the nature of the automation interference (what part of the task is being automated).

The first study to model the taxonomy of the automated system's authority was made by Parasuraman et al. (2000), based on the observation of aircraft control systems. The scale purposed by this study divides the system's autonomy into ten levels (see figure 2.3).

LOA	Description
10:	Fully autonomous: The automation system decides everything; act autonomously, yet collaborating with other autmation systems, ignoring the human.
9:	The automation systems inform the human supervisor only if they decide to.
8:	The automation systems inform the human, only if asked.
7:	The automation systems execute autonomously and then necessarily inform the human supervisor.
6:	The automation systems allow the human supervisor a restricted time to *veto* before automatic execution.
5:	The automation systems execute that suggestion if the human supervior approves.
4:	The automation systems suggest a decision action alternative.
3:	The automation systems narrow the decision choice selection down to a few.
2:	The automation systems offer a complete set of decision/action alternatives.
1*:	The automation systems acquire data from the process and register them without analysis.
0*:	Fully manual: The automation systems offer no assistance: The human decides and acts.

Figure 2.3 – Levels of automation. Adapted from: Parasuraman et al. (2000) (Expanded copy in annexes).

In this list, it is easy to identify the frontiers of human activity on the task, as the level of automation goes up. The automation intervention on the task can vary from only providing advice to the human operator (LoA – levels of automation 1 to 4); to a hybrid approach between information presentation and active support (LoA 5 to 8); until the full control of the task (LoA 9 and 10), being even capable to override a human intervention in critical cases. This is a generic model, which focuses in characterize the different possible interactions with automation, regardless of the task it acts on.

Regarding the nature of the automation intervention, Parasuraman et al. (2000) also affirm that the system behaviour can be divided into four different categories: 1) information acquisition; 2) information analysis; 3) action selection; 4) action execution. Each one of those groups represents one kind of activity inside the task that the automated system may assume, integrating with the scale presented above to characterize the two aspects of the autonomous interference: where it interferes and in which intensity.

Still related to the nature of the automation interference, some authors such as Norman (2009) and Young et al. (2002) define that each one of the categories of activity that the system can assume does not only interferes in the human role on the task but also on their state of consciousness and mental models. Both authors define three subcategories of activities in which the automation may substitute the human labour: 1) Operational (Young et al., 2002) or Visceral (Norman, 2009), generally related to primary motor execution or muscular memory - such as turning the steering wheel, which can last from 0.5 to 5 seconds; 2) technical or behavioural, generally related to learned abilities or quick decision-making - such as changing lanes or access one certain route, which can last from 5 to 60 seconds; 3) strategic or reflexive, related to higher-scale task planning, generally related to the task's goals – such as decide how to reach certain destination in a certain amount of time, which can take minutes or even days. The main point that must be considered in this subdivision is that it highlights which of the functions of the human operator are substituted, and what are the others that he/she must focus on, changing with this their degree of engagement with the task and the human resources needed for its development. Once the operational and technical levels are removed, the human operator must focus only on the task's goals, the same way that in case the automation assumes the strategic level, the human must concentrate solely on the motor execution.

In more recent studies, already focused on the autonomous driving context, the Society of Automotive Engineers (SAE, 2014) has developed another scale with six levels of automation, separating them according to the number of activities which the system takes control in place of the human driver (see figure 2.4). Considering the driving as a more significant task, composed of several sub-activities of high complexity, as the level of automation increases, the driver's role resumes itself just to monitor and do not act on the task. As in the previous scale, this one is subdivided into two groups: the ones where the driver still need to monitor the driving environment and the ones which the driver can focus only on watching the automated task – without caring to the traffic around them.

SAE level	Name	Narrative Definition	Execution of Steering and Acceleration/ Deceleration	*Monitoring* of Driving Environment	Fallback Performance of *Dynamic Driving Task*	System Capability *(Driving Modes)*
***Human driver* monitors the driving environment**						
0	**No Automation**	the full-time performance by the *human driver* of all aspects of the *dynamic driving task*, even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a
1	**Driver Assistance**	the *driving mode*-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	Human driver and system	Human driver	Human driver	Some driving modes
2	**Partial Automation**	the *driving mode*-specific execution by one or more driver assistance systems of both steering and acceleration/ deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	**System**	Human driver	Human driver	Some driving modes
***Automated driving system* ("system") monitors the driving environment**						
3	**Conditional Automation**	the *driving mode*-specific performance by an *automated driving system* of all aspects of the dynamic driving task with the expectation that the *human driver* will respond appropriately to a *request to intervene*	System	**System**	Human driver	Some driving modes
4	**High Automation**	the *driving mode*-specific performance by an automated driving system of all aspects of the *dynamic driving task*, even if a *human driver* does not respond appropriately to a *request to intervene*	System	System	**System**	Some driving modes
5	**Full Automation**	the full-time performance by an *automated driving system* of all aspects of the *dynamic driving task* under all roadway and environmental conditions that can be managed by a *human driver*	System	System	System	**All driving modes**

Figure 2.4 – Levels of vehicle automation. Source: SAE (2014) (Expanded copy in annexes).

The most significant benefit presented by the SAE's (2014) scale consists in the integration of the Human-Automation Interaction model specifically to the driving task. It is understood that the more advanced is the automation, not only the autonomy and authority of the system increases but also the level of complexity of the automated intervention on the driving task. In other words, highly automated vehicles are capable of taking control of even strategic functions of the task, not being restricted to the operational ones. This is the limit that divides the autonomous driving to an assisted driving. When it comes to autonomous driving, it is considered that decisions in reflexive/strategic levels – as defined by Norman (2009) and Young et al. (2012) will not be on driver's responsibility anymore, as they will be made by the system. With this, there is a shift in the human cost involved in the task, once the driver's mental model will not be more focused on driving, but on the system monitoring.

In this new structure, we have one autonomous system, responsible for all the operational and strategic functions of the driving task. At the same time, we have the human driver, responsible for one initial indication of the beginning of the automated activity and its monitoring, without the plenty sensation of vehicle control. In this sense, this new driver can be compared to a passenger or a co-pilot of the vehicle. With this absence of the operational role of the driver, the driving cannot be seen in the same way as before. Louw et al. (2015) affirms that automated driving tasks does not follow most of the paradigms studied on the classical theories of human factors for drivers – such as the studies from NHTSA (ANGEL et al., 2013), due the fact that the driver is not the primary actor of the driving task anymore. But this does not mean that it should be ignored. A myriad of new other issues is related to this context and will be discussed in the following chapters of this dissertation.

2.1.3. System fallibility

As already stated before, automated systems have much higher precision and speed than human beings, but they cannot interpret qualitatively complex situations. Such conceptual limitation is the primary barrier to the complete independence of automation for the development of tasks.

According to the supervisory control paradigm, the automated systems' workflow can be divided into the following steps: 1) observation of changes in certain variable(s); 2) orientation of this perceived variation according to the system's thresholds; 3) decision of one optimal action, according to the scenario; 4) execution of the chosen action. Several authors (Young et al., 2002; Degani, 2004; HSE, 2003; Sheridan & Parasuraman, 2005) defend that within this scheme, all the actions performed are subordinated to one or more numeric variables (from the system's sensors). In certain specific values, those variables are interpreted as one given scenario, without necessarily consider read errors or other situations/factors that may lead to the same value on the sensor reads. In this same line of thought, Norman (2009) alerts that automated systems are not "really intelligent", but yet responsive. Their operation is based merely on pre-programmed responses to pre-defined scenarios, which makes those systems always prone to errors.

Norman (2009) defines common ground as a series of common knowledge between two individuals necessary for them to establish proper communication. In the author's opinion, the absence of this common ground is the main cause of our inability to communicate with machines/automation. Norman claims that humans and machines belong to distinct universes, one of them, the machine, completely logical, where every scenario and situation follows a mathematical model, with a series of variables precisely indicating how they have to act. On the other hand, human, as more rational that they can be, live in a word surrounded by subjectivity and interpersonal relations, in a way that depending on the context and the perspective that the fact is observed, the same situation can lead to different interpretations. In summary, Norman (2009) claims that there is no way to establish perfect communication between humans and machines due to a linguistic problem, the bases of communication are incompatible.

As already discussed, according to HSE (2003), automated systems have their performance optimized in closed, or deterministic environments, in other words, where there is plenty of notion of every element that composes the environment, and the automated system is capable of mathematically model all the possible scenarios in which it must act on. The problem begins when the automated system is inserted in a stochastic/probabilistic environment, which means, where the number of possible scenarios tends to infinite, predicting every single situation an impossible task. In this kind of environment, all the system's actions are based on a mathematical approximation to a model, which may generate occasional errors, as there is no way to predict every single possible scenario, nor even verify if the assumption of the system being actually according to the real situation. Norman (2009) believes that the real world cannot be described merely by numbers, leading to a critical interpretation problem on the data collected by the automation, which cannot be corrected with the current state of the art of computational technology (see figure 2.5). To model a stochastic and complex environment, it is necessary to analyse an infinite number of variables, which is physically impossible for computers, as there is no way to store an endless number of variables in a hard driver, and even less possible to program this analysis on their conception project.

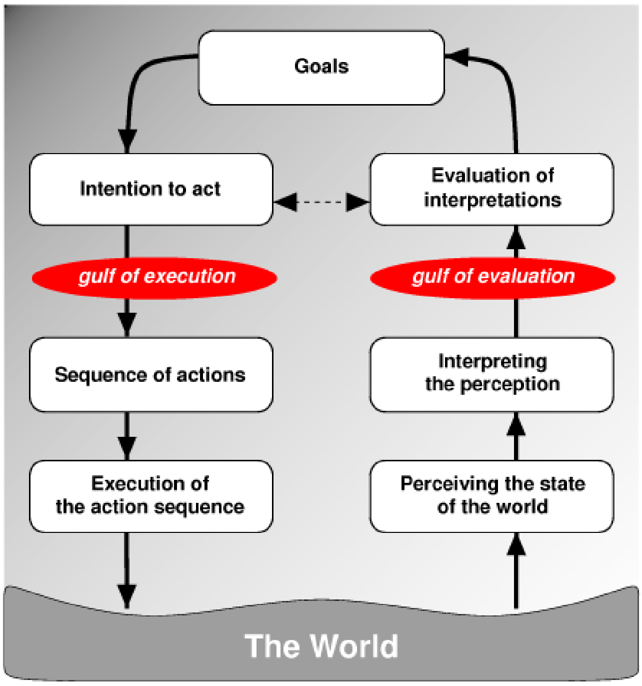

Figure 2.5 – System fallibility explanation model. Source: Norman (2009) (Expanded copy in annexes).

Analysing the problem through the perspective of the research object of this dissertation, interaction with highly automated vehicles (HAVs), it can be affirmed that the driving task as we know today is primordially a human activity. Authors such as DaMatta et al. (2010) claim that beyond the legal sphere, the actions performed in the traffic environment are mainly social. For this very reason, the traffic environment cannot be considered deterministic. Even if during autonomous driving the vehicle won`t need the driver to carry the task over, all the surrounding environment is composed by human beings, unpredictable by nature, which makes the driving automation always prone to eventual accidents – due to a lack of common ground of communication between machine and men. The argument presented above reinforces the idea that does not matter how complete and independent the HAV can be, the vigilant role of the human driver is essential for a safe driving task. As already stated by Sheridan & Parasuraman (2005, p124):

> There is a belief among many automation engineers one can eliminate human error by eliminating the human operator. To the extent a system is made less vulnerable to error, it is made more vulnerable to designer error (Parasuraman & Riley, 1997). And given that the designer is also human, this simply displaces the locus of human error. In the end, automation is really human after all. (Parasuraman & Sheridan, 2005, p. 49)

2.1.4.
OODA LOOP and the supervisory control paradigm

Whenever an operator is in a supervisory control state, or even in other activities of continuous decision-action flow – such as driving a vehicle, this person executes one rapid cycle of operations of observation, orientation, decision, and action. This sequence is commonly called OODA LOOP (Observation, Orientation, Decision, Action Loop) (Thomas, 2001 apud. Gikkas 2012), which models in detail all the factors that are involved in the process of vigilance and decision making during Human-Automation Interaction (see figure 2.6). Beyond operational and strategic issues that compose the human vigilance, it is worth noting that the OODA LOOP also considers subjective and internal factors of the operator/driver that can influence on the different activities during the performed task – for instance, the driver's experience with automation, cultural heritage and fatigue.

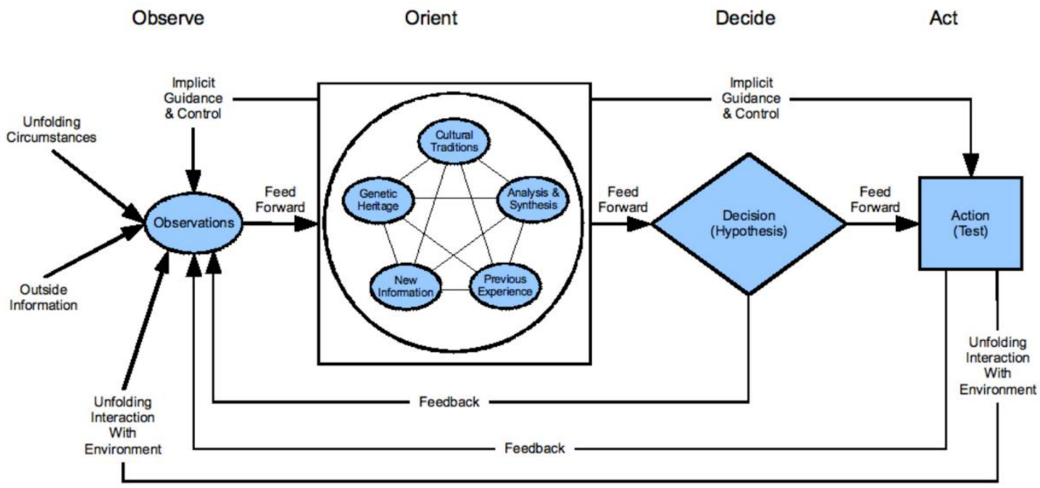

Figure 2.6 – OODA LOOP Model. Source: Thomas, 2001 apud. Gikkas (2012) (Expanded copy in annexes).

Carefully analyzing the scheme exposed above, it can be affirmed that this is a cyclic and processual model, where a failure in any of the stages of the process compromises all the subsequent steps, due to the fact that the model uses information of the previous iterations to decide how to act in next yet to come. Still related to the errors and failures that may occur during Human-Automation Interaction, some authors such as Young (2012) and Parasuraman et al. (2000) defined a set of 3 factors that appear to be essential for a good relationship between the system and their respective operators:

Trust: Related to humans' acceptance and conveyance to different activities performed by the system. Chancey et al. (2015) define trust in automated systems as a mediating factor between fallibility of a given system and the non-interference of its operator. Young (2012) believes that this element is deeply related to the degree of human vigilance over the task, once it affects how much someone exposes him/herself to a possible risk scenario.

Workload: Directly related to the disposal of human cognitive and physical effort necessary to achieve the task's goals. Even with no laboural activities, the supervisory vigilance task also demands significant amounts of energy and resources from the driver/operator. Hughes & Cole (1986) apud. Gikkas (2012) claim that an excessive workload can leave to fatigue and a decrease in human's vigilant capabilities. The author believes in the same way that the lack of workload can lead to monotony and tedium, and remove the driver/operator from the loop[1] (Louw et.al., 2015).

Situation awareness: Parasuraman et al. (2000) and Young (2012) have as the definition of situation awareness (SA) as a notion of a cause-consequence relationship between the operation of the automated system and its outcomes for the ongoing task. As it is a crucial aspect of this research, this concept will be later addressed in detail, during the subsequent chapters of this document. In summary, SA is the knowledge necessary for an operator to make decisions and choose to intervein or not on the automated system's workflow.

As in the OODA LOOP model, Parasuraman et al. (2000) defend that these three factors are profoundly correlated. One loss of situation awareness can lead to lesser trust on the system, in the same way, that increased workload can generate lower levels of situation awareness. In the end, it can be affirmed that both theories are related to each other. Each of the processes on the vigilance task (observation; orientation; decision and action) are in function of these three pillars fundamental for a good Human-Automation Interaction (trust, workload and SA), in a way that a lack of any of these factors in any of the stages of the loop can lead to different types of interaction problems (Gonçalves & Quaresma, 2015).

[1] Referent to the OODA LOOP model (Thomas, 2001 apud Gikkas, 2012)

2.2. HAVs and the driver as a task supervisor

When we think about automated systems, it is impossible to design and analyse them without considering the context in which they are inserted. It is so necessary to fit the theory presented in the last chapter to the context of this dissertation, the autonomous driving. Different situations bring new challenges to the task, especially in such a complex environment as the traffic. DaMatta et al. (2010) claim that the traffic is mainly a social environment, and does not restrict itself to traffic rules and legislation matters, being able to present a myriad of complex variables that may interfere on the driving task. Parallelly, McKnight & Adams (1970) reported on their studies that the driving task is composed of over 1700 simultaneous activities, which ends up bringing barriers for the drivers' operational capabilities. In light of the arguments presented above, it is necessary to understand how the autonomous driving is inserted on the driving context, and how it interferes with the Driver-Environment-Vehicle system.

2.2.1. Definition of HAVs

Similarly, to what was made with automation, it is first necessary to introduce the definition of autonomous driving and highly automated vehicle. As already presented on the previous section of this chapter, SAE (2014) divides vehicle automation systems into two groups, according to their level of automation (LoA): from 0 to 2 and from 3 to 5. This separation is made based on the degree of driver's engagement with the driving task – once the second half does not need the human interaction to carry over the primary task of controlling the vehicle. The National Highway and Traffic Safety Administration of the United States of America (NHTSA, 2016) defines in their report Autonomous Vehicles policy guidance that HAVs are the vehicles equipped with automated systems with LoA equal or higher than 3. In summary, one autonomous car is the one that does not need one actual driver to drive – which does not necessarily mean to remove them from the task entirely.

Based on the definition presented above, we can distinguish autonomous vehicles (HAVS) from driver assistance tools, or ADAS (Advanced Driving

Assistance Systems). Young (2012) and Knapp et al. (2009) define ADAS as systems capable of assisting the driver on the primary task of driving, without removing them from the decision-making process. Its workflow consists mainly of providing feedback or active support for the driver's activities, such as perform manoeuvres and keep the vehicle's stability. The significant difference between that kind of systems is that ADAS (LoA <=2) needs constant driver supervision and intervention, in the pace that HAVs (LoA >=3) do not. Even though, both systems interfere actively on the driving task, in activities of operational nature; visceral or reflexive (Norman, 2009). Despite its similarity, NHTSA (2016) and SAE (2014) makes clear this frontier that makes ADAS and HAVS fundamentally different, as the driver role on the task is not the same.

2.2.2. Driving automation taxonomy

Analysing the progression of the automation levels (LoA), it can be established different taxonomies for automated driving assistant systems. Golias et al. (2002) and Rangarajan (2008) defines simple ADAS (LoA = 1) as systems dedicated to assisting in essential activities of the driving task (of visceral or behavioural nature), generally related to the vehicle controllability. There is no case when this kind of system interfere in the driver's decision-making process, but instead focuses in reduce their mechanic activities. Some examples that can be presented (Rangarajan, 2008) to illustrate this kind of system are ABS (antilock-breaking system), automatic gear shifters and parking aid sensors.

By observing each one of these systems' workflow, it is evident that the driver is still responsible for all the planning and execution of the activities, just with reduced operational cost. For instance, when someone is using a parking aid, he/she is still responsible for manoeuvring, the system only makes the observation of the surrounding easier. In this perspective, even if the task is simplified by the automated system, the driver is still the leading actor of the task, performing all or most of the micro activities that compose the primary task.

System with medium complexity (LoA = 2) are defined by SAE (2014) as partial automation systems, in a way that the driver is still in charge of controlling part of the driving task, but some secondary activities (such as lateral or longitudinal control of the vehicle) is performed by the automated system. Some examples of this kind of technology are cruise control systems, lane keeping assistants; stop and go systems or any combination of those (Rangarajann, 2008). Any of the systems defined as partial automation occupies itself of one or more activities of the driving task – generally of behavioural nature, but the strategic planning and the operation of the other activities are still on driver's responsibility. One point that worth noting is those partially automated systems, as they do not take care of the task in a strategic level, still requires the driver to pay attention to the road environment, and not only the automation. According to NHTSA (2016), systems in this category may cause diminishing driver's capabilities, as they take out part of the human manual activities in the driving task (Flemisch et al., 2008), and the same is applied for the following levels of automation.

As already said before, for NHTSA (2016) and SAE (2014), assistant systems with LoA higher than three are considered conditional automation. Conditional automation is as far as technology goes nowadays for vehicle automation running openly on the environment. SAE (2014) defines conditional automation as systems capable of controlling the driving task completely, but in limited situations, such as driving straight ahead, or even on selected areas (only roadways for instance). The first civil car for open use with level 3 automation was developed by Tesla (2016), but others, such as Volvo (Volvo Cars, 2013), with the Drive Me Project, are developing models of its own.

The whole point of level 3 automation is that it is a hybrid stage between the assisted drive and the full autonomous drive. In this level, even if the driver is not fully aware to the road environment (and is supposed not to be), he/she may still be required to take over control of the vehicle. This may lead to several problems, that will be explained next (Merat et al., 2014; Louw & Merat, 2017; Gold et al. 2013; Damböck, 2013).

For systems with LoA = 4, SAE (2014) gives the name of High automation. This is the first level where the driver can be removed entirely from the driving task. Even in emergency situations, the system is supposed to perform minimum risk manoeuvres and entirely exclude the driver, in case they want to. The only difference between this level and the full automation is that, on level 4, there are some cases where the driver can choose to manually control the vehicle, even though it is not necessary.

Currently, we have no functional level 4 vehicle for open use in the streets, due legal and infrastructural issues. However, there is some research that has been testing the acceptance of this kind of technology in limited and controlled environments. One example that might worth citing is the project CityMobil 2 (CityMobil, 2012), where level 4 public transport was put to open usage on specific cities of Germany and Netherlands, to evaluate its performance and people acceptance towards this technology. Yet, we have still a long way to go before this can be available for the whole world (Merat & Waard, 2014).

For the level 5 and last level of vehicle automation, SAE (2014) gives the name of Full automation. In this level, the concept of the driver will be excluded entirely from the driving task. There will be no need for steering wheel nor any other kind of control. One company that is working towards it the Google, with their Waymo Project (Google.inc, 2017). According to the CEO of the company, the vehicle automation will change completely the way we see transport, in a way that people will not even need vehicles of their own (Google.inc, 2017), and everything will be public.

2.2.3.
New challenges and perspectives

During the past few years, autonomous vehicle (AV) technology have been rapidly evolving and becoming a promising reality. While we are still far away from level 5 vehicle automation (NHTSA, 2016), partial automation (SAE lvl 2), like adaptive cruise controls capable of assuming part of the driving task, and conditional automation (SAE level 3), capable of handling full control of the driving task in a limited array of situations (e.g., Volvo Chauffeur programme, Volvo Cars; 2017) are present on the market, and gaining visibility all over the world.

It[2] is no surprise how big this market already is, and is predicted to be even more. In a recent study, Lux research (2015) released a report estimating that vehicle automation market will worth around 100 Billion dollars by the year of 2030. Researchers like Merat & Waard (2014) believe that it is just a matter of time until we reach level 5 driving automation technology, even though, there are some critical issues yet to be solved – such as system fallibility and human reliance on

[2] This part of the text is based on a paper related to this research (Gonçalves et al., in press)

imperfect automation – to make AVs suitable for open use. There is a large expectation for vehicle automation to provide several benefits for the traffic environment, such as the aid of non-drivers/people with limited capabilities' mobility (Litman, 2017; Young & Bruce, 2011); reduction of traffic congestion (Litman, 2017; Fagnant & kockelman, 2013); economic benefits (Fagnant & Kockelman, 2013) and most notoriously, reducing human error as a cause of accidents (Norman, 2009). Looking forward to those benefits, several companies and research groups are trying to achieve such technology. Some of the most common examples are the Google car (Google.inc, 2017) and research projects funded by the European Community, such as the CityMobil (Toffetti et al., 2009), and the Automated Driving Applications & Technologies for Intelligent Vehicles (AdaptIVe) (Langenberg et al., 2014 apud. Louw, 2017).

As already said in the subchapters above, we are still far away from removing the driver from the driving task. Unfortunately, the driving task is complicated, and safety-critical situations cannot be modelled in a limited set of possibilities, making automation always prone to error (Norman, 2009). Due to this limitation, vehicle automation still needs to rely on the human driver in some situations, and he/she must always be able to resume control to ensure road safety (NHTSA, 2016). For this reason, the highest level of vehicle automation available in the market is the level 3, where the human driver is not directly engaged, but always present, as a fall back for emergencies.

The issues regarding automation fallibility wouldn`t be a problem if the driver/operator were always capable of reacting appropriately to the system`s limitations, but the case is not real. According to Jones (1992, p17) "(…) unfortunately, humans are not particularly good at maintaining passive monitoring of an automated system for long periods of time (…)." As the role of the driver/operator changes from the active controller of the task to a passive monitor, they change their behaviour to better adapt to the situation – a phenomenon called behavioural adaptation (Rundin-Brown & Jamson, 2013; Flemisch et al., 2008), but this new behaviour is not necessarily safety oriented. For this reason, many authors see the transition of control in vehicle automation one of the most significant challenges on state of the art for human factors in transport systems (Louw, 2017), and will be the main topic of this dissertation.

3
Take-over scenarios: human process of resuming control of HAVS

According to what was said in the previous chapter, the human interaction with the automated system is composed of a vigilant task. But as already claimed by Parasuraman et al. (2000), the insertion of automation on specific environment changes the task's context completely, and for that reason, the human performance can be compromised. It is then necessary a deeper understanding of how this kind of technology affects drivers' relationship with the driving task. This chapter aims to enlighten the cognitive process behind the human control of an autonomous vehicle and how he/she interacts with issues related to automation. In the end, a parallel will be made with interface design and how it can be used to create safer transitions of control.

3.1.
Challenges on the driver-automation interaction

Skinner (1953) claims that human behaviour is in constant conditioning process, in the sense that individuals' past experiences affect the way they act and interact with the world, in an iterative cycle. In this perspective, we can understand that vigilance and attention are not excluded from this process. According to the Signal Detection Theory, as described in Ritter et al. (2014), the human capability to respond to signals provided by the environment is in constant shaping process based in the conditions where the individual is inserted, needing stronger or weaker stimuli to draw his/her attention. Adapting this theory to the context of Human-Automation interaction, we can understand that the capability of a driver/operator to detect one critical situation – where they might need to take-over control – can vary during the vigilance task, depending on the scenarios that they may face.

Parasuraman & Manzey (2010) and Jones (1992) affirm that after prolonged exposure to one automated task, the human vigilance capabilities are gradually compromised. Skinner (1953) claims that when one behaviour such as vigilance is not adequately reinforced, it tends towards extinction. In other words, in case there is no countermeasure to the removal of one individual's operational functions inside a task, he/she might end up losing their vigilance capabilities regarding the system's workflow. Issues such as "Out-of-the-Loop" (OotL) state (Endsley, 1995a), behavioural adaptation (Rundin-Brown & Jamson, 2013; Flemisch et al., 2008), or automation-induced complacency (Parasuraman & Manzey, 2010) are likely to happen as the operator is removed from the decision-making process (Young, 2012). For that reason, on the following sections, there will be presented a brief introduction to the problems related to the phenomenon described above and the driver-HAV interaction during situations of resumption of control.

3.1.1. Behavioural adaptation

As the role of the driver/operator changes from being an active controller of the task to a passive monitor, his/her behaviour adapts to the situation – a phenomenon called behavioural adaptation (Rundin-Brown & Jamson, 2013; Flemisch et al., 2008). As an operational term, behavioural adaptation is defined as "behaviours which may occur following the introduction of changes to the road-user-vehicle system which were not intended by the initiators of the change" (Rudin-Brown & Jamson, 2013). Considering the context of this dissertation, the phenomenon is defined as the reduction of the drivers' vigilance capabilities after exposure to automated driving.

Many studies addressed this topic and found relevant evidence of the risks of continuous usage of vehicle automation, which can be understood as a reinforcer of drivers' unsafe behaviour. Rudin-Brown & Parker (2004) reported in test track studies after prolonged exposure to lane keeping systems, drivers were more prone to engage in a secondary task, and their response time for hazard detection on the road was increased. This study also reported higher lane variability – related to unsafe driving behaviour, and constant increase in the drivers' trust on the system. Similarly, Carsten et al. (2012) found in a driving simulator experiment study that drivers under highly automated driving (HAD) were more prone to engage in non-task-related activities (such as operating DVD players; radio; reading a magazine and operating infotainment systems) when compared to a manual drive. Jamson et al. (2013) had also reported on their driving simulator studies that drivers that expected automation tended to be less attentive to the road environment, and interacted more with in-vehicle entertainment systems, especially during heavy traffic conditions.

This constant interaction with parallel activities ultimately diminishes driver performance for a resumption of control. Miller & Boyle (2017) have found through repeated driving simulator experiments that the more drivers interact with automation, their reaction times to unusual scenarios is increased, as they were distracted with secondary activities. Piccinini et al. (2013) have used both naturalistic studies and simulator data to identify that during prolonged exposure to automation can affect the drivers' safety directly, as more they rely on the system to perform the task, more they gradually lose their manual skills. If the driver is inattentive during a critical event, he/she might not be able to react in time, as their overall driving skills will be diminished.

3.1.2.
Automation bias and complacency

Parasuraman & Manzey (2010), published essential studies that depict those two critical concepts for the understanding of the diminished human performance induced by continuous exposure to automation. According to the authors, complacency can be understood as a reallocation of attentional resources away from the automated task, in favour of the manual ones. Moray & Inagaki (2000) defines complacency as reduced attention to the system behaviour, and not necessarily the ability of an individual to detect relevant information provided by the system. Ultimately, Thomas apud Prinzel et al. (2001) defines as a state of mindlessness where the driver/operator is unable to perceive changes on the system/or the environment, where he/she must act. In this sense, automation-induced complacency can be considered one state where the driver/operator is unable to monitor the system workflow, due to several factors that will be discussed later. According to Parasuraman & Riley (1997), it deals the individual's trust directly on the system assuming that it will not fail, leading to an over-reliance on automation.

When it comes to automation bias, Parasuraman & Manzey (2010) defines as a phenomenon where operators are less aware of system failures, and omit themselves from the monitoring role. This is caused by effects of over trust and overreliance on the automation (Parasuraman & Riley, 1997), where even when the human is monitoring the system, he/she assumes it will not fail. One example that can be seen of previous studies about this phenomenon was reported by Lyons et al. (2016) on the field of military aviation, where the researchers found that pilots tend to push over the safety margins of the aircraft, the more reliable its automated control system is.

Parasuraman & Manzey (2010) have created a model to illustrate better how both phenomena interact with the diminishing operators' vigilance through the use of automation, as can be seen on the image below (figure 3.1).

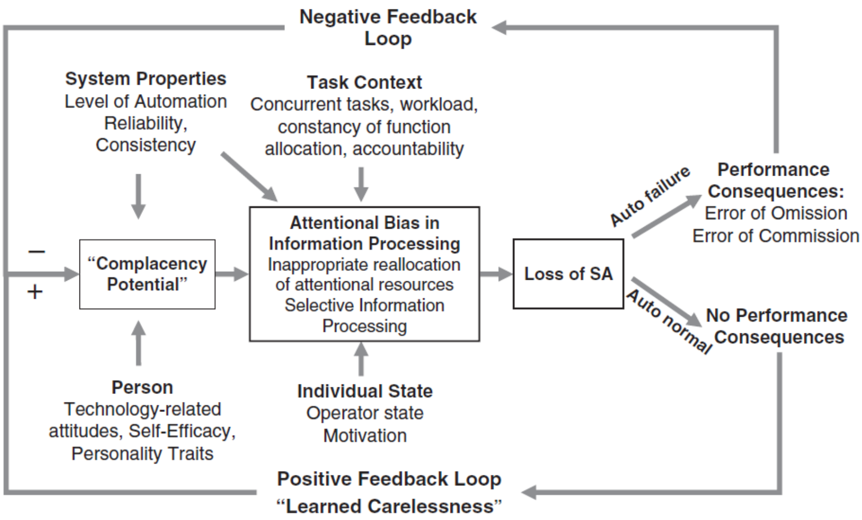

Figure 3.1 – Automation bias and complacency model. Source: Parasuraman & Manzey (2010) (Expanded copy in annexes).

As already observed on the previous chapter in the OODA LOOP model, this is an interactive process, deeply related to the operator's past experience with the system, which reaffirms the dynamic aspect of the automation bias and complacency (Manzey & Bahner, 2005). Other factors such as the system reliability and interface clarity also seem to interfere directly with the phenomena, as it deals directly with the operator's trust (Dixon & Wickens, 2006; Lyons et al. 2016). Some authors, such as Jones (1992) believe that this is a fatalistic process, where every individual that is exposed to automation will eventually become complacent due to a lack of stimuli for their attention. The author found on his studies in flight simulators that 20 minutes of automated flight is enough to jeopardize their vigilance in a way to compromise the pilot's safety.

Even though most of the studies on this topic are originally from aviation, the same principles can be applied to the road. Some evidence can be found in studies from Strand et al. (2014), which reported that drivers on highly automated conditions had limited monitoring capabilities and consequently poorer driving performance.

3.1.3. The Out of The Loop (OoTL) Problem and the loss of situation awareness

The "out-of-the-loop" (OoTL) state can be defined as a state of mindlessness of certain driver/operator where he/she is unable to detect critical events in the system workflow; accept or reject actions of a computer controller and decide whether or not to intervene in an automated task (Kaber & Endsley, 2004). As the driver/operator is not actively engaged in the task, they are not fully aware of the vehicle nor the road (Kleine, 2009). Endsley & Kris (1995) states that OoTL state is related to loss of awareness to both the system and the task environment due a lack of system interaction. According to the authors, as the driver/operator is removed from the real-time control of the system, he/she gradually loses situation awareness, resulting in them being unable to react effectively in a time of need. As said before, OoTL concerns more to the state of the system than the other elements of the environment (Louw, 2017). Other concepts such as situation awareness (SA) and (Endsley, 1995b) are crucial for the full enlightenment about how humans re-gain control of vehicle automation. Situation awareness is defined by Endsley (1995b) as: "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 shortly". In other words, the ability to perceive, discriminate and project how specific relevant information might affect the task at hand. According to Parasuraman et al. (2000), this construct is crucial to a safe interaction with automation, as it is responsible for developing in the driver a clear notion of how different states on the system workflow might generate specific outcomes on the driving task. In light of this, it is safe to assume that there is no possible safe decision-making/reaction without regaining the level of situation awareness required for the task at hand.

In[3] line with these arguments, Louw & Merat (2017) found that the further drivers were OoTL, the more they looked around and deviated their sight towards different areas of the road environment. Ultimately, such dispersion may lead to impairments on drivers' situation awareness and on the ability to resume control of the vehicle. Regarding vehicle control, Merat et al. (2014) showed that it took drivers approximately 15 to 40 seconds from the resumption of control to the point their vehicle was fully stabilized in the lane. Louw et al. (2015) found that drivers in an automated driving condition had much more aggressive and dangerous reaction to a safety-critical situation when compared to an identical manual driving condition. The authors reported that drivers on automated driving condition had higher maximum lateral acceleration, and also had a more sudden brake/deceleration. Similar findings were also published by Damböck et al. (2013). Gold et al. (2013) also found that, as drivers were given less time to react to a take-over request, drivers responded faster to a critical situation, at the cost of vehicle controllability, regarding higher lateral acceleration. Louw et al. (2017) showed that this more aggressive response is not necessarily bad, but required for the collision avoidance during take-over reactions in automated vehicles, proving that drivers are capable of resuming control and avoiding crashes, even on the influence of vehicle automation. Even though, the studies cited above showed that manual response to a critical situation is smoother and more predictable for other individuals in the traffic environment. It is argued here that drivers are able to avoid collisions with similar efficiency on both automation and manual control, but the less controlled and more sudden reactions from automation may increase risks of collateral crashes with other vehicles on the road, not directly involved in the first scenario. It is clear that the transition to manual control can bring issues to driver safety, so, it is necessary to deeper understand what factors may influence this phenomenon to mitigate the risks related to it.

[3] This text is part of a published article related to this research Gonçalves, Madigan, Louw, Quaresma & Merat (in press)

3.2. TOR (Take-Over Request) and the satisficing decision making

Since the Vienna convention for road traffic (Dokic et al., 2015), drivers have to keep their hands on the steering wheel still while driving partially-automated vehicles, and be prepared for take-over control in a case of need. Even though, the arguments presented above have proved that once the driver is removed from the loop, it is not trivial to return to it (Merat et al., 2014; by Damböck et al., 2013; Louw & Merat, 2017).

Many were the researchers looking for possible solutions for this problem, considered to be critical for state of the art on the field (Schieben et al., 2014; Banks & Stanton, 2015; Dizzenus et al., 2016, Melcher et al., 2015). However, state of the art is still far from a consensus on this topic, and there are still many issues yet to be solved related to it. This chapter will address precisely the subject of the transition of control, their challenges and possible approaches for enhancing human response in those scenarios.

3.2.1. TOR: Definition and issues

Take-Over Requests or TOR can be defined as a system initiated an alarm to invite the driver of an autonomous/automated vehicle to resume one or both lateral or longitudinal control of the car (Melcher et al., 2015, Erikson & Stanton, 2017, NHTSA, 2016). In other words, whenever a system reaches a perceived limitation and knows beforehand that will not be able to deal with the given scenario accordingly - for example, loss of connectivity with the GPS; entering in a construction zone, where the vehicle cannot locate himself on the road, and/or a system failure, it warns the driver, that may or not be aware of the situation, and provide relevant information about how he/she must act.

There are many variables involved in TOR, and the way it is provided to the driver might affect their response and performance during transitions of control. Erikson & Stanton (2017) had proven through an extensive literature review that several studies reported differences on drivers' response, regarding time and quality, when they were exposed to different TOR modalities and time budgets for the transition of control. As already said before, Gold et al. (2013) reported in their driving simulator studies that the time gap between the trigger of the TOR and the imminent crash situation affected the drivers' vehicle controllability, causing higher lane deviation and also more frequent crash hate. Parallelly, Schieben et al. (2014) also reported different reaction times to take-over scenarios of drivers that were exposed to various TOR modalities (visual, haptic or auditive).

While some authors purpose some specific time that would be ideal for take-over, using take-over time and lane deviation as metrics as safety parameters (Gold et al., 2013; Petermann-Stock apud. Melcher et al.,2015; Damböck et al., 2013), others argue that this might not be the correct approach (Louw et al., 2017, Erikson & Stanton, 2017). Gold et al. (2013) affirms on the conclusion of their experiments that 7 seconds of take-over time might be enough to grant safe transitions on most of the situations. Similar results were found by Petermann-Stock apud. Melcher et al., (2015) and Damböck et al. (2013), who purposed 8 and 8.8 seconds respectively. On the other hand, Erickson & Stanton (2017) argues that those numbers might vary according to the situation drivers are exposed to, and defining an ideal take-over time is still a challenge to the field. Louw et al. (2017) argue on the other way around, claiming that the metrics used for evaluating what defines a safe transition, regarding collision avoidance is not sensitive enough for the context of automation. According to the authors, drivers tend to respond to the kinematics of the unfolding take-over situation, and not necessarily to the TOR. In other words, even if they receive this information in advance, people perform the collision-avoidance maneuver prior the eminent situation, resulting in longer take-over times; shorter maximum TTC (time to collision) and higher lane lateral deviation. For this reason, we must not consider only take-over time as the way to tackle the problems inherent to the transition of control. It is necessary a deeper understand of how people regain situation awareness to react.

3.2.2.
Situation awareness

This subchapter will focus on summarising the factors that are used to build situation awareness and the challenges inherent to it during the transition of control. Endsley (1995a) has purposed a model that defines the process of situation awareness building, and what are the essential elements that interfere with this process (see figure 3.2).

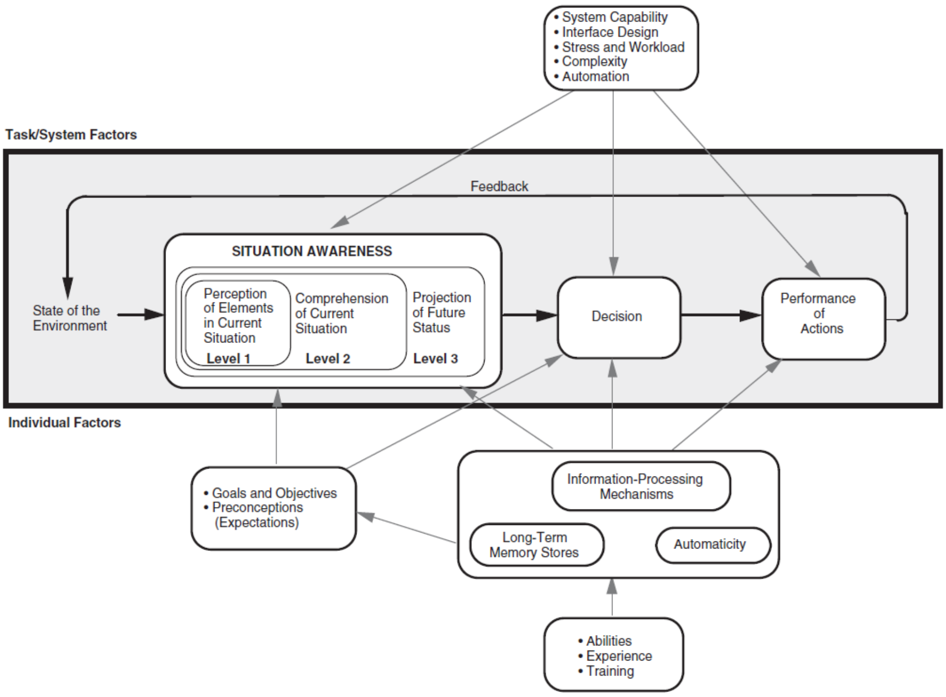

Figure 3.2 – Situation awareness acquisition model. Source: Endsley (1995a) (Expanded copy in annexes).

The first point that should be highlighted is that according to Endsley (1995a), situation awareness can be divided into three levels. The first level is called the perception of elements in the current situation. According to the author, this is the stage where the individual can perceive the status of the task, its dynamics (how it works) and relevant elements of the environment. On the second level, called comprehension of the current situation, the individual can synthesize the information acquired on the level 1, and understand the significance of each perceived element for the task completion, in light of its goals. The third and last level is named projection of future status, and can be defined as the capability of the individual to understand the consequences of their possible actions, and the outcomes to the task environment, being so able to choose the best way to act on the given situation to achieve the task's goals.

Another thing that should be noted about this model is that, when it comes to the interaction with automation, situation awareness is divided into two scopes: awareness of the system, generally related to understating the workflow of the automation, and identification the take-over scenarios; and the second one is the awareness of the environment, which can be defined as a deeper understand of the bigger task, and how the automated system behaviour interacts with other elements related to the task's goals. This is especially important for the interaction with autonomous vehicles, where the interaction with the system is just a small part of a bigger task, which is the lateral and longitudinal control of the vehicle. Being said that, the driver not only must be aware of the take-over but also of how to perform the best collision-avoidance manoeuvre, in a time of need.

The last thing that needs to be addressed in this model is the individual assets that might affect the human capability to acquire situation awareness. According to Endsley (1995a), experience with the system plays an important for acquiring situation awareness. The more one individual understands how the system behaves; easier will be the projection of the outcomes of his/her actions during the transitions of control. Another factor which is considered of significant importance is the operator's workload. The more overwhelmed is the individual with parallel activities, less he/she will be able to process the information they need to regain control of the system. The last one is considered to be the system/task complexity. The more elements the individual has to keep track of, harder will be for them to maintain full awareness of the system.

3.2.3. Situation awareness challenges

Endsley (2006) also stated that the process of acquisition situation awareness is susceptible to several issues that may impair a proper transition of control. Those problems are called situation awareness challenges, which will be discussed individually, based on the studies from Endsley (2006), in the section below.

Attention tunnelling: Humans have limited capabilities in splitting their attention in more than one source. According to Wickens et al. (1992), the human information processing occurs procedurally, it is not possible to deal with two concurrent information, jeopardizing the situation awareness acquisition, as it is generally linked to two different sources of information (system and environment).

Requisite memory trap: Many features of the situation awareness requires the individual to store high amounts of information on their working memory at the same time. As the complexity of the system or the environment increases, it limits the capability of people to understand it, as they will end up stressing their short-term memory.

Workload, anxiety, fatigue, and other stressors: As the information acquisition process is by itself a demanding task, any additional parallel stressor may hamper it, as it competes with slots on the individuals' working memory and also their physical capacity of dealing with the demands.

Data overload: The high amounts of data flux and sudden needs for information in certain situations may exceed the individual's capability to process it to acquire situation awareness. In case an abrupt transition of control is needed, and the operator/driver is not aware of it, he/she might not be able to process it in time.

Misplaced salience: The human perceptual system is more sensitive to specific features than to others. There are cases where the most relevant information for situation awareness acquisition is presented in a way that competes with another attentional salience of minor relevance to the task, which might compromise the individual's reaction time, or even make him/her miss this information.

Complexity creep: As already said before, the more complex is the system, more time humans will take to understand it and acquire significant levels of situation awareness. For this reason, the author warns for the number of features one automated system may have. The higher is the amount of information; harder will be the transition of control.

Errant mental models: All the process of acquisition of situation awareness is dependent on the individuals' mental model. Through their mental models, they decide how to guide their attention and define how to sample information. In case someone has one errant mental model, not aligned with the actual system/environment behaviour, all the outcomes of the information sampling process end up being compromised.

OotL syndrome: As already discussed above, as the automation removes the operator from their active role of the task, they cease the continuous flux of information that is crucial to maintaining appropriate levels of situation awareness. Endsley (2006) claims that as automation reduces workload (which can be beneficial), it also creates the OotL state, as a huge barrier for the maintenance of situation awareness.

After observing all the possible barriers for the process of acquisition of situation awareness, it is now necessary to understand how they interact with the context of vehicle automation and transition of control. The first thing that must be pointed out is that situation awareness is related to both the system and the environment (Endsley, 1995b), so drivers have to split their attention between several sources of information to acquire enough knowledge to resume control. Supporting this idea, Boer & Hoedemaeker (1998) defend that during the operational control of a vehicle, drivers need to be aware of the state of four elements (driver him/herself; car; automation; and environment) and continuously manage their attention resources between them. Even though there are many sources to be monitored, humans have limited capability of information processing, needing to sample them one at a time - a phenomenon described by Endsley (1995a) as attention tunnelling. Wickens (1981) also says that humans process information in a procedural way, so, to manage their attention resources and demands, data is individually acquired then stored and interpreted in short-term memory. This is specially important considering the context of common everyday drivers, where there is no proper training about how to take over control, which makes them need to figure out by their own judgement how to gather information, and not follow one previously-trained procedure.

Another factor that constrains drivers' ability to resume control of the vehicle from autonomous mode safely is that they have to do so in a very limited space of time, and it might not be enough for them to gather proper amounts of information (Endsley, 2006; Parasuraman & Riley, 1997). Several studies confirm the theory that huge spread amounts of necessary information, allied with drivers' limited capability of information processing and short time term to act contributes for poor transitions to manual and bad decision making on critical situations. Merat et al. (2014) proved that there is a gap of approximately 15-40 seconds from the time the automation is disengaged until the time that the vehicle's position is entirely stabilized on the road. Louw et al. (2016) proved that the more drivers are removed from the loop, more likely they are to collide in a safety-critical situation. On the same line of thought, Gold et al. (2013) have proven that drivers are less successful to react to a critical situation when the time term for takeover is reduced, suggesting that humans are not naturally capable of performing proper transitions of control on sudden situations.

3.2.4.
Satisficing decision making

Based on what has stated above, it is safe to assume that it is not feasible/possible to gather all the information related to vehicle control during take-over situations. In the driver-related task, where the time and resources are limited to the decision making, drivers have their abilities constrained by a phenomenon called bounded rationality (Boer, 1999). Bounded rationality is defined by Simon (1995) as the limited capacity of humans to sample complete information about specific situation, impacting directly on their decision-making process, as some assumptions and simplifications are made on the individual's mental models, in order to adequate the parameters for their decision to the amount of information they have. Transferring this concept to the field of the transition of control, Boer & Hoedemaeker (1998) stated that drivers generally could not gather sufficient information to perform an optimal take-over on the time term given on most of the situations, adopting a satisficing rather than optimized decision-making process.

The term "satisficing decision making" is a neologism that mixes satisfactory and sufficing decision-making process. Boer (1999) defines satisficing decision making as a change in the driver decision criteria, looking for the first perceived option that attends to the task's goals and requirements (in this case, resume the control of the vehicle in time to avoid collision) with the minimal amount of information, rather than look for optimal solution. Based on this theory, it is safe to assume that must be one threshold of specific information necessary for drivers to acquire to resume control. Goodrich & Boer (2003) believes that by understanding drivers' perceptual-motor; motivational and cognitive characteristics, it is possible to design tools better tailored to facilitate their decision-making process on automation control, prioritizing the information they need - in this case, better adapted human-machine interfaces (HMI). Gonçalves et al. (2017) have shown through a literature review that HMI design might be one efficient way to enhance driver's vigilance capabilities on vehicle automation, as it is the responsible for mediating the interaction between the driver and the system and is in total control of automation designers. Empirical studies reported by Schiben et al. (2014) and Dziennus et al. (2015) provided data to support this theory, as different HMI approaches provided enhanced human reaction to take-over scenarios on driving simulator experiments. In light of these statements, it is necessary to deeper understand drivers' decision-making process and information gathering patterns during transitions from automation to manual control.

3.3.
Human information scanning for resumption of control

One thing that should be noted is the intrinsic relationship between situation awareness and visual information and how it might affect the resumption of control. Previous studies on hazard perception and manual driving (Horswill & McKenna, 2004) found a strong correlation between drivers' visual attention and their ability to respond to dangerous situations. Similarly, Kountouriotis & Merat (2016) reported an increase in vehicle's lateral lane deviation – which might suggest a decay in controllability – as drivers diverted their sight away from the road environment. When it comes to automation, de Winter et al. (2014) have found through literature review a strong relationship between visual attention to the road centre and situation awareness, by comparing results of self-reported situation awareness scales – such as SART and MARS (Stanton & Young, 2005) - with lateral and vertical gaze dispersion collected on empirical studies published on papers in the field of Human Factors and Safety. As the more disperse is the driver's sight, worse will be his/her ability to detect a critical scenario (assuming lower situation awareness). This argument is with the findings of Louw & Merat (2017), proving that an increase on gaze dispersion induced by vehicle automation not only impairs the perception of risks but also compromises their ability to resume control of the vehicle in a time of need. Similar results were found in a driving simulator study by Zeeb et al. (2015), who showed that eye tracking gaze dispersion was a good predictor of reaction times during the resumption of control from automation.

3.3.1. Decision making and visual guidance

Louw et al. (2016)[4] analysed the allocation of drivers' eye movements in the road scene following the resumption of control from automation in a safety-critical scenario. The authors found that drivers who could avoid a collision had a more consistent gaze pattern towards the road centre, while those who crashed presented a more erratic one. These findings suggest that there may be a specific set of information that drivers need to regain situation awareness and perform a safe transition of control in each situation. Such assumption is also supported by the satisficing decision-making theory (as described by Boer, 1999; Boer & Hoedemaeker, 1998; and Goodrich & Boer, 2003), which holds that drivers' vision is guided by their need for specific information to fulfill their mental model and decide how to act. Following the basic structure of the decision-making process, after attempting to the eminent scenario, the driver will seek for the information he/she still not have to find one possible out the given situation. For example, studies related to manual drive and lane change tasks reported in their driving simulator experiments (Doshi & Trivedi, 2009) that drivers tend to look to their rear-view mirrors right before performing the manoeuvre (assuming that they might have been checking for incoming vehicles on the offside lane).

This argument is in line with Endsley's (1995a, 2006) account of the process of information acquisition for regaining situation awareness. According to the author, the visual scanning pattern follows a top-down and goal-oriented structure. Based on previous experiences, humans look for the information missing on their mental models to attend to their goals and direct their eyesight to the place where they assume that this information will be present. In other words, based on the information they lack about both the environment and the system they define one search strategy which is continuously readjusted based on the new information they sample.

If drivers' gaze behaviour is driven by seeking the relevant information to decide whether, when and how to resume control, then a deeper understanding of drivers' visual information needs may provide valuable insights for the development

[4] This is part of a published article related to this research (Gonçalves, Madigan, Louw, Quaresma & Merat; in press).

of better tools to enhance drivers' performance during the resumption of control. It can be done by, for example, presenting key relevant information on the user's interface (Goodrich & Boer, 2003). It is now necessary to understand where each of this information is located to the drivers to access on different scenarios.

3.3.2. Information sources

Once situation awareness is related to both system and environment, in order to analyse drivers' eye-gaze behaviour to depict their scanning pattern and understand what information they need to acquire before take-over control of a HAV, it is necessary to understand what information is available for them to gather and which are the sources of such information.

Regarding the driving environment, Goodrich & Boer (2003) identified that the three most relevant information for drivers to resume control are: 1) vehicle's speed and its relative difference to other cars on the road; 2) headway distances of the vehicle to potential obstacles and time to react; 3) breaking potential based on their current speed and distance to obstacles. Although, due the fact that the authors' studies were based on car-following tasks, they did not consider the presence of obstacles on the side lanes nor the possibility of a lane change, which were added for this study. In terms of information sources that may provide this kind of information, we can assume that the most relevant areas of the vehicle are: 1) the road ahead – which provides most part of the information related to the situation on the road and vehicle controllability; 2) the wing mirrors, that generally provides information about the traffic surroundings and drivers' relative speed in comparison with other vehicles on the road (the same goes for the side windows); 3) the rear-view mirror, which informs about the driver's position in lane and also about other vehicles on the surrounding traffic; 4) the instrument cluster, which generally provides information about their speed and even, in case of HAVs, the system interface, that can contain information about the road environment in some instances.

Regarding system information, Norman, (2009) suggests that every automated system must be able to inform its controller about the context of the transition; their decision-making criteria; current status; goals and rules. The primary source of system information is the system HMI, or Human-Machine Interface (Gonçalves et al., 2017). According to Endsley (2006), the system is one relevant source of situation awareness, as it can be tailored to present the most relevant information to each situation.

Once understanding the possible information to be provided to the driver during take-over situations, it is now necessary to understand the process of how each of this information is acquired and used in different scenarios.

3.3.3.
Eye tracking metrics and vehicle control

Various studies have also shown a strong link between drivers' eye movements and their driving behaviour, with the process of information acquisition proposed as a key aspect. It is possible to identify metrics, which were successfully used in previous literature to model driver behaviour through eye tracking data, which can be used to understand how drivers sample information to resume control in vehicle automation, and how it affects their manual performance. In their studies, Posner (1980) and Underwood et al. (2005) proved that fixation duration, as well as visual attention allocation, are good measures of where drivers' attention is being placed. Similarly, Chapman et al. (1998) proved in their experiments that increases on drivers' lateral angle of gaze deviation are indicative of their information scanning caused by changes in the demands of the road environment. On the other hand, in their studies, Merat et al. (2014) used the amount of deviation of driver's sight away from the road centre (PRC, percentage road centre) as a measure for driver distraction – which is also supported by Reimer et al. (2009) and Carsten et al. (2012). Therefore, depending on the situation, drivers' gaze deviation can both signify information acquisition and alertness or distraction, as the fixations on road centre are linked to attention to vehicle lateral and longitudinal control (Kountoriotis & Merat, 2016; Reimer et al., 2009).

Moreover, several factors have been shown to influence in the way drivers scan environmental information and to react to certain situations during the driving task (Chapman et al., 1998; Underwood et al., 2005; Crundall et al., 2003). Among these are driving experience; criticality of the situation; type of road environment; road visibility; and age. According to Underwood et al. (2005), different settings/

conditions and driver profiles lead to different strategies to acquire information. Therefore, drivers may require different information to regain situation awareness at the various levels of automation. Damböck et al. (2013) have shown that drivers' horizontal gaze deviation varied during events of resumption of control on different levels of driving automation, which might suggest that they sampled information differently to react to similar scenarios on different conditions. Even though, the authors' study was not focused on visual attention allocation, but rather in how those levels of automation impact reaction times and drivers' ability to avoid accidents. Sheridan & Parasuraman (2005) claimed that the importance/relevance of different information provided to the human operator during the supervisory control of the system varies as the level of automation increases in a particular task, and in this line of thought, it might also apply to the scope of automated driving. That said, it is now important to understand which and how information is accessed by drivers to resume control of the vehicle under different levels of automation.

4
Methodology

The theoretical chapters presented previously have identified several issues on the processes of transition of control in vehicle automation, especially when it comes to acquisition of situation awareness to re-enter in the decision-making loop and perform the take-over. The literature review also pointed out for the advantages of the usage of HMI communication, as a possibility to enhance human performance during these situations, increasing safety and user acceptance of this kind of technology. But to do so, it is first necessary to depict the human information acquisition process during transitions of control in vehicle automation, and also identify what factors may affect this behaviour (such as the driving environment; HMI design and levels of vehicle automation).

Based on the argument presented above, the main goal of this research was to understand how drivers acquire information to regain situation awareness during transitions of control in vehicle automation. To achieve this goal, the research aimed to identify which sources of information they rely on and how information should be provided on systems' HMI to enhance human response and take-over times. To tackle this problem, the research methodology used a bibliometric approach (meta-analysis), followed by the analysis of two driving simulator experiments. Those experiments were developed on the Institute for Transport Studies (ITS) of the University of Leeds, with a miscellaneous research partnership with PUC-Rio – by sending the author of this dissertation in an exchange program. Both experiments were conducted as part of the EU founded project AdaptiVe, and the reports of the primary results can be found on its official webpage (https://www.adaptive-ip.eu/). On this chapter, it will be discussed in detail how this research was conducted how each technique was applied.

4.1. Meta-analysis on driver’s vigilance during vehicle automation

This first technique had one exploratory approach, which aimed to identify the causes for the loss of alertness in vehicle automation and behavioural adaptation. It also tried to understand how human factors specialists and product manufacturers could work to enhance driver response in take-over scenarios, and consequently grant safety to the driver by changing their behaviour. It is worth noting that it was not directly related to the topic of transitions of control and information acquisition process, as it was an initial part of the research, it had a much broader approach to the problem, trying to understand the issues behind it and how to tackle the problem efficiently. To do so, the technique chosen was a systematic literature review followed by a content analysis. The following subchapters will be responsible for describing better the methodological procedures used for this method.

4.1.1. General description

Objective: The goal of this technique was to list the most prevalent factors in the literature for the loss of driver's vigilance capabilities during the use of autonomous vehicles (HAVs - Highly Automated Vehicles).

Research question: Taking into account the interaction with automated vehicles what are the factors that influence the loss of the drivers' vigilance capabilities?

Hypothesis: The level of automation and the distraction present on the environment play a significant role on the reduction of drivers' vigilance capabilities, but a presentation of timely and proper information may also collaborate to keep them engaged on the decision-making loop.

Methodological approach:

- Systematic literature review on human factors; Human-Automation Interaction; autonomous vehicles and behavioural adaptation;
- Content analysis based on Bardin (1977) to collect the factors pointed out by the authors as aggravating the phenomenon studied;

- Statistical tests to identify which of the factors (indexes) found can be really considered preponderant within the field.

4.1.2. Corpus and literature selection

Firstly[5] , to have an overview of the subject, the boundaries of publications were defined for the systematic literature review, through databases such as Science Direct/Elsevier, Google Scholar, and Sage Publishing for the selection of papers. Each of them was selected due to its size and scope. The keywords for the search were: automation, behavioural adaptation, autonomous vehicles, and driver behaviour. It is believed that these keywords accurately model the studied subject, due to its high occurrence rate in the publications related. Once collected, the papers were analysed and submitted to a selection according to the following criteria: 1) deal directly with the topic of autonomous driving; 2) be directly related to the field of ergonomics and human factors; 3) have driver's vigilant behaviour as a research variable; 4) be a conference paper or journal article, due to the presence of an evaluation committee; 5) be published after the invention of the first autonomous vehicle, beyond 1984 (Carnegie Mellon University, 2015).

The initial sample of the study was composed of 114 publications taken from 32 different sources (journals or conference proceedings), collected on 07/12/2016, but 67 of them were discarded as they did not meet the previously proposed criteria. Therefore, the final sample size (n) was 47 publications.

4.1.3. Content analysis procedure

Once the data sample was collected, the papers were carefully analysed by a content analysis (Bardin, 1977). According to the method, the authors' discourse was relativized and pondered to extract its essence, taking into consideration the author's position regarding the theme. This technique was chosen because of its ability to standardize a diverse set of verbal discourses, making it a valid sample for scientific inquiry.

[5] This description is part of one published article related to this dissertation (Gonçalves, Mont'Alvão & Quaresma; 2017).

Firstly, extensive reading of the selected publications was made to search for the factors (indexes) reported by the authors as responsible for reducing the driver's vigilance capabilities. Within this process, each element found in the articles was observed separately and then grouped by semantic similarity with the others, since they were not necessarily seen with the same terminology. After consolidating all of them, each group/category was named to generalize the discrepancies between the data and generate a valid sample for analysis. Finally, the frequency of factors was counted among the publications of the sample, in other words, how many different authors considered this factor as relevant for the occurrence of the studied phenomenon. At the end of this stage, it was possible to list which elements each of the selected authors considered relevant for the appearance of the behavioural adaptation phenomenon and reduction of the driver's vigilance capabilities during the use of HAVs.

Once organized and properly compiled, the data were treated using statistic metrics to identify which of the clusters of factors could be considered significant for the field. For the accomplishment of this process, the data were treated within a binomial model. This kind of structure is capable of modelling the occurrence of successes within repeated probabilistic experiments, in this case, the appearance of a given factor within a text, according to a factor that indicates the probability of occurrence of this result, due data's physical nature. To verify the level of significance of the factors, proportion tests (Conover, 1999) with [6]α=0.05 (95%), were used in order to verify if a factor has a null representativeness (p <10%) low (10% < p <30%), medium (30 %<p <50%) or high (p >50%), similar to Schaefer et al.'s (2016) technique. See below the formula used for the calculation.

$$Z = \frac{(\bar{p} - np_0)}{\sqrt{np_0(1 - p_0)}}$$

$\bar{p}$ can be defined as the sample probability of occurrence of a factor in the different articles observed; $p_0$the theoretical probability to be tested (in this case, the thresholds); n the sample size (47) and Z the statistics of the test to be compared

[6] α (ALPHA) is the safety margin for error applied to any statistical test. It is responsible for defining the limits which the results of the statistical test should reach in order to approve/reprove its null hypothesis. It is a convention in this field to use 5% of safety margin (α=0.05).

with a critical value within a normal distribution for validation of the hypothesis. The tests used as a significant α error of 5% (0.05). In other words, in case the Z presented in the test was higher than -1.96 (0.05 in the Z scale, Conover, 1971), it would be considered to have that certain level of significance. The calculations used for this analysis can be found on Appendix A.

4.2. *Post-hoc* analysis of lane change experiment

The[7] second technique applied to this research had as its overall objective to understand how drivers change their eye gaze behaviour during transitions of control on different levels of automation. To do so, *post hoc* statistical tests were used on the eye tracking data provided by a driving simulator experiment developed by the AdaptiVe project (Langenberg et al., 2014 apud. Louw, 2017). In this analysis, drivers' prioritization of specific information was evaluated, trying to identify differences between the information required by each group of drivers, to resume control of vehicle automation. As the experiment was developed before the development of this research, most of the techniques were not planned on the initial project but were made in a bottom-up approach, trying to extract from the data available relevant information to achieve the research objective.

To simulate a scenario of ideal transition, the studied experiment focused on non-safety-critical situations, where drivers have time to process information and react appropriately. Chapman et al. (1998) and Crundall et al. (2003) stated that there is a narrowing on drivers' scanning pattern when faced one critical situation (focusing their eyesight on the perceived hazard), which might create a bias in the data. As this study targets to identify which visual information drivers attend to in different levels of driving automation, a narrowing focus on one specific point might reduce the difference between the test conditions and invalidate the research findings. For more information related to this experiment see in Madigan et al. (In Press).

[7] This description is part of one published article related to this dissertation (Gonçalves, Madigan, Louw, Quaresma & Merat; In Press).

4.2.1.
General description

Objective: Evaluate the influence of different levels of automation on drivers' visual scanning pattern for information acquisition during the resumption of control.

Research question:

- During the events where driver's interference was required, did they disperse their gaze differently on different levels of automation?
- What information scanning patterns can be identified for drivers on the different levels of vehicle automation?

Hypothesis: The higher the LoA is, the more disperse drivers' gaze pattern will be. In higher levels of automation, people will fixate on the HMI to acquire situation awareness.

Methodological approach: Analysis drivers gaze dispersion and visual attention allocation during the transition of control from three different levels of vehicle automation, from the experiment developed by Madigan et al. (in press). Based on the theories described in the previous chapters, it was expected that those variables together could depict how the level of automation might alter the way drivers look for information to regain situation awareness.

4.2.2.
Experiment design

As already said above, this experiment was not done specifically for this research, but its data was treated *Post hoc*. The experiment design above was not designed by the authors, but its design will be presented here for methodological measures. For more details, please address to its original research (Madigan et al., In press).

Participants: A total of 29 fully licensed U.K. drivers took part in the experiment (15 male and 14 female). All subjects had experience of at least 2 years (M = 13.62, SD = 9.62) and age varied from 21 - 60 years old (M=34.21, SD = 8.94). All of them were recruited through the University of Leeds Driving Simulator (UoLDS) database and received £20 for partaking.

Materials: The experiment was conducted at the University of Leeds Driving Simulator, which consists in a Jaguar S-Type cabin with fully operational controls, located inside a 4m spherical projection dome with 300° projection angle and equipped with an 8 degree of freedom motion system (see figure 4.1). To record the participants' eye movements, a v4.5 Seeing Machines FaceLab eye tracking device was used in a configuration of 60Hz.

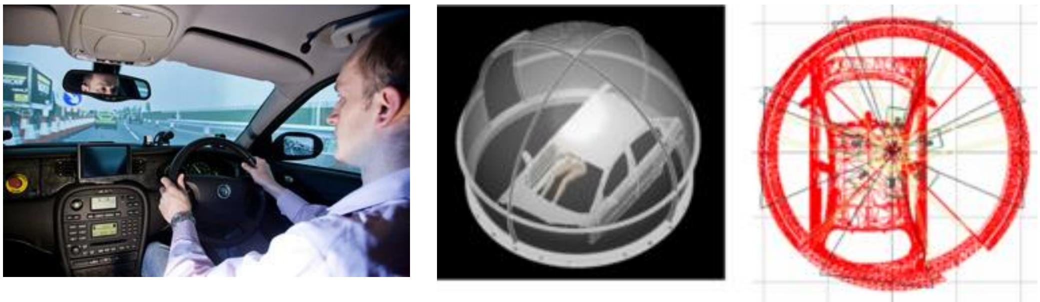

Figure 4.1 – University of Leeds Driving Simulator (UoLDS). Sourece: https://uolds.leeds.ac.uk/facility/.

Design: The experiment followed a repeated measures within-subject design, where all the participants had to perform the same task, under three different driving automation conditions (manual drive, partially-automated driving, and conditionally-automated driving) in an entirely counterbalanced order, with one participant removed, due to experimental problems. The experiment scenario consisted of a three-lane motorway, with speed limit of 70 m/h, where participants were instructed to keep driving straight ahead on the middle lane. There was always constant traffic in the left lane and no vehicles on the right nor on the middle lane (most of the time). Participants had to keep their speed stable near the speed limit and turn on the automation system as soon as it was ready (in the conditions where it was applicable).

During each one of the drives, there were twelve events where a vehicle driving slowly (50 m/h) appeared on the middle lane, and the participants had to overtake it by the right, as soon as they feel safe to do so. After the overtaking, participants had to return to the 70m/h speed or turn the automation on again, depending on the test condition. A visual representation of the scenario can be seen in figure 4.2. The experiment was designed to simulate a non-critical driver-initiated take-over situation, so, it was possible to evaluate how would be one ideal information acquisition and decision-making process, where the drivers had plenty of time to decide how to act

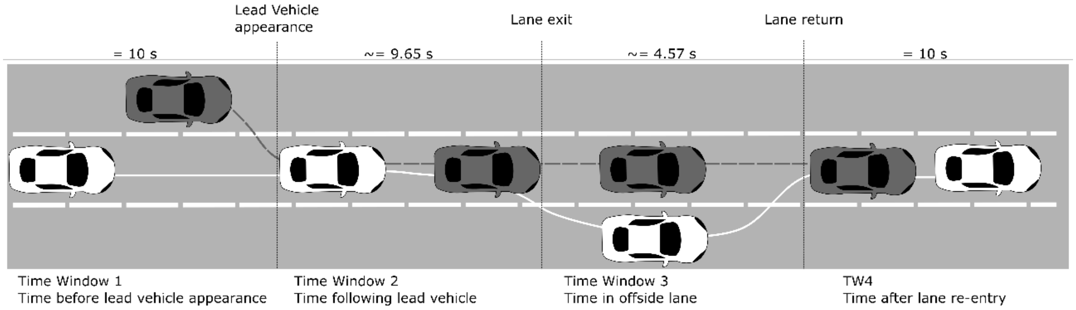

Figure 4.2 – Representation of the various phases of the traffic scenario during the Lane Change experiment. Source: The authors based on Madigan et al. (in press).

As outlined above, the independent variable controlled in this experiment was the level of automation (LoA) of the driving assistant system running on the vehicle in each condition. Also, based on the test condition, the human-machine interface (HMI), located in the cluster, presented different information related to the system workflow. This interface was provided by CRF (FIAT) and was adapted to fit the experiment's needs better. The details of each test condition are presented below:

Manual driving condition (Manual): The driver was entirely in control of the vehicle's lateral and longitudinal position (SAE level 0). All the overtaking manoeuvres and vehicle control were performed manually by the participants (acting as a baseline). Regarding HMI (see figure 4.3), as automation was not available throughout the manual condition, there was no automation-related information displayed.

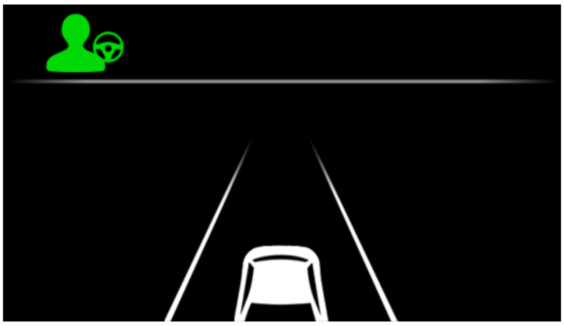

Figure 4.3 – HMI for manual drive (no automation available). Source: Madigan et al. (in press).

Partially-automated driving condition (PAD): Both lateral and longitudinal control of the vehicle was controlled by the system with a combination of a virtual adaptive cruise control (ACC) and a lane-keeping system (SAE level 2). The system was responsible for maintaining the vehicle in the middle lane at a constant 70 mph or with 2 s minimum headway of a lead vehicle. However, in this condition, the system was not able to perform overtaking manoeuvres. Therefore, drivers had to regain control of the car and perform any manoeuvres manually. Regarding HMI, the system started with the same information as the manual driving and informed drivers when the automation was available, by means of a flashing a blue steering wheel icon (see figure 4.4). This would occur when drivers were in the middle of the lane traveling at approximately 70 mph. Once the automation was engaged, the colour of the steering wheel icon changed to green. Once the automation was disengaged, the HMI would present a written message, after which it would revert to the manual mode status.

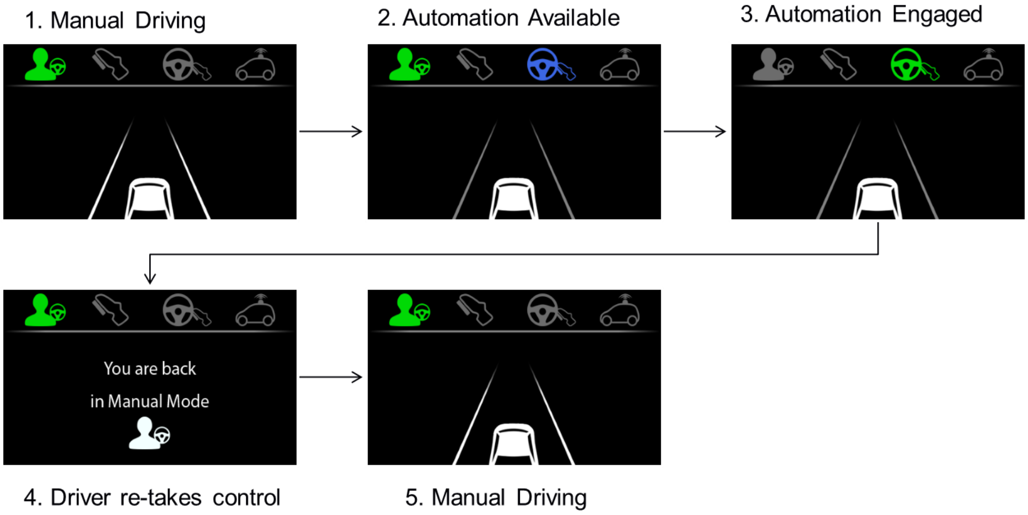

Figure 4.4 – HMI for Partially Automated Condition: HMI operated on a loop starting at 1 and finishing at 5. Source: Madigan et al. (in press).

Conditionally-automated driving condition (CAD): Similar to the previous condition this system also kept both lateral and longitudinal position of the vehicle stable. The main difference between the two is that in this condition, the system could perform the overtaking manoeuvres itself. The only thing that the driver had to do was push the indicator lever on the steering wheel, and the system would perform it automatically (SAE level 3). Even though in this condition there was no transition to manual, there was still a need for the driver to act, though to a lesser extent than the other two conditions. So, he/she still had to regain situation awareness and acquire enough information to decide as to when to initiate a lane change manoeuvre. This condition was used to evaluate whether different levels of system interaction influenced the way drivers acquire visual information or if they rely on various information sources to make their decision. Regarding HMI (see figure 4.5), when the automation was on, a green car icon appeared on the screen (instead of the steering wheel from the CAD condition), and the background also turned to green. When the participants pressed the indicator lever, an arrow icon appeared on the lane, pointing to the direction of the manoeuvre.

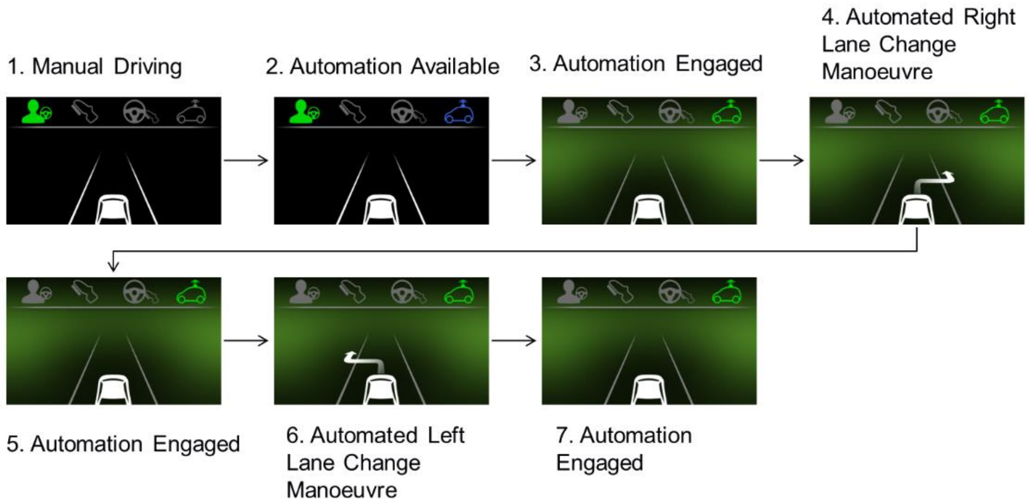

Figure 4.5 – HMI for Conditionally-Automated Condition. Source: Madigan et al. (in press).

4.2.3.
Research variables and data analysis

The data was compiled and treated using MatlabR2016a (MathWorks, 2017) and analysed using IBM SPSS v21 (IBM Corp., 2012). Kolmogorov-Smirnov[8] test (Conover, 1999) was used to check for normality and proved that part of the data was not normally distributed. To apply parametric statistical tests, proper transformations were made in cases where it was applicable. All the plot and graphs presented on the results of this experiment were based on the untransformed data, and the ANOVA[9] test results are based on the corrected/transformed samples. A α-value of 0.05 was used as the criterion for statistical significance, and partial eta-squared was computed as an effect size statistic. Where Mauchly's test indicated a violation of sphericity, degrees of freedom were Greenhouse-Geiser corrected.

Research variables: To measure drivers' gaze behaviour, the first metric analysed was the percentage of driver`s eye fixations on the road centre (PRC – Percentage Road Centre), and how it varies over time, according to the different

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[8] Test used to verify the normality of the distribution. Parametrical tests such as ANOVA can only be applied on Normal distributions.

[9] Test used to verify differences in the mean of two given samples. The result is given in form of a p value. Whenever p is lower than the alpha (in this case, 0.05), it is assumed that the means of both samples are different.

situations faced during the unfolding task. The reference point for this metric was defined for each participant as the mode of their gaze fixations within a 6° circular limit. It is assumed that this location would most accurately represent the position of the road centre relative to the driver's position in the vehicle, as it is the place where generally people most concentrate while driving (Kountouriotis & Merat,2016). Fixations where calculated based on a 200 ms threshold with a standard deviation of gaze position below 1°. Several other studies used this metric as an indicator of drivers' situation awareness (e.g. Carsten et al., 2012; Merat et al., 2014; Louw & Merat, 2016; Louw et al., 2017; de Winter et al., 2014) and information processing about vehicle control (Kountoriotis & Merat, 2016; Reimer et al., 2009). Considering this information, lower levels of PRC can be interpreted as drivers' little concern about the vehicle's lateral or longitudinal position, caused by either an OotL state or an increasing demand for other information. To observe how this variable change during the task, drivers' PRC scores were analysed across each overtaking event and divided into 17 intervals of 2 s, using the time for exiting the middle lane as a reference point (10 intervals before and seven after). It is assumed that this number of intervals would be enough to cover all steps make up the overtaking manoeuvre (based on the mean duration of 34.22 s), since the point there was no vehicle on the middle lane, until the moment the lead vehicle was completely overtaken.

The second metric analysed in this study was drivers' vertical and horizontal gaze dispersion. The metric was calculated using the mean standard deviation for drivers' raw gaze yaw – for lateral deviation – and pitch – for vertical – over a certain period. A similar approach was used by Chapman et al. (1998) as an indicator of drivers' scanning behaviour due to increasing demands imposed by the task environment. Some examples that can be highlighted for the purposes of this research are the need for information related to the vehicle's speed or system automation status – characterized by increasing vertical dispersion, and for information regarding the presence/distance other vehicles in the vicinity – characterized by increasing lateral dispersion. Other research also defends that gaze dispersion can be an indicative of OotL state, depending on the situation, such as reported by Louw & Merat (2017), when they varied drivers' road visibility on driving simulator studies to induce the OotL state and found an intrinsic correlation with gaze deviation. Once these metrics are based on gaze raw standard deviation, the division of the data in two-second intervals would not give accurate results. As it is a dispersion metric, shorter divided data samples would reduce the overall deviation, when compared with the whole event, creating particular bias on the data. To calculate them, the overtaking events were divided in four specific time windows (which size might be different for each driver), based on the different stages of the task performed (as can be seen in Figure 4.2): 1) 10 seconds be before the appearance of the lead vehicle; 2) from the lead vehicle appearance until the time when the participant exited the middle lane (M = 9.65 s, SD = 2.91 s); 3) from the lane exit until the time when the participant returned to the middle lane (M = 4.57 s, SD = 3.88 s) ; 4) 10 seconds after the lane return.

4.3. Driving simulator experiment on HMI design for transitions of control

The last technique applied was specifically developed to answer the main questions of this research. In this line of thought, its objective was to evaluate how humans would respond to transitions of control in vehicle automation aided by different interface design modalities. By varying the information provided to the driver to take-over, it is possible to relate the attendance to the HMI to the information they rely on to acquire situation awareness and resume control. As it still measures human information processing patterns, the scenario used was also non-critical, to give to drivers the ideal time to decide how to act. As an addition to the previous study, this experiment also analysed the traffic environment as a second variable, that might affect human eye-movements. To see more details about the procedure, please access the experiment plan in the appendix 2.

4.3.1. General description

Objective: Identity which information provided by the system`s HMI drivers rely on to gain situation awareness on take-over scenarios of automated driving.

Research question:

- Which information sources do drivers rely on to gain situation awareness in take-over scenarios?

- Which information do drivers look for on the system`s HMI to gain situation awareness in take-over scenarios?
- When is the information provided by the HMI accessed by the drivers?

Hypothesis: Drivers concentrate their sight more to the HMI whenever the system status is present, but the active information about the road environment have no effect on their visual attention to that area, as the same information can be acquired in other information sources. The presentation of active support for the task on the HMI improves peoples' time for resumption of control and task execution.

Methodological approach: To access the drivers' information gathering patterns and assessment to information sources during take-over request scenarios in automated driving, a driving simulator study was conducted. In this study, participants experienced a series of take-over request situations in automated driving, aided by different HMI modalities, providing information about both system status and environmental condition. After each run (one for each HMI modality), a small questionnaire evaluated the opinion of the drivers about the relevance of the information provided by the system`s HMI. Eye tracking data and the results of the questionnaire were used to evaluate how drives prioritize information on take-over scenarios.

4.3.2. Experiment design

Subjects: All subjects had at least 21 years old; were licensed drivers for at least two years and had normal/corrected vision. In case they had to wear glasses/contact lenses to drive, they had also to do so to participate in the test.

Materials: The experiment was conducted at the University of Leeds Driving Simulator (UoLDS) (see figure 4.1), which consists in a Jaguar S-Type cabin with fully operational controls, located inside a 4m spherical projection dome with 300 degrees projection angle and an 8 degree of freedom motion system. To record the participant's eye movements, a FaceLab seeing machine eye tracking device was used in a configuration of 60Hz. Inside the simulator`s vehicle cabin a Lilliput 7" VGA touchscreen with the 800X480 resolution was installed in the panel, located on the vehicle`s console, nearby the gear shifter. This screen was used to display one secondary activity, aiming to remove the driver of the loop and better reproduce a real take-over request scenario.

Scenario: For this experiment, a non-critical driver-initiated take-over scenario was chosen, because it is believed that a critical situation and limited time budget to react would create a bias in the drivers` gaze behaviour. Evidence for this can be found in Louw et al. (2015).

The experiment scenario consisted of a three-lane motorway, generally straight with some bends and speed limit of 70 m/h. The subject was instructed to drive in the middle lane, as it was free most of the time and there was traffic in the other two side lanes. They had just to drive until the end of the road, and follow the instructions they received during the briefing section, related to different situations that could have happened during the experiment section.

The participant`s vehicle was equipped with one automated driving system (SAE level 3), that controlled both speed and vehicle position, keeping a minimum headway of 2 seconds of every obstacle ahead, and held its position on the centre of the middle lane as long as it was active. To activate it, drivers just needed to press the indicator lever on the steering wheel once the system was ready, in other words, as soon as the vehicle reached the speed limit of the road (70 m/h). It could be deactivated by either braking/accelerating or turning the steering wheel more than two degrees to any direction. It could also be shut down by pressing the same button used to turn it on. Participants were instructed to turn on the system as soon as possible and keep it active as often as they could. The only thing varied across the experimental conditions was the information provided on the HMI, to evaluate if this change affected the way drivers sample information to perform the given task.

To evaluate which information drivers used to gain situation awareness, it was first necessary to induce a state where drivers were out of the decision-making loop (Endsley, 1995a). To do so, once the automation was turned on for the first time on each run, a secondary task was displayed on the screen on the console, and drivers had to engage with it as long as the automation was active. The secondary task chosen for this experiment was the arrows task, similar to the one used in Kountouriotis et al. (2016). Before the actual test, drivers had time to try this task, also used for them to get used to the simulator.

For the arrows task (see figure 4.6), several arrows were displayed on a 4X4 grid on display, pointing to different directions. Drivers had to locate the one arrow point up and click on it as fast as they can. There could always be one and just one arrow pointing up, and once they clicked on it, the screen displayed a new set of arrows in an iterative process. The task was presented for the whole duration of the experimental runs. To not interfere with the other HMI information already provided to the driver, there was no sound feedback to indicate the success of the task, nor to its activation. Drivers knew beforehand that they would have to engage with it as soon as the automation was turned on.

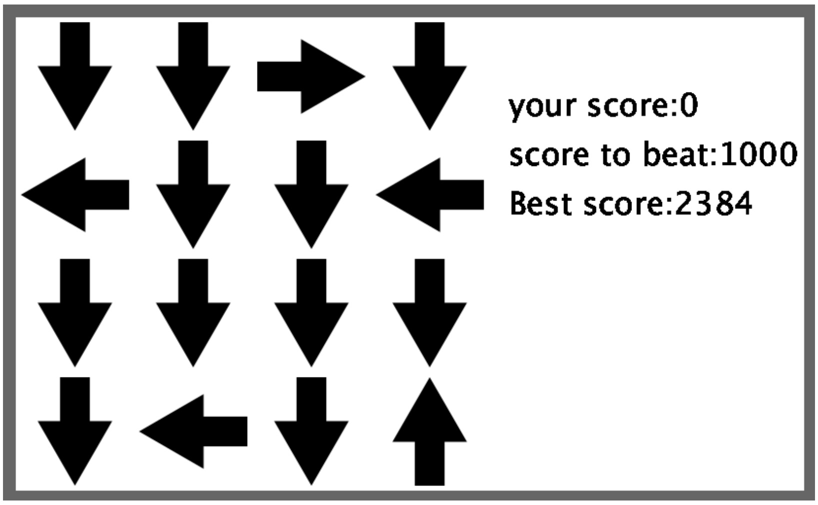

Figure 4.6 – Arrows task representation. Source: the authors.

Subjects were instructed to find as many arrows as they could, being told that they would be rewarded afterward accordingly to their score (just as an incentive, as every participant received the same amount as if they have reached the ideal count). When a vehicle appeared in the middle lane, and the automated system started to brake, participants were instructed to stop the secondary task to overtake it. They were only allowed to return to the arrows after passing the vehicle and re-engaging the automation system.

During each experiment run, there were six events where one lead vehicle appeared in the middle lane at an average speed of 50 m/h (see figure 4.7), and participants had to overtake it. There was no alarm warning the lead vehicle`s presence, as the speed deceleration itself was supposed to give enough cues to inform the driver (participants were told that the system would only brake in case of an obstacle/slower vehicle ahead). Once the automation system was not capable of performing the overtake manoeuvre by itself, drivers had to disengage the automation and perform it manually (through the right lane[10]) and then re-engage the system as soon as possible.

During the overtake events, there was no car in the right lane impeding the manoeuvre (considering a right-hand drive vehicle). They were distant, keeping different headways randomized by events (15 meters; 25 meters; 100 meters). They maintained their speed paired with the ego-vehicle, so, the driver had plenty of space to perform the manoeuvre. It is believed that due to the distance gap and the constant speed, the presence of this vehicle on the right lane would not interfere in driver`s behaviour nor performance, but simulate a more real traffic environment, since there would be information on both lanes, to avoid drivers to learn the scenario. At last, there was no take-over event during bends on the road and events had a minimum of 30 seconds interval between the triggers.

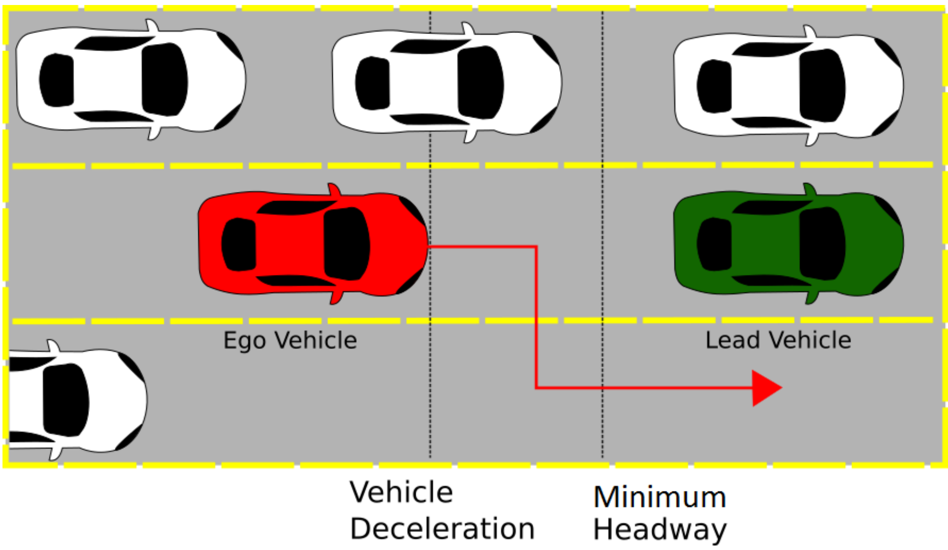

Figure 4.7 – Graphical representation of the experiment scenario. Source: the authors.

Experiment design structure: The experiment followed a within-subject repeated measures design, where each participant had to perform the same drive three times, with different test conditions. The independent variable that varied across the three conditions was the system`s HMI modality. Those modalities showed different kinds/amount of information, allowing to measure which information from the HMI drivers relied on during take-over situations. Participants were informed about the various test conditions before experienced it, during the briefing session. Once the goal of this research was measure information

[10] Mind the fact that the experiment was made in the United Kingdon, where the Fastlane in roadways is located on the right.

assessment, the lack of knowledge about the HMI content might have created a bias in the result.

On the first condition (baseline), there was no information on the system's HMI, located in the cluster. There was just a beep when the system was turned on/off, to inform the driver that he/she was in control or not, and one voice instruction, to notify the driver that the automation was available. The screen on the cluster stayed turned off. The goal of this approach was to see if any information added to the other conditions were able to increase the importance drivers gave to the HMI, acting as a baseline.

The second condition presented one HMI that indicated to the driver the system state (automation on/off/ready/disengaged), as can be seen in the scheme below (figure 4.8). When the automation was off, and the vehicle was in manual mode, the driver symbol in the left flashed green. When the automation became available, the steering wheel symbol turned to blue and once engaged, green. When disengaged the system beeped and wrote a message on the screen. The objective of this condition was to see if drivers relied or not on information about system status to take over control.

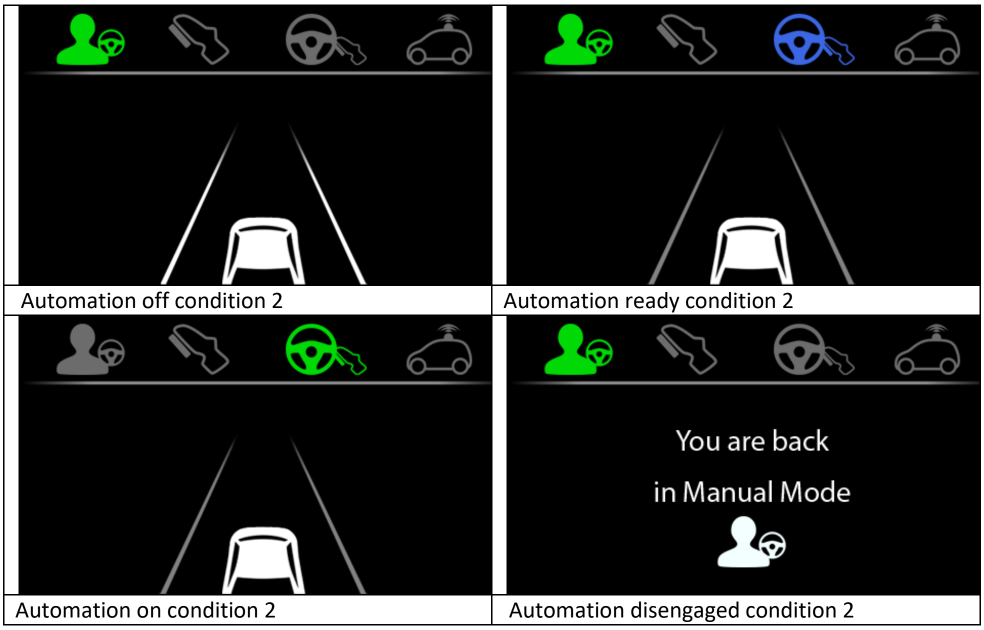

Figure 4.8 – HMI condition 2. Source: the authors.

The third condition's HMI contained the same information present on the previous one, but also adding information about the road environment (presence of the lead vehicle and overtake suggestion), as can be seen on the table below (figure

4.9). Once the system perceived the presence of a car ahead (6 seconds headway), a car symbol appeared in the HMI. When the ego-vehicle started to brake, to match with the speed of the lead vehicle (2.8 seconds headway), an overtake suggestion was triggered. In this situation, participants were informed that the green arrow meant that it was safe for them to overtake (there was no car on the right), and they should do so. The figure also shows a situation where there was a vehicle close by in the right lane, but this case has never happened on the actual drives. It was used just to simulate for the participant a real driving environment, where this possibility might occur. The goal of this condition was to evaluate if drivers accessed environmental information on the system's HMI to take over the control of the vehicle.

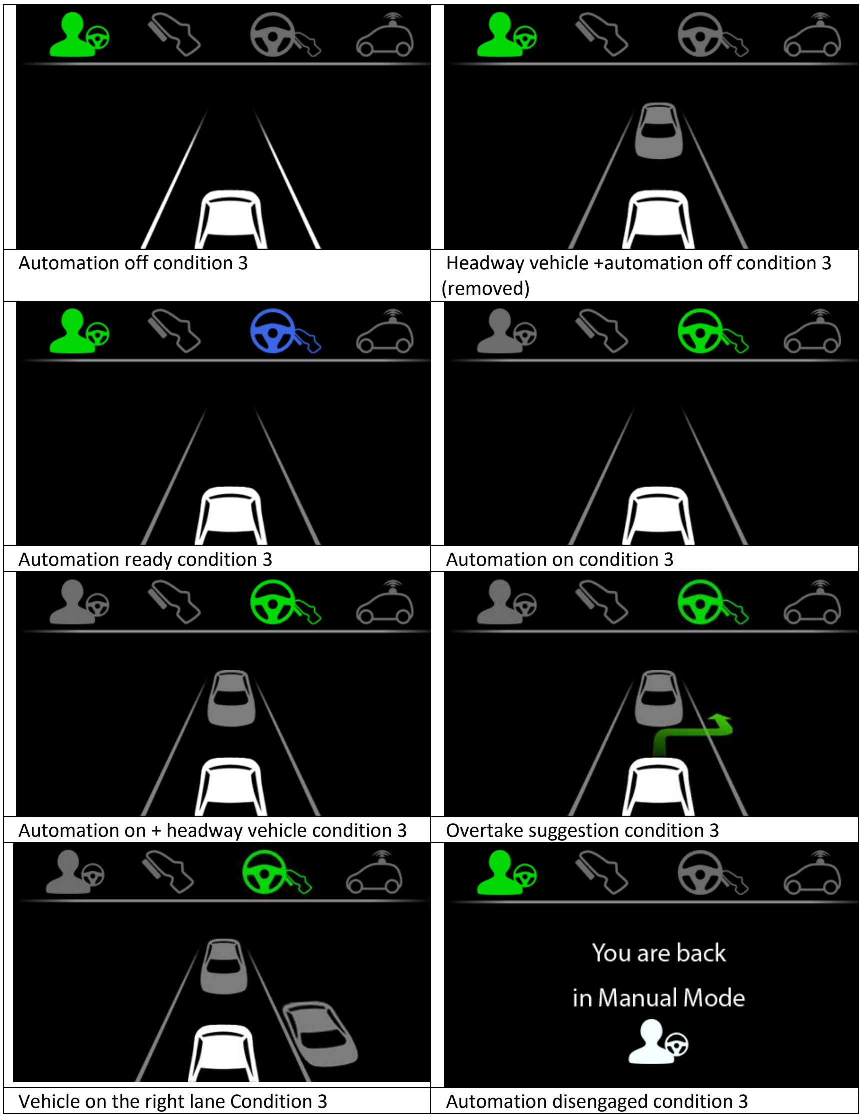

Figure 4.9 – HMI condition 3. Source: the authors.

To avoid biases created by the sequence of exposure of drivers to the conditions (HMI modalities), the order of the test conditions was fully counterbalanced (as can be seen in appendix 3). The headway distances for the vehicles on the right lane on the overtaking events were displayed in a randomized order, to simulate a more natural environment and avoid learning effects. The total sample size of this study was 30 participants, and six pilots, following the counterbalance order.

After each run, participants had to fill up a quick questionnaire, asking them how they would evaluate the importance of each information source to the tasks/manoeuvres they just performed. It asked which information they were looking for on the system`s HMI, as the eye tracking device might not be able to capture this information with such precision.

Each information source was evaluated by the subjects in a five-point Likert scale, varying from useless to fundamental to the manoeuvres performed, the goal of this technique was to generate a parameter to compare the driver prioritization of information sources on the different task conditions. See example below (figure 4.10):

1. How important is the information provided by each of the sources below for the safe execution of your overtaking manoeuvres?

	Not Important				Very Important
Road ahead	☐	☐	☐	☐	☐
Speedometer/cluster	☐	☐	☐	☐	☐
System`s interface	☐	☐	☐	☐	☐
Rear view mirror	☐	☐	☐	☐	☐
Wing mirrors	☐	☐	☐	☐	☐

2. Which information did you look for on the system`s user-interface during the overtaking manoeuvres? (you can choose more than one option)

System status (On/Off/ Available)	Information about the road ahead (presence or absence of a vehicle ahead)	Overtaking suggestion (green arrow on the screen)	Didn`t look at the interface
☐	☐	☐	☐

Figure 4.10 – After test questionnaire example. Source: the authors.

This questionnaire was used to measure the importance of each information source for the drivers to take over. It was accompanied by a system usability scale (Shneiderman, 1997, Brooke, 1996). Also, it was used to see which information they were looking for on the system's HMI, once the eye tracking may not be able to measure this feature (the options were based on the information provided on the three conditions). With the results, was be possible to verify if their reliance on the HMI increased as more information was provided. In the end, there was an open question, asking for the subject's opinion about the information used to perform the task. This question was used for qualitative analysis, understanding the motivations behind the drivers` behaviour.

4.3.3. Variables and data analysis

Independent variables:

- HMI Modalities (Condition 1/2/3).
- Time intervals. The results were analysed at three different time intervals trying to identify if the drivers` gaze pattern varied as the situation on the road changes. For a first analysis, there were three separate time intervals: from the TOR to the time of lane exit; from the lane exit to the lane return; 5 seconds after returning to the lane. Those time intervals were chosen to evaluate when each information source was accessed.
- The distance of the drivers on the offside lane (15, 25, 100M (meters), randomized).

Dependent variables:

- Fixation percentage on each AoI (Centre; Top; Left; Bottom; Right). Aois (Areas of Interest) separated the eye tracking gaze and fixation captures in 5 main regions of the drivers` field of view. The centre region was defined as a 6 degrees circular area, centered on the mode of drivers' fixations (where it is believed to be the centre of the road, as it is the point most looked by the drivers). The other four regions were equally splinted lateral and vertical sections of the screen (See figure 4.11). A similar technique was used in other research, such as Carsten et al. (2012) and Louw et al. (2015). It is believed that the Top AoI contains the fixations located on the rear mirror; the left and right AoIs represent the side windows and mirrors and the bottom the HMI and cluster.

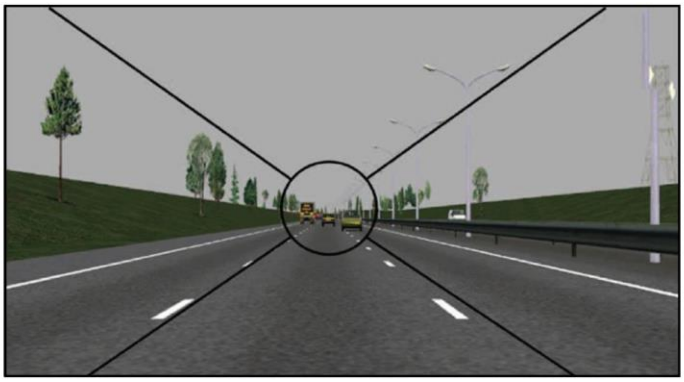

Figure 4.11 – AoI division representation. Source: Carsten et al. (2012).

- Lane exit time, which was used to evaluate driver's response to the scenario (how quickly they were able to decide aided with certain information).
- Results of the questionnaires.

Statistical analysis:

The data was compiled and treated using MatlabR2016a (MathWorks, 2017) and analysed using IBM SPSS v21 (IBM Corp., 2012). Kolmogorov-Smirnov test (Conover, 1999) was used to check for normality and proved that part of the data was not normally distributed. A proper transformation was applied to rely on parametric tests for the statistical treatment. All the plots and graphs referent to this experiment will be based on the untransformed data, and the tests will use the transformed one. A α-value of 0.05 was used as the criterion for statistical significance, and partial eta-squared was computed as an effect size statistic. Where Mauchly's test indicated a violation of sphericity, degrees of freedom were Greenhouse-Geiser corrected.

5
Results

On this chapter, it will be presented the individual results of the three techniques applied in this research. Every one of them had a quantitative approach, answering the research questions purposed through statistical tests, and mathematical models. Most of the raw data used for the calculation of the results below will not be presented on the body of the dissertation but will be available on the annexes at the end of the document.

5.1.
Meta-analysis on driver's vigilance during vehicle automation

As already explained in the previous chapter, the objective of this technique was to understand the main factors that may interfere with the relationship between drivers and autonomous vehicles during transitions of control. It was also responsible for updating knowledge about the state of the art in the area, and better develop the following steps of the research.

The results[11] of this technique identified fourteen factors influencing the behavioural adaptation process, as can be seen in the Pareto chart below (figure 5.1). Each of these refers to an issue inherent to the individual (personal factor), the system (hardware/software) or the environment (internal or external to the vehicle), directly affecting the way drivers handle their vigilance task regarding trust; wakefulness and responsiveness to scenarios where they should intervene.

[11] The results reported on this sub chapter are part of a paper related to this dissertation (Gonçalves, Mont'Alvão & Quaresma; 2017).

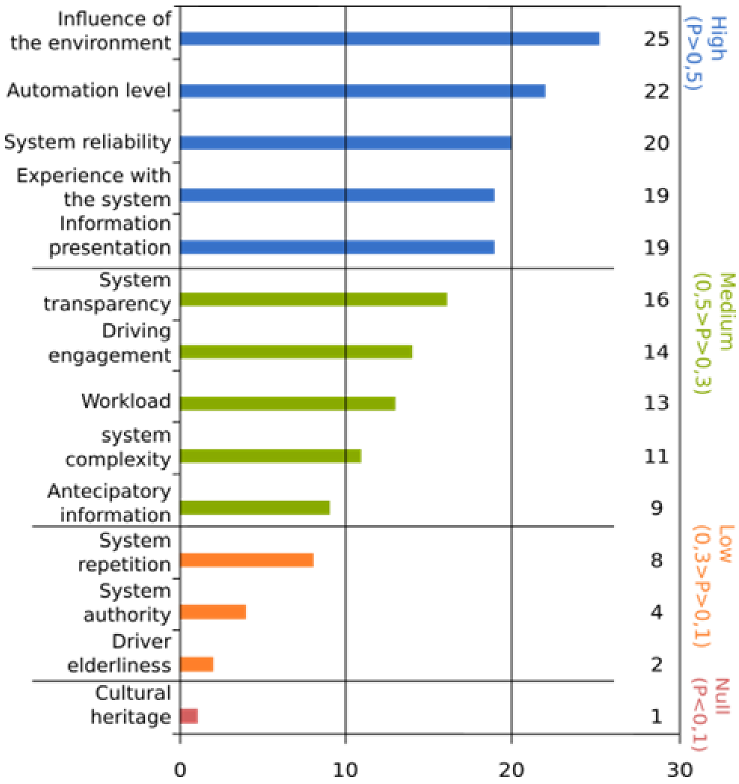

Figure 5.1 – Pareto chart of the listed factors (n=47). Source (Gonçalves, Mont'Alvão& Quaresma; 2017).

By carefully analyzing the Pareto chart above[12], it can be seen that the cumulative frequency of the first eight factors corresponds to 80.87% of the sample distribution. According to the Pareto theory (Evans, 2014), all factors after workload can be considered insignificant for to the state of the art of the theme for the occurrence of the studied phenomenon.

One issue that should be noted is that most of the factors found to be relevant are referent to the system itself - such as the *Level of automation* / *System reliability*, or the *Influence of the environment*, much more than characteristics inherent to the driver - such as *Driver elderliness* or *Cultural heritage*. The only exception to this rule is the *Experience with the system*, which, despite being linked to the human being, is directly interfered with by other factors such as *System reliability* and *Driving Engagement*. This finding is in agreement with the studies of Sheridan & Parasuraman (2005), who defend the thesis that the insertion of automated technology better adapted to the specific needs of the human in the task improves its performance, and models its behaviour to guarantee the adequate development of the task.

[12] A chart used to organize the divisions on the sample size based on their frequency (from the more to the less frequent).

By analyzing the division of factors into their significance for the field, the results of the proportion test (figure 5.2) point out that of the eight elements considered relevant in the Pareto chart, only five can be considered as highly representative for the field. See below the description of each factor and how the state of the art of the field describes its relationship with drivers' vigilance capabilities during vehicle automation:

Factors:	Frequency	Sample P	Z Low	Z Mediu	Z High	Influence level	Critical Z
Influence of the environment	25	0.53	9.87	3.47	0.44	High	-1.96
Automation level	22	0.47	8.41	2.51	-0.44	High	
System reliability	20	0.43	7.44	1.88	-1.02	High	
Experience with the system	19	0.40	6.95	1.56	-1.31	High	
Information presentation	19	0.40	6.95	1.56	-1.31	High	
System Transparency	16	0.34	5.49	0.60	-2.19	Medium	
Driving engagement	14	0.30	4.52	-0.03	-2.77	Medium	
Workload	13	0.28	4.04	-0.35	-3.06	Medium	
System complexity	11	0.23	3.06	-0.99	-3.65	Medium	
Anticipatory information	9	0.19	2.09	-1.62	-4.23	Medium	
System repetition	8	0.17	1.60	-1.94	-4.52	Low	
System Authority	4	0.09	-0.34	-3.21	-5.69	Low	
Driver elderliness	2	0.04	-1.31	-3.85	-6.27	Low	
Cultural heritage	1	0.02	-1.80	-4.17	-6.56	Null	

Figure 5.2 – Results of the proportion tests (n=47). Source: The authors.

5.1.1. Influential factors

Influence of the environment, regarding the amount of attention required by the driver to issues not related to the vigilance of the automated system. Authors believe that the greater the interference, the more drivers must divide their attention. This contributes to a gradual degeneration of the vigilance of the system (Zeeb et al., 2015; Loon & Martens, 2015; Terai et al., 2015; Payre , Cestac & Delhomme, 2014; Aziz, Hiroguchi & Sawaragi, 2013; Brookhius & Waard, 2009; Maltz & Shinar, 2007; Rudim-Brown & Parker, 2004; Rudin-Brown & Jamson, 2013; Louw et al., 2015; De Winter, Happee, Martens & Stanton, 2014; Schiben et al., 2014; Stockert, Richadson & Lienkamp,2015; Hergeth et al., 2016; Parasuraman & Manzey, 2010; Wickens et al., 2015; Ma & Kaber, 2006; Neubauer et al., 2012;

Bashiri & Mann, 2013; Young & Stanton, 2000; Fletcher & Zelinsky, 2009; Allahyar et al., 2016; Young & Stanton, 2002; Sheridan, 1999).

Automation level, related the degree of automated interference in the driving activities according to the SAE (2014) scale. Most of the literature categorically states that the more automated the task, the greater the apathy of the driver. As a consequence for that, the faster the process of loss of vigilance (Lu & De Winter, 2015; Strand et al., 2014; Terai et al., 2015; Weyer et al., 2014; Rudin-Brown & Parker, 2004; Rudin-Brown & Jamson.,2013; Louw et al., 2015; De Winter et al.,2014; Banks & Stanton, 2013; Stockert et al., 2015; Terai et al., 2015; Gonçalves & Bengler, 2015; Hergeth et al., 2016; Shen & Neyens, 2014; Payre et al., 2016; Neubauer, Matthews & Saxby, 2012; Mulder, Abbink & Boer, 2012; Bashiri & Mann, 2013; Young & Stanton, 2000; Allahyar et al., 2016; Young & Stanton, 2002; Sheridan, 1999).

System reliability, refers to the ability of the system to perform its activities without discrepancies regarding the task goal. In this aspect, some authors pointed out different points of view regarding Behavioural adaptation. Some argue that the possibility of system failure makes drivers less trustful in the vehicle, increasing their alertness (Strand Nilson, Clarckson & Nilson, 2014; Gold, Körber et al., 2015; Brookhius & Waard, 2007; Rudin-Borwn & Parker, 2004; Ruscio et al., 2014; Larson, Kircher & Hultgren, 2014; Banks & Stanton, 2014; Banks & Stanton, 2013; Payre et al., 2016; Saffarian, De Winter & Happee, 2012; Allahyar et al., 2016; Blair, Sandri & Rice, 2012). Other authors argue that the incoherence between the information provided by the system and its activity causes the driver to stop considering system alerts. This ends up aggravating the complacent state (Madigan, Louw, Merat, Graindorge & Ortega, 2016; Weyer et al., 2014; Schiben et al., 2014; Parasuraman & Manzey, 2010; Wickens et al., 2015; Ma & Kaber, 2006; Beller, Heesen & Volrath, 2013; Bashiri & Mann, 2013; Schieben et al., 2016; Sheridan, 1999).

Experience with the system, refers to the amount of exposure and driver training with a particular automated system. Part of the collected studies claims that greater experience contributes to a greater understanding of the processes of the system - and consequently better vigilance (Zeeb et al., 2015; Strand et al., 2014; Aziz et al., 2013; Mulder & Abbink, 2014; Kircher et al., 2014; Saffarian et al., 2012; Xiong, Boyle, Moeckli & Brown, 2012; Allahyar et al., 2016; Sheridan, 1999). On the other hand, part of the literature showed that experience with the system could lead to a customary routine. So, the long-term apathy can aggravate the loss of vigilance capabilities (Payre et al., 2014; Gold et al., 2015; Banks & Stanton, 2015; Rudim-Brown & Parker, 2004; Beggiato et al., 2015; Ruscio et al., 2014; Payre et al., 2016; Wickens et al., 2015; Young & Stanton, 2000; Blair et al., 2012).

Information presentation, regarding the quality of presentation of information about the procedures performed by the system. Issues related to the user interface (HMI), communication channels and strategies for calling the driver's attention are included here. Many authors argue that the prioritization of relevant information, as well as developing an appropriate plan for their presentation, contribute to the driver's alertness (Zeeb et al., 2015; Loon & Martens, 2015; Lu & De Winter, 2015; Gold et al., 2015; Aziz et al., 2013; Mulder & Abbink, 2010; Weyer et al., 2014; Desmond & Matthews, 1997; Schiben et al, 2014; Parasuraman & Manzey, 2010; Wickens et al., 2015; Saffarian et al., 2012; Beller et al., 2013; Mulder et al., 2012; Xiong et al., 2012; Fletcher & Zelinsky, 2009; Allahyar et al., 2016; Young & Stanton, 2002; Chien et al., 2016; Sheridan, 1999).

System Transparency, relates to the ability of the automated system to elucidate its decision-making criteria and operating procedures to the driver. Many authors argue that a higher situation awareness reduces the process of loss of vigilance due to the greater understanding of possible failure scenarios (Loon & Martens, 2015; Lu & De Winter, 2015; Strand et al., 2014; Banks & Stanton, 2015; Madigan et al., 2016; Ruscio et al.,2014, Schiben et al., 2014, Banks & Stanton, 2015; Payre et al., 2016; Wickens et al., 2015; Saffarian et al., 2012; Beller et al., 2013; Allahyar et al., 2016; Chien et al., 2016; Sheridan, 1999).

Driving engagement, relates to the ability of the system to keep the driver as a participatory agent in the task. This maintenance can be achieved by including him/her in the decision-making process or by the engagement in parallel secondary activities. Authors believe that the more involved in the operations the driver is, the less they are likely to lose vigilance (Lu & De Winter, 2015; Payre et al., 2014; Banks & Stanton, 2015; Parasuraman & Manzey, 2010; Saffarian et al., 2012; Neubauer et al, 2012; Mulder et al, 2012; Bashiri & Mann, 2013; Fletcher & Zelinsky, 2009; Allahyar et al., 2016; Young & Stanton, 2002; Sheridan, 1999).

Workload, concern the mental and physical energy expenditure required for the driver to maintain his/her task of monitoring the system. Authors claim that issues such as fatigue and mental or motor overload may reduce the driver's alertness (Lu & De Winter, 2015; Payre et al., 2014; Gold et al., 2015; Aziz et al., 2013; Brookhius & Waard, 2009; Weyer et al., 2014; Desmond & Matthews, 1997; Terai et al., 2015; Shen & Neyens, 2014; Wickens et al, 2015; Neubauer et al., 2012; Young & Stanton, 2002; Sheridan, 1999).

System complexity, concerns the capacity of the system to be understood in general. This factor includes issues like the number of actions performed concurrently; the volume of information offered to the user and complexity of the information provided. Authors claim that the higher the complexity of the system, the more costly the interaction becomes, which ultimately reduces the driver's vigilance capabilities (Loon & Martens, 2015; Gold et al., 2015; Desmond & Matthews, 1997; Gonçalves & Bengler, 2015; Shen & Meyens, 2014; Saffarian et al., 2012; Bashiri & Mann, 2013; Young & Stanton, 2000; Allahyar et al., 2016; Young & Stanton, 2002; Chien et al., 2016).

Anticipatory information, relates to the system's ability to inform the driver its status before carrying out its activities. Authors believe that the less sudden the information, the longer drivers will have to process it, ensuring greater situation awareness for decision making (Lu & De Winter, 2015; Mulder & Abbink, 2010; Weyer et al, 2014; Ruscio et al., 2014; Schiben et al., 2014; Gonçalves & Bengler, 2015; Payre et al., 2016; Saffarian et al., 2012; Fletcher & Zelinsky, 2009).

System repetition, refers to the frequency of issuing the same information by the system to the driver. Authors believe that the same repeated information can often become a nuisance to the driver, leading to saturation of this signal, especially if the information does not require some action/interference (Schiben et al. 2014; Beller et al., 2013; Sheridan, 1999). On the other hand, other authors argue that a large spacing between signals causes the driver to gradually forget to observe certain aspects of the system's operation, and no longer get that information (Banks & Stanton, 2015; Saffarian et al., Fletcher & Zelinsky, 2009).

System Authority, is the ability of a system to ignore human action and perform processes according to its criteria. Authors claim that once a system imposes its authority on the driver, he/she ends up failing to observe the progress of the task, assuming that his/her interference will be ineffective again (Lu & De Winter, 2015; Banks & Stanton, 2014; Allahyar et al., 2016; Sheridan, 1999).

Driver elderliness. Some articles have claimed that elderly drivers are, due to issues of experience in their time, more disbelieving about the use of an automated system, relying more on their instincts than on the system itself (Zeeb et al., 2015; Banks & Stanton, 2013).

Cultural heritage. Authors argue that different environments and diverse contexts change the way one behaves towards an automated system. Issues such as technology consumption culture in the country, quality of the road infrastructure and cultural tradition should be considered as elements that shape the driver's trust in HAVs (Chien et al., 2016).

5.1.2. Implications on the system design

Once described all the factors found in the literature to be considered influential to the process of loss of drivers' vigilance capabilities, it is necessary to consider how the most relevant ones impact on the practice of designing this type of vehicle concerning behavioural adaptation.

The first point to be addressed and considered the most influential factor is the *Influence of the environment*. Despite its notorious importance for the occurrence of behavioural adaptation, little can be done in the development of systems to avoid the distraction of the driver, since this factor is out of scope for automation designers. Authors such as Norman (2009) argue that it is a matter of time until autonomous driving becomes common sense and reduces the effects of the environment, due to the withdrawal of the human factor from the driving task.

In the second place, the *Automation level* was observed to reduce the driver's vigilance capabilities, as this level rises. Despite being a consensus within the literature, many authors argue that HAVs will improve safety, much more than generate risks for the road environment (Merat & Waard, 2014; Norman, 2009; NHTSA, 2016; Young, 2012).

Regarding the *System reliability*, there was a disagreement among the authors about its impact on the studied phenomenon. However, it is argued here that it is incoherent to intentionally reduce the reliability of an HAV to make the driver more attentive it. Such reduction would go against safety regulations for HAVs, such as those established by the NHTSA (2016), for inducing failures and potential accidents.

Another point to be considered as highly influential of the behavioural adaptation is the driver's *Experience with the system* (HAV). Although it is a personal characteristic of each person, it should be pointed out, as already mentioned, that this factor is closely related to all others. Therefore, the developers need to think about how to make the system adaptable to cater for individual's differing requirements and enhance the experience.

The last factor considered to be highly relevant to the occurrence of driver behavioural adaptation to autonomous vehicles, as well as all classified of medium influence, are related to the *Information Presentation* or to the control of the interaction. These factors shape the way the driver interacts with the system, either by the information offered to the driver or by the level of engagement of the individual. Since these stimuli to attention come from the interface, a better design can reduce the effects of the loss of vigilance, keeping the user alert.

5.2.
Post-hoc **analysis of lane change experiment**

Once the previous technique indicated for the possibility that the level of automation and interface design may have a direct impact on driver's vigilance capabilities during a transition of control, this second technique aimed to depict how the level of automation might alter the way drivers look for information to regain situation awareness. The secondary objectives attended by this technique were to understand the priority given by drivers to each information present on the road/vehicle during take-over scenarios in different levels of automation, and identify the sequence of drivers` information attendance during takeover scenarios.

To do so, this study focused on eye-tracking-based data. The main variables observed were drivers' attendance to the road environment along the task – represented on this study by the PRC (percentage road centre), and drivers' gaze dispersion on the times of transition of control – represented by eye-pitch and yaw raw standard deviation. The results of each metric will be presented separately.[13]

5.2.1. PRC

To observe the changes on drivers' visual attendance to the road centre, a two-way repeated measures ANOVA was conducted to measure the effect of Drive condition (Manual, Partially Automated Drive [PAD], Conditionally Automated Drive [CAD]) and Time (17 intervals of two-second length) on PRC (see figure 5.3). With this approach, it was possible to describe step by step how the drivers` gaze behaviour diverted during the whole task. The test identified significant effect of Drive condition on PRC [$F(1.408,33.796)=5.458, p=.007, \eta2=.185$][14], where the Bonferroni[15] *post hoc* tests (Tabachnick & Fidell, 2001) identified a higher percentage of fixations in the central region during manual driving when compared to CAD. This finding is in line with previous literature, which states that as the driver is removed from the active role of the driving task and assumes the monitoring role, little relevant information is provided by the road centre, which makes them divert their eyesight elsewhere, both for a secondary activity (Carsten et al., 2012; Merat et al., 2014) or sampling information from other sources (Zeeb et al., 2015).

The time windows (TW) also caused a significant effect on PRC scores [$F(5.162,161.846)=8.898, p<.001, \eta2=.270$]. As can be seen in the graph below, *Post hoc* test identified one specific point where the PRC is significantly lower than the previous points in time. This ultimately suggests that drivers deviated their sight away from the road centre, right before the time when drivers exited the middle lane to overtake (TW 9 < TI 1,2,3,4,5,6,7,8,10,11,12 13), followed by a sharp rise during the manoeuvre itself (TW 11> TI 7, 8,9,10,15,16), and another reduction in PRC scores immediately following lane re-entry, (TI 1 5 < TI 1, 5, 11, 12). In addition, there was also an interaction of Time window and automation condition

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[13] The results presented below are is part of one published article related to this dissertation (Gonçalves, Madigan, Louw, Quaresma & Merat; In Press).

[14] This notation is the standard report for an ANOVA result. F is used to observe the internal variance of the test; p is the actual result and $\eta2$ is used to measure the effectiveness of the sample size. Whenever $\eta2$ is lower than the alpha, it is assumed that the sample size was too small.

[15] Test used to identify what was the significant interaction between variables inside an ANOVA test with more than two independent variables.

[F(10.859, 260.624)=2.929, p<001, η2= .109], where the manual condition had higher PRC than CAD on time windows 15 and 16.

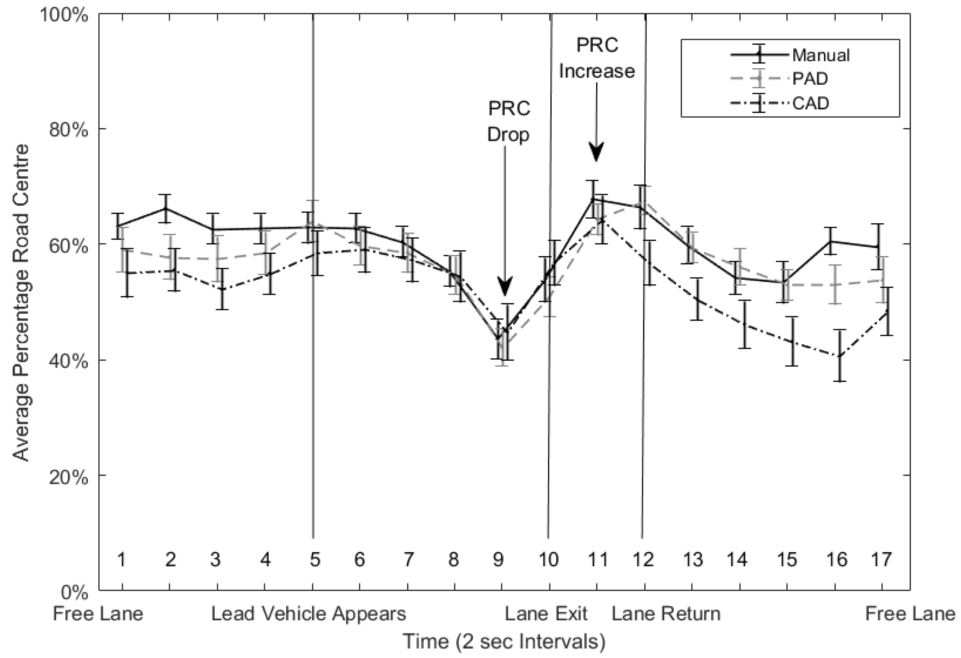

Figure 5.3 – Average Percentage Road Centre score over time on different automation conditions. The vertical lines represent the starting points for the different phases of the overtaking manoeuvre, which are based on the average duration of each phase for all the drivers, using the lane exit as the anchor point. Source: Gonçalves et al. (in press).

All the significant differences in PRC were found on the same time windows for every one of the three drive conditions. Regardless the automation level (Manual, PAD or CAD), all the drivers diverted their eyesight from the road centre at a similar point in the lead up to an overtaking manoeuvre. This finding suggests that the events on the road have similar effects on drivers' gaze behaviour, even if they do not require to re-take manual control of the vehicle.

Considering these results, it is possible to draw one general pattern for drivers' information acquisition process, based on the way they reacted to the scenario. After attempting to the need of one eminent intervention/decision, there is a sudden drop of attention to the road centre, which can be explained by the fact that drivers might have been sampling information from the road environment, to decide whether it was safe to overtake. Once they have acquired the information needed, there is a sharp increase in the amount of attention towards the road centre, as they focus on the task development/monitoring of the system behaviour, which is reasonable, as they were in the middle of an ongoing manoeuvre (Kountoriotis & Merat, 2016;

Reimer et al., 2009). After completely entering the offside lane, until the point they completed the manoeuvre, there was another drop in PRC scores. This result is similar to the one reported by Merat et al. (2014), that drivers divert their sight away from the road centre after re-gaining manual control of the automation. This leads to the assumption that drivers were possibly checking if it was safe to return to the middle, and after that looking if they are stable on the lane, as some people might struggle to do so, especially with vehicle automation (Merat et al., 2014). Similar patterns can be found in literature related to drivers' lane change and gaze behaviour, such as Doshi & Trivedi (2009) and Salvucci & Liu (2002), which both suggest that drivers divert their attention away from the road centre to the mirrors before overtaking and then refocus again to the road centre to perform the manoeuvre. One point that must be noted is that those studies were focused on manual driving, and did not look to the effects of automation. Even though, the results found, regarding gaze patterns were similar, with the only correlation between the studies being the nature of the task performed. In addition to that, the results reported here identified no difference in the gaze pattern for the three levels of automation. This suggests that, even with different levels of automation, the nature of the performed task still has a strong influence on the way drivers behave, which is in line with the findings of Underwood et al. (2005).

5.2.2. Horizontal and vertical gaze dispersion

The analysis of PRC scores was able to identify one similar pattern of gaze behaviour between the three control groups. Unfortunately, such metric is not sensitive enough to detect differences in the gaze dispersion. It is possible that people diverted their sight way at the same time on different conditions but focusing on distinct places. To characterize differences on gaze dispersion, two repeated measures two-way ANOVAs were applied to assess the effect of automation condition (Manual PAD, CAD) and time windows (1-before lead vehicle appearance; 2- time behind lead vehicle; 3- time on offside lane, and 4- after overtaking manoeuvre) on both drivers' yaw and pitch standard deviation.

When it comes to horizontal gaze dispersion, the data for drivers' yaw standard deviation was not normally distributed, showing a slight positive skew, which was corrected through logarithm transformation. There was no main effect of automation condition [$F(2,32)=.845$, $p=.439$, $\eta2=.050$]. However, there was a significant main effect of time window [$F(3,48)=21.803$, $p<.001$, $\eta2=.577$], where the time windows 2 and 4 (before and after the manoeuvre) were significantly higher than the other two. There was a significant interaction effect between time window and automation condition [$F(6,96)=2.235$, $p=.046$, $\eta2=.123$], where post-hoc Bonferroni tests showed that CAD had the highest deviation between the conditions during the time window 3 (time on the offside lane). See the graphical results on the plot below (figure 5.4):

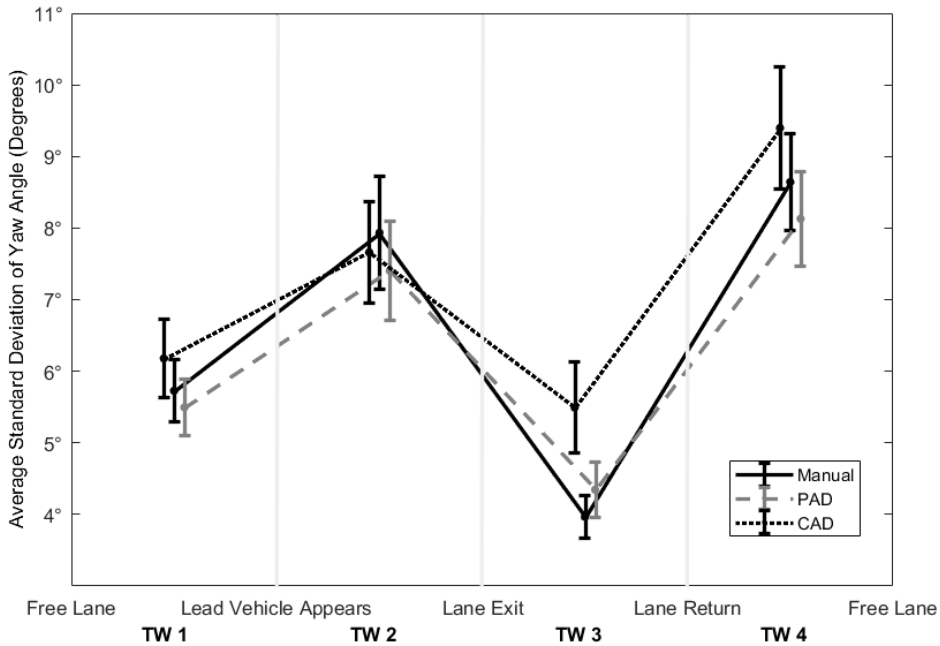

Figure 5.4 – Average gaze yaw standard deviation over time on different automation conditions. Source: Gonçalves et al. (in press).

These results reaffirm what was found in the PRC analysis, where drivers' visual attention to the road centre varied across time in the same way on the three automation conditions. Comparing the results from PRC and Yaw standard deviation it is evident that the drop on the PRC scores occurred on the same moments when the Yaw standard deviation increased on the three conditions of the test: before and after the manoeuvre. Even though the standard deviation varied across conditions (CAD < PAD & Manual on-time window 3), we can see that the significant drops and increases in the scores occurred in the same moments. These findings just reinforce the idea that the nature of the task – in this case, overtaking a lead vehicle – have a strong influence on drivers' gaze behaviour, regardless the automation condition.

The only difference in the pattern of the three conditions, when it comes to horizontal dispersion, was that during the overtaking manoeuvre, there was a higher lateral deviation of driver's gaze on CAD when compared with the other two conditions. It may be that the lack of need for manual control of the vehicle reduced the need for drivers to look ahead. In that case, it seems that drivers looked more away, presumably to observe the task execution, looking through the window to see how well the system is overtaking the lead vehicle. Those findings are aligned with the general theories of supervisory control (Parasuraman et al., 2000), which hold that whenever automation assumes the operational role of the task, its operator (driver) changes the focus of his/her attention away from it, and focus on the system behaviour.

For the results of the ANOVA tests for vertical gaze dispersion (figure 5.5), there was a significant main effect of automation condition [$F(2,34)=6.361$, $p<.001$, $\eta2=.272$], where vertical gaze dispersion was higher in PAD than in CAD. There was also a significant effect of time window [$F(3,51)=7.606$, $p<.001$, $\eta2=.309$], where vertical gaze dispersion was higher in time windows 2 and 4 (before and after the manoeuvre) than in time window 1 (before lead vehicle appearance). Finally, there were significant interaction effects between the automation condition and time window [$F(3.18, 54.151)=9.973$, $p<.001$, $\eta2=.370$], where the vertical gaze dispersion on manual driving condition was higher than on both PAD and CAD on time window 1. It was also identified other points of interaction on time windows 2 and 3, where PAD had higher vertical deviation than CAD and on time window four where PAD had significantly higher deviation than both others.

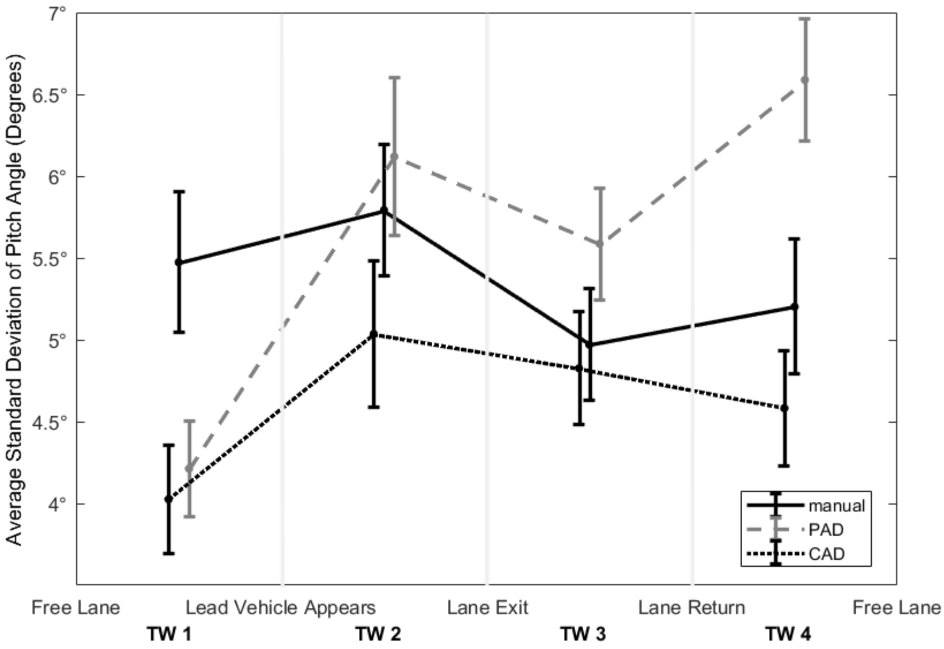

Figure 5.5 – Average gaze pitch standard deviation over time on different automation conditions. Source: Gonçalves et al. (in press).

Regardless of what was expected, CAD condition had the overall lowest vertical gaze dispersion (significantly lower than PAD). These results suggest that drivers in this condition might gather visual information to decide how/when to act by looking the system operating on the road, and not on the HMI. This hypothesis goes against Young (2012) and Sheridan & Parasuraman (2005), who claimed that, as the level of automation rises, the more a driver/operator relies on system information to perform their supervision task and intervein on automation in case of need. Considering the data from this study, it seems that people prefer to rely on their skills and experience to analyse the scenario rather than on system feedback to know when/how to act, at least considering the information provided by the HMI used for this study. It may be that the prime motivation for the participants on PAD condition to look down was the resumption of control, which might have created an urge for them to check the system status in the HMI. Once there was no disengagement, nor another source of interaction conflict between the system and the driver on CAD, there was no need for them to rely on the HMI, rather than on their skills. It must be noted that the situations on this study were not safety-critical, so, there was no sudden system disengagement nor a near-crash traffic scenario to make drivers look for some malfunction or error on the interface and perform a collision-avoidance manoeuvre.

Considering the interaction effects found on the ANOVA tests on vertical gaze dispersion, it is clear that on time window 1, the manual condition had the highest vertical gaze dispersion. This is a plausible outcome, if we consider gaze dispersion as an indicator of visual demand (Chapman et al.,1998) and assume that drivers on manual driving mode will have more demands than the ones on automated vehicles. This was the only condition where drivers had to control their speed while there was no vehicle ahead, and consequently, look down to the speedometer – as they were strictly instructed to keep their speed as close as possible to the national speed limit of 70 m/h. It seems that drivers have reduced attendance to information about things that are being controlled by the vehicle automation, such as vehicle speed and lateral lane position. Those findings are aligned with the ones from Louw & Merat (2017) and Carsten et al. (2012) who proved that drivers tend to look around more under the influence of vehicle automation, as they are removed from the decision-making loop and do not need to sample information to maintain control of the vehicle. On a similar line of thought, by analyzing the differences between vertical dispersion between the three conditions on TW 4, it is clear to see that the only condition where drivers had one actual demand to look down was on PAD. It is believed that demand is related to the urge for them to check for the status of the automation, as it was re-engaged after returning to the middle lane. Based on previous studies that observed gaze behaviour changes before sudden demands from the environment (Chapman et al., 1998), It is believed that the automation disengage/re-engage was a strong motivator for drivers to look down to the HMI, and consequently increase their vertical gaze dispersion.

5.3.
Driving simulator experiment on HMI design for transitions of control

The last experiment was able to evaluate the impact of different levels of automation on driver's gaze behaviour for acquiring situation awareness during transitions of control in vehicle automation, as well as the sequencing of eye paths during the unfolding of the take-over situation. It is now necessary to take a more in-depth look at human reliance on information sources, and how the presentation of information on the system's interface might affect their information prioritization during the task performance.

The secondary research objectives answered by the results of this experiment were: 1) identify which information source is accessed by drivers to acquire each specific information needed during take-over scenarios; and 2) evaluate the impact of different HMI approaches on the system`s usability during a transition of control. To do so, this experiment's analysis was based on drivers' eye-tracking data, combined to objective simulator data, that was responsible to understand and depict drivers' prioritization of information sources under the influence of different HMI modalities and traffic conditions. To analyse their reliance on the information sources, as well as their perceived usability of the system, the analysis was based on the results of the questionnaire data.

5.3.1. Gaze behaviour analysis

To observe how drivers distributed their eyesight along the task on the different test conditions, a three-way repeated measures ANOVA was conducted to measure the effect of the order of the events (before take-over, during take-over, after take-over) and HMI modalities (no information, system information and environmental information) on the fixation percentage of drivers' eye fixation on each of the five AoIs (Centre, Top, Left, Bottom, Right). According to Posner (1980), the higher fixations on one specific AoI may indicate higher reliance on it, as more information, as drivers might be accessing more information provided by this source.

The ANOVA results have identified significant main effect of AoI on the fixation percentage [$F(3.427, 89.110) = 15.087$, $p<.001$, $\eta2 = .367$], where *post hoc* Bonferroni tests showed that the AoI 1 (centre) was higher than the other four, suggesting that the situation ahead/ driving environment might be the main information source for resuming control, regardless the HMI modality. No other differences were found regarding HMI percentage of fixation. This result was already suspected, based on the previous findings and the studies from Kountouriotis & Merat (2016) related to vehicle controllability. The test also found a significant interaction effect between AoI and time window

[F(3.881,100.907)=2.954, p=.025, η2=.102], where the fixation on bottom AoI (where the HMI was located) was higher on time window 3 (after the manoeuvre) see figure 5.6). Considering the right AoI (where the wing mirror and side windows were located), the fixation percentage was significantly higher before the manoeuvre (TW1), than during it (TW2) (see figure 5.6). This result may lead to the assumption that people access the system's HMI right after reengaging the vehicle automation, to check the system status, as the amount of fixation on the bottom HMI increased on all conditions. This interaction effects also reinforce what was found in previous tests. The nature of the task (overtaking) performs a major role on drivers' gaze behaviour, dictating their need for specific information, as this increase of fixation on the wing mirrors were also reported by other studies on lane change (Doshi & Trivedi, 2009; Salvucci & Liu, 2002).

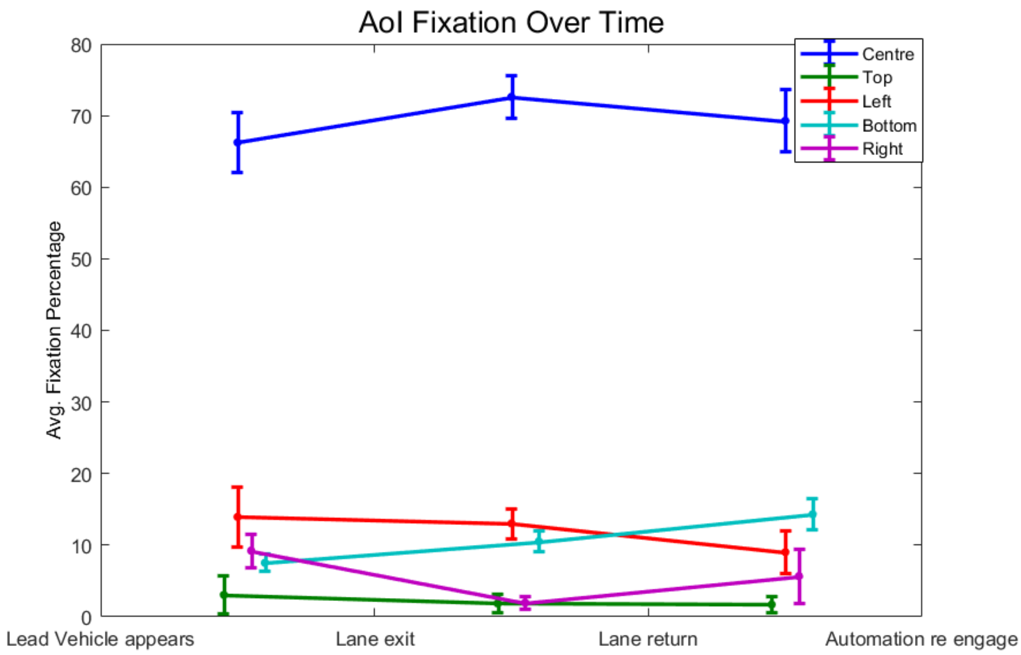

Figure 5.6 – Average percentage of fixation on each AoI on different HMI modalities. Source: the authors.

Unfortunately, a three-way ANOVA with such a sample size (30) do not have enough strength to draw conclusions on the impact of the HMI modalities on drivers' attendance to specific AoIs, especially when it comes to the different driving environments and distances of the vehicles on the offside lane. Also, as the focus of this research is on the transition of control. The inclusion of time windows after the transition itself would not provide any relevant information, based on the research objectives, and would only delude the results, due to the different behaviours that might be adopted during different parts of the task. For the following set of tests, the data from each AoI were treated individually, as one separated distribution from the other. Also, those tests only considered the fixations before the transition of control, as it provided more relevant information about the situation awareness acquisition process.

To evaluate how the HMI modalities and the traffic environment density affected drivers' prioritization of environmental information, this research chosen to use a repeated measures two-way ANOVA test, measuring how both variables (HMI modalities and offside distances) affected the fixation percentage on the right AoI (representing the wing mirror, where the relevant environmental information should be available). The results (figure 5.7) have shown no significant main effect of HMI modality [F (1.802, 95.524) =.182, p=.811, $\eta 2$=.003] nor of offside distance [F(1.755, 92.996)=1.596, p=.210, $\eta 2$=.029] on fixation percentage in the right AoI. This result suggests that people tend to look to the right, regardless the offside distance or the presence of additional information elsewhere. Although, there was a significant interaction effect between the two independent variables [F(4,212)= 3.438, p=.01, $\eta 2$=.061], where on the no HMI condition, people seem to look more to the right when the vehicle is close (25 m).

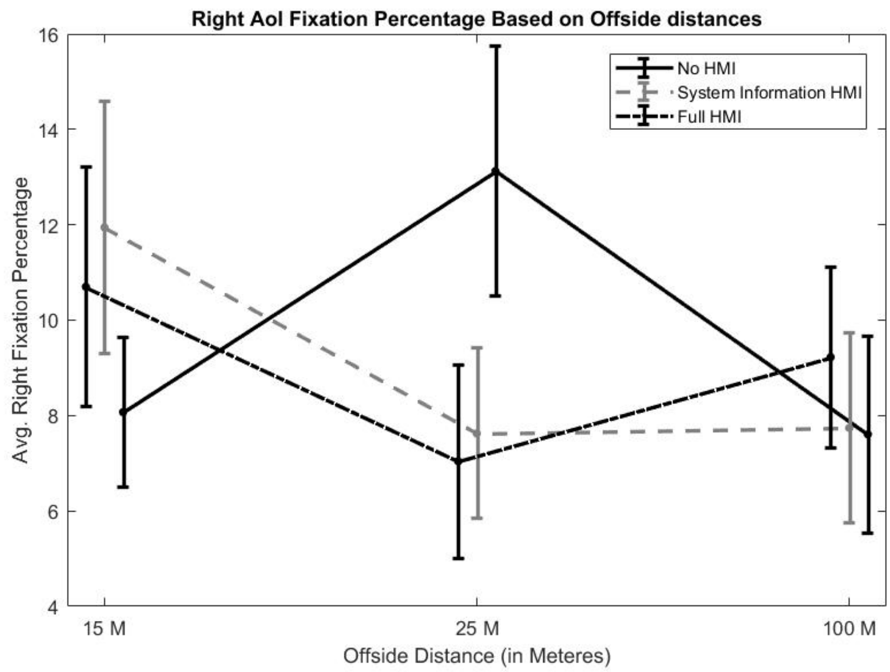

Figure 5.7 – Average percentage of fixations on the right AoI before the transition of control. Source: the authors.

This interaction deserves particular attention, as it might bring substantial evidence of the impact of the system design on drivers' behaviour. When the distance of the offside vehicle was too short (15m), it was expected from drivers not to have significant differences on their concentration of fixations on the wing mirrors, as the situation was challenging, making them spend more time processing the information to judge if it was safe or not to overtake (Underwood et al., 2005). On the other hand, when the offside distance was too long (100m), the decision was obvious, reducing the necessary time looking at it, which may have ended up reducing the differences between conditions. When it comes to a moderate-difficulty task (25m), some drivers still had to spend their time looking to the right. Even though, whenever other information sources were also bringing relevant information to the task (in this case, the system status on the two last conditions' HMI), it is reasonable that most of the drivers would reduce the number of fixations on the right and look down. This result suggests that drivers do not look down to check the vehicle's speed. As the system provides more information about its status, drivers' gaze to the environment seems to be reduced, suggesting that they might be accessing this new information on the interface.

To confirm hypothesis presented, a new repeated measures two-way ANOVA test was developed, aiming to evaluate the impact of HMI modalities and offside distances on drivers' fixations on the bottom AoI (the interface). There was a significant main effect of HMI modality on fixation percentage in the bottom AoI [$F(1.588, 84.716) = 16.37$, $p<.001$, $\eta 2 = .187$], where people fixated more on the bottom using the full HMI (condition 3). On the other hand, there was no significant main effect of the offside vehicle's distance [$F(2,106)=0.64$, $p=.983$, $\eta 2 = .073$], suggesting that this factor was not relevant for drivers decision to rely on the HMI. In the end, no significant interaction between the independent variables was found [$F(4,212)=.344$, $p=.8499$, $\eta 2=.041$] . It seems like regardless the complexity of the scenario, people will look more to the system in case more information is provided, even if they can sample it elsewhere (see figure 5.8).

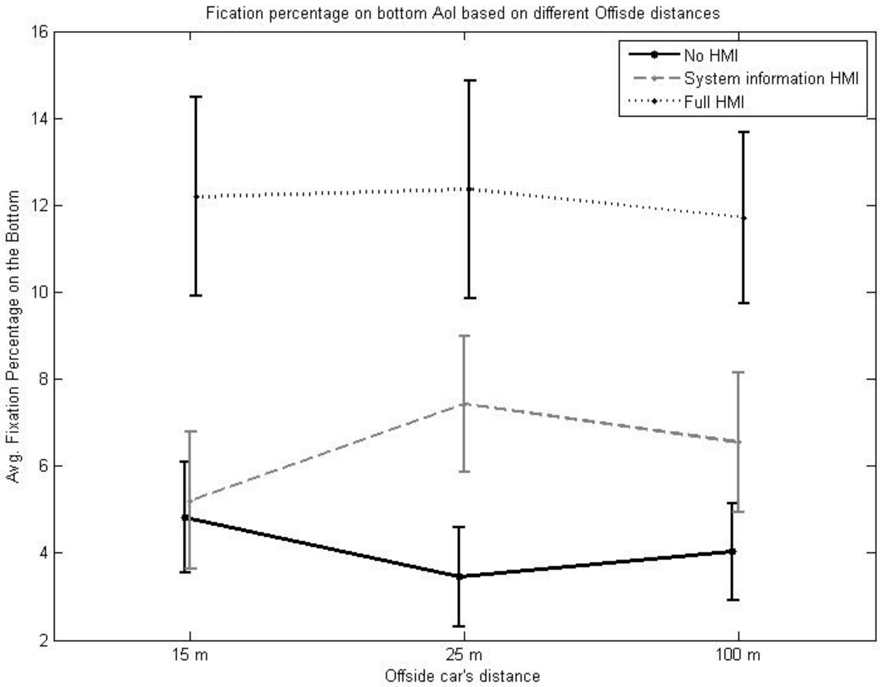

Figure 5.8 – Average percentage of fixations on the bottom AoI before the transition of control. Source: the authors.

Even if the ANOVA test have not confirmed the interaction between the offside distances and HMI modalities, it is perceivable that the difference between the no HMI condition and the system information HMI increases, whenever the decision to overtake or not becomes easier (as the offside distance is increased). This evidence collaborates to the arguments presented above, suggesting that as the relevance of environmental information decreases and the amount of information on the HMI increases, it is assumed that drivers may look down, to check other information such as the system status.

The test above indicated that if the environmental information is provided by the system interface, drivers will access it, even if the same information is present in the outside environment. It is now necessary to know if this approach is useful, to enhance drivers' performance during a transition of control. To do so, another two-way ANOVA test was applied, measuring the impact of HMI modality and offside distance on the duration of the time window 1. This metric was used to calculate drivers' performance, as it indicates how fast was their decision-making. In other words, how much time they needed to acquire enough situation awareness to decide how to act. Similar metrics were used before as a measure of drivers' performance during transitions of control (Stanton & Erickson, 2017; Gold et al., 2013; Damböck et al., 2013). There was significant main effect of HMI modality [F (1.202, 63.696)= 4.78, p=.021, η2 =.083], where the full HMI condition had lower time window duration than the system information HMI condition, which was quicker than the no HMI one. The more information provided, the better is the resumption of control. There was also a significant main effect of the offside distance [F(1.321, 69.989)=3.855, p=.042, η2 =.068] Where the closer is the vehicle on the offside lane; more people are uncertain about how to behave and take a longer time to resume control (see figure 5.9).

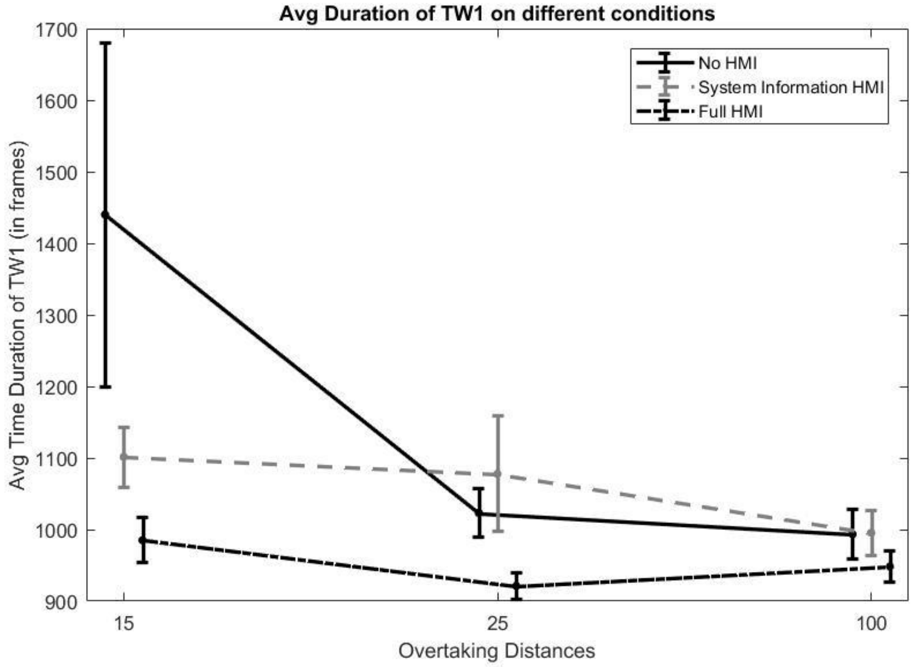

Figure 5.9 – Average duration of the first time window on different offside distances and with different HMI modalities. Source: the authors.

It seems like the environmental information on the HMI is a good partner for a second opinion. As the easier the decision-making process is, the lower is the difference between the three conditions. Also, the first ANOVA test provided on this subchapter have shown that the fact that regardless of both HMI modalities and offside distances, people do not stop looking to the right prior an overtaking manoeuvre. Apparently, they use the information provided by the system to double check if their judgment was correct. This assumption is also in line with the reports of the qualitative interviews, where participants on the experiment reported that they checked the system's interface after looking to the mirror, just to have a second opinion about their eminent manoeuvre.

5.3.2. Questionnaire data

As already said on the methodology, the main goal of this technique was to evaluate drivers' perceived prioritization to the different information sources, as well as evaluate driver's perceived system usability with each HMI design. As the literature review found to be of little relevance, this research have not used any demographic oriented data provided by the participants of the test, but it can be accessed on Appendix C on the end of this document. To evaluate drivers' reliance/prioritization of information, a one-way ANOVA test was performed looking for different scores drivers' self-reported given importance to the information provided on the system's HMI on the three different test conditions (no HMI, system information HMI, full HMI). To analyse drivers perceived usability and system preferred interface, another one-way ANOVA was performed, measuring the impact of HMI modalities on the SUS score results (Brooke, 2005). To measure drivers' preference, regarding interface, individual proportion tests (Conover, 1999) were used to look for differences in the count of drivers' self-reported preferred system.

The first ANOVA results have found significant main effects of HMI modality on the importance given to the information on the interface [$F(2, 7.51) = 4.9121$, $p<.001$], where the no information HMI condition had a lower mean than environmental information HMI condition (see figure 5.10).

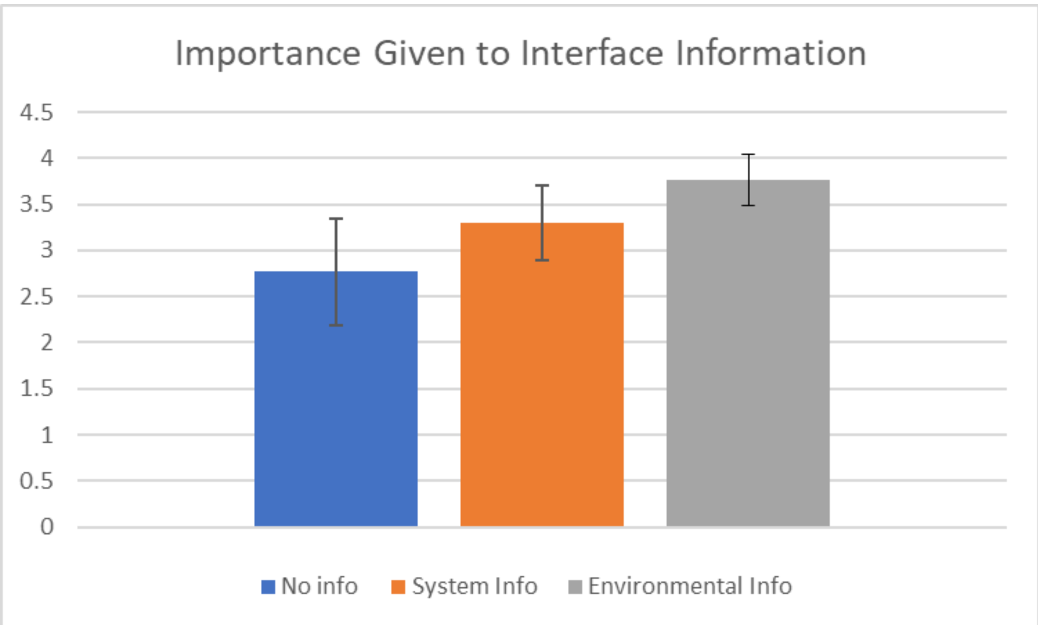

Figure 5.10 – Average importance given to interface information on different HMI conditions. Source: the authors.

This result was already expected, based on the previous findings presented above. It is reasonable that the more information is provided to the driver on the interface (in case it is relevant for the task in hand), higher will be their perception of the importance of this specific information source. This information only reinforces the idea that drivers seem to access active support for the driving task and consider it relevant to their overall performance and relationship with the vehicle automation. Although, the research was not able to find a significant effect of the addition of just the system information alone. It is possible that the perceived difference on the results may have been caused by a multi-factor increase (both system status and environmental information, rather than just one). As those two variables were not tested individually, no further conclusions can be drawn regarding this topic, being a study limitation that can be solved in future experiments.

Regarding the system's perceived usability, there was found no significant main effects of HMI modalities on the perceived task usability [$F(2, 21.3485) = 0.1302$, $p = 0.878$], as can be seen on figure 5.11. It seems like even if system information notoriously enhances drivers' performance and they do acknowledge it, their overall perception of usability seems not to change. The overall usability perception of the systems was high, (no HMI = 79.5; system information HMI = 78.42; full HMI = 80.08), so it is possible that all drivers found the task too simple and easy, making this technique not sensible enough to measure any statistical difference.

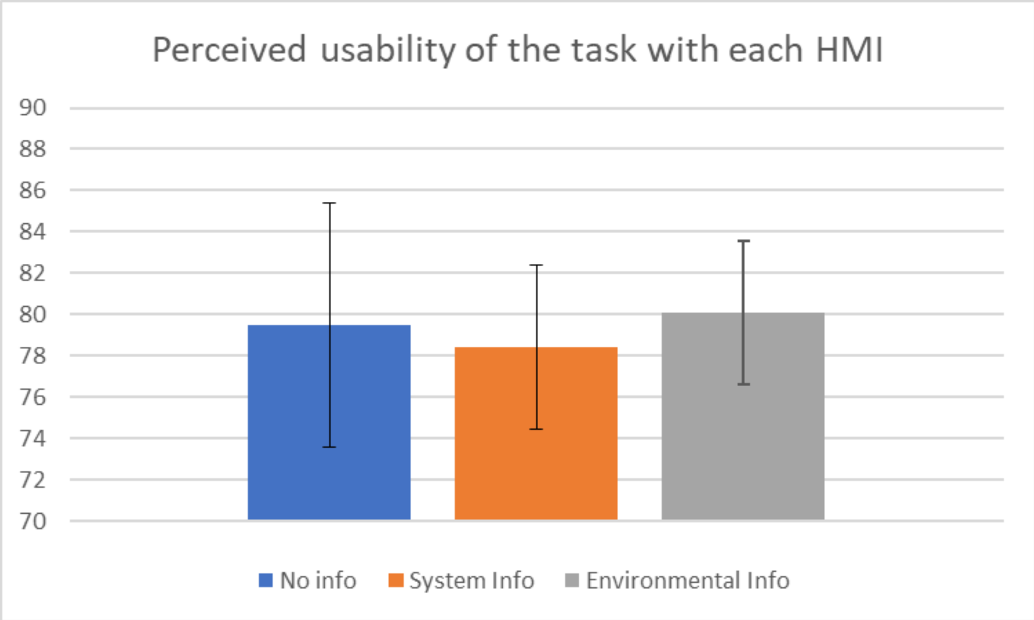

Figure 5.11 – Average SUS scores of the different systems. Source: the authors.

As a complementary result, the proportion tests on regarding the preferred system found that people seem to prefer the system information HMI a bit more than the full HMI (z=3.038). No other significant difference was found. The graphical results can be seen in figure 5.12.

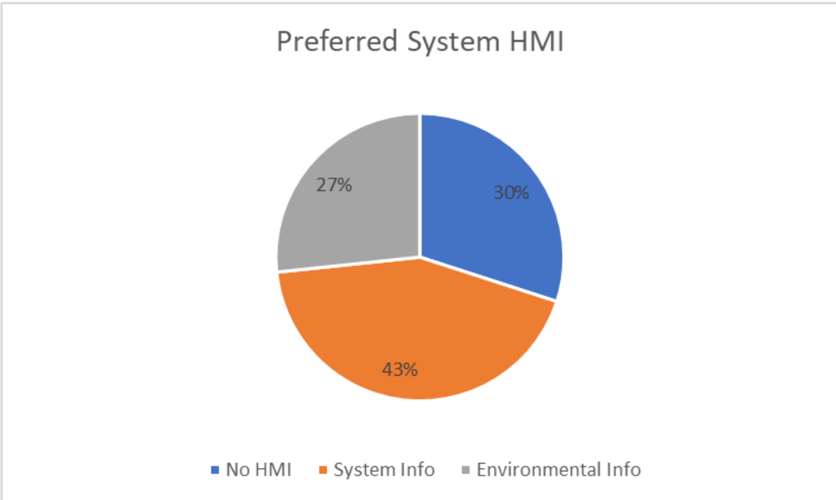

Figure 5.12 – User's self-reported preferred system ratio. Source: the authors.

Based on the interview results, it seems like that even when the system helped the drivers on their decision-making, they have claimed to be capable of deciding for themselves, and the help was not necessary, but rather handy. Some people even complained about the amount of information on the interface, making it too complex and hard to read. This result reinforces the idea presented during the SUS's results, that even if the system helped the driver, their perception is that it was not relevant. Maybe this result was caused by the simplicity of the test, as it was not a critical situation, and might be a study limitation to be tackled in future research.

6
Discussion

On this chapter, the results of the field techniques described on the previous section of this dissertation will be pondered in light of the research problem. This chapter aim to discuss what the practical implications of the findings on each experiment/review are, trying to answer the research questions, leading towards the confirmation or rejection of the research hypothesis. The following section will be divided according to the three questions purposed on the problem of this research.

What information drivers need to acquire in order to regain situation awareness to decide how to act in different levels of driving automation?

The *Post hoc* analysis of the eye tracking data of Madigan et al.'s (in press) driving simulator experiment has shown that the information required to regain situation awareness to resume control of vehicle automation is highly dependent of two main factors: the level of automation and the task in hand (nature of the manoeuvre).

The results of the eye tracking data from the lane change experiment identified one similar pattern of gaze dispersion and fixations to the road centre (PRC). The identified pattern was: 1) a drop of PRC and increase of lateral deviation right before the eminent overtaking situation; 2) an increase of PRC during the performance of the manoeuvre itself; 3) another deviation of lateral gaze dispersion after returning to their original lane. Regardless the driving automation condition, all the participants reacted similarly to the presented scenario. As already said before, this pattern was similar to other results reported by previous research related to eye movements in lane change tasks (Doshi & Trivedi, 2009; Salvicci & Liu, 2002), suggesting that this increase of lateral deviation may have been caused by an increase of attention to the right wing mirror, as it is essential to perform an lane-change manoeuvre, once drivers need to check for the presence of incoming faster vehicles on the offside lane. This assumption is also supported by the results on the second experiment (which varied the HMI modalities), that found that the more challenging is the lane change task (characterized by shorter distances of the offside vehicle), lower will be the differences of concentrations on the right AOI, assuming that every participant consistently looked to the wing mirror to acquire the information they needed.

It must be noted that even comparing different experiments (some of them even with no vehicle automation), the gaze dispersion pattern prior a lane change was similar. With that in mind, it can be assumed that at least to acquire situation awareness related to the environment, the level of automation seems to present little impact on drivers' information prioritization, on the other hand, the task to be performed presents a major role on dictating their need for specific information.

This study (Madigan et al., in press) limited itself to deal with lane change scenarios. That being said, little can be concluded about what other information sources drivers would look at on other take-over situations, such as a rear-end collision. It is possible that different scenarios might require from the driver information present in other information sources, and a proper model cannot be made. As an automated driving system must be prepared to deal with every single kind of take-over situation, new studies are necessary to model which are the most relevant information on the driving environment for each situation, so they can be coupled together and presented by the system in a synthetized way, in order to enhance drivers' response in a time of need.

If the level of automation had little impact on the process of acquiring situation awareness of the environment, when it comes to the system awareness, the results seems to be the opposite. The eye tracking analysis of Madigan et al.'s (in press) experiment showed that the level of automation caused significant main and interaction effects on drivers' vertical and horizontal gaze deviation along the take-over task. This result suggests that even if they deviate at the same time from the road prior to the task in hand, the place they divert to in order to understand the system varies, as the system behaviour changes.

As presented on the previous chapters, drivers seem to focus their visual attention to the information that was previously on control of the automation and was handed over to their responsibility during the transition of control. For instance, it was noted that drivers on Madigan et al.'s experiment, when performing the tasks on partial automation condition (LoA = 2) had much higher vertical gaze deviation, when compared to the conditional automation condition (LoA = 3). One point that should be noted is that the main differences between those tasks were that drivers on partial automation had to look after their actual speed and check for the system status (which were both controlled by the vehicle during conditional automation). These results suggest that the reason for them to look down was to access the information they had to assume to re-gain control. On the other hand, people seem to prefer to look to the environment to monitor system behaviour, rather than to the HMI, whenever the transition of control is not required. Similar findings were also noted on the results of the questionnaire of the experiment of this research, where drivers claimed to be more confident on their own judgements than on the interface, to monitor automation behaviour.

Those assumptions have direct implication on system design, especially when it comes to level 2 and 3 automations, where the resumption of control is needed and/or only part of the task is actually in control of the system. The results of the tests indicated that drivers do not look to the interface to monitor the system when the automation is still in control of the task/activity, but rather access after having to recover it. That being said, system designers should focus on prioritize to the driver not what the system is currently doing, but information which is relevant to the transition itself. In other words, drivers should receive supportive information about things that will not be in control of the automation anymore, as drivers will need to be up to date to that information to resume control. Some examples that should be highlighted are the prioritization of the vehicle's current speed during a disengagement of a cruise control, as well as a clear information that the system is actually turned off.

Considering the arguments presented previously to answer the research question, it can be briefly summarized that the task performed during the take-over dictates what information drivers need to access in order to gain situation awareness about the environment and the level of automation dictates what information is needed to re-gain situation awareness about the system. As implications, system designers must prioritize on the interface brief information about the surrounding situation, and focus on informing the driver about what was previously controlled by the system, and will need to be handed to the human.

Which information sources do drivers rely on to acquire the information they need on take-over scenarios?

Both the *Post hoc* eye tracking analysis and the experiment developed on this research have shown that the road centre seems to be the most accessed source of information, with the average of over 50% of the overall driver's gaze fixations on all the conditions of each study. Based on the literature on eye tracking measures and information processing (Posner, 1980), it can be assumed that, as expected, the centre of the road will always be the most relevant information source, as it provides information related to the ongoing situation that will require a driver's action, as well as provides relevant information about vehicle's controllability (Kountouriotis & Merat, 2016).

This is a good and expected result. According to Lee et al. (2012), diversion from the road centre can cause reduction of driver's performance to critical events, and this measure is deeply related to collision avoidance (Horswill & McKenna, 2004). Similar findings were also reported by Harbluk et al. (2007), on manual driving simulator experiments, where researchers found that the more drivers glanced outside the centre of the road, worse was their response to a near-end crash scenario.

Even though, the results on the systematic literature review conducted in this research suggests that even not being the main source of information, the information on the HMI might have strong influence on driver's gaze behaviour and on their ability to safely resume control from vehicle automation. Such findings were also supported by Zeeb et al. (2015), which reported a strong correlation between drivers' attendance to the system interface and their capabilities to avoid collision prior transitions of control. It is now necessary to evaluate which information drivers accessed on the interface, and what was their impact on the overall task performance.

The driving simulator experiment (which varied the HMI modalities) showed that during less demanding tasks (where the decision to change lane was easier due higher distance of the vehicle on the offside lane), the number of fixations on the HMI had increased, on the conditions where the system status was present. The reported result suggests that this information might be important during transitions of control, and it cannot be acquired elsewhere, as it is deeply related to the system itself. Another thing that was perceived on the experiment was that the more information provided to the driver on the HMI, higher will be drivers' attendance to it. In the case of the experiment of this research, it was found that active support to the take-over task (represented by an overtaking suggestion), as well as the information of the system status, made drivers look more to the interface, suggesting that this information was important, and drivers trusted on the system to provide them.

To complement the argument, the results of the questionnaire found that whenever system information and environmental information were present on the HMI, higher was drivers' reliance to it. During the interviews, they reported that have used the HMI specially during the reengagement and disengagement, to check if the system was working correctly. Participants also claimed that the system active information was a very good second opinion on difficult situations, when they were unsure about how to act. According to them, the system provided synthetized information, easy to read, which is vital to when they are distracted, as the road ahead might be too complicated for them to figure out what to do.

The presentation of active information not only affected driver's perception but their overall performance in terms of decision making. The experiment showed that active information about the take-over manoeuvre actually reduced their response time, suggesting that this more clear and direct information actually helps in their decision-making process. The implications of this statements are that the system HMI can be a source of situation awareness about the system status, but can also provide valuable active support, that is accessed by the drivers during the take-over situations, with perceived positive improvement of their performance. With that in mind, system designers should provide mainly those two types of information on their interfaces: system status and active support (which can synthetize information about the environment and what they need to do to take-over).

Regarding other sources of information, the experiment data reinforces the importance of the nature of the task (as the right wing mirror seemed to be the third most influential source of information, considering a right-hand-drive vehicle), supporting the findings of the *Post hoc* eye tracking analysis. It also was found that the task complexity has strong influence on the amount of fixation on certain information sources. As closer the vehicles on the offside lane were, more drivers were looking to the right, suggesting they were processing this information to decide how to act (Posner, 1980). System designers must be aware about the challenges of each possible take-over situation, to understand how to make their decision-making clearer by providing accurate active information about how drivers should act. Beforehand it must be noted that this experiment also focused on lane-change and non-critical situations, which might have affected their overall behaviour. That being said, new studies are necessary to create a complete model of drivers' overall gaze behaviour.

What is the impact of different information provided on system's HMI on its usability during transition of control?

When it comes to human performance during the transition of control, the results of the experiment have shown a clear enhancement on driver's decision-making times. Despite this improvement, the results on the after-test questionnaires have shown no significant differences on their perceived usability of the system. In fact, the most preferred HMI for the participants of this experiment was the system information one (which presented only the system status, with no overtaking suggestion). According to the interviews, participants complained about the high density of information on the Full HMI claiming that the overtaking suggestion was a little bit unnecessary, as they were able to judge how to drive by themselves. Also, some people liked the no information interface, due the fact that the "automation available" signal was triggered by sound, and they did not have to look down to the HMI to acquire this information.

In terms of information to be displayed, it can be argued that people like to have at least system status information on their HMI, as the second and the third conditions together (which presented system status information) had significant more preference ratio than the no information interface. This result was expected, as drivers have no source of system information other than the HMI, suggesting that this information might be essential for a good interaction between the driver and the HAV. Even though, it seems like drivers do not perceive the benefit generated by the active support provided by the system's HMI. This result is supported by the theories of Dejoy (1989), which claims that drivers behind the steering wheel tend to believe to be more skilled drivers than they actually are. Even if their performance increased, they believed to be equally capable to do the task without help.

In terms of interface design and information presentation, the data suggests that the density of information might be a problem for drivers' acceptance of the system. This assumption is also supported by the results of the literature review, where several authors pointed out for the very same problem. As implications for the interface design, manufactures must attempt to not overload their cluster with too much information, and only provide the most relevant information (use a minimalist design). Another solution is present the information by other channels, such as sound and vibro-tactile feedback. The interviews have shown that the main reason for people to like the no information interface on the experiment two was the presence of a voice, saying when to turn on the automation. It is believed that this same approached can be used to provide other kind of relevant information, such as reaction suggestion and/or the system status. This belief is in line with the findings of Schieben et al. (2014), which found that different non-visual HMI approaches might influence positively on driver’s resumption of control.

Concerning the hypothesis validation, it is first necessary to address to the specific hypothesis of the techniques and after that observe the implications for the main hypothesis of this research.

The hypothesis formulated for the systematic literature review was that the literature would agree that the level of automation and the distraction present on the environment play a significant role on the reduction of drivers' vigilance capabilities, but a presentation of timely and proper information may also collaborate to keep them engaged on the decision-making loop.. This hypothesis was confirmed, as most part of the reviewed papers showed those factors as the most influential on drivers’ take-over performance. Based on this, it is believed that the information presented by the vehicle automation, as well as their LoA may influence on the resumption of control, which was empirically tested on the two experimental procedures.

The hypothesis purposed for the *Post hoc* eye tracking analysis of Madigan et al.’s (in press) experiment was that The higher the LoA is, the more disperse drivers' gaze pattern will be. In higher levels of automation, people will fixate on the HMI to acquire situation awareness. Considering the results presented above, it can be assumed that this hypothesis was partially rejected. Yes, higher levels of vehicle automation caused a higher gaze dispersion, as expected, but not caused by distraction, but by different demands during the transition of control. The hypothesis did not also consider the impact of the task in hand, which seemed to be of strong impact on driver’s gaze Behaviour. In the end, higher levels of vehicle automation have not caused an increase of assessment of information on the HMI, but the opposite. It seems like people look to the HMI to update the information they need related to the task that they will resume control, and not to monitor the system Behaviour, which can be done by simply looking to the road and the vehicle in movement.

The hypothesis of this research's experiment was that drivers concentrate their sight more to the HMI whenever the system status is present, but the active information about the road environment have no effect on their visual attention to that area, as the same information can be acquired in other information sources. The presentation of active support for the task on the HMI improves peoples' time for resumption of control and task execution. The data showed that the more information is provided by the system, more drivers will access it, not only the system status. This information ultimately improves their decision-making times, but, surprisingly, this improvement is not perceived by the drivers.

In the end, it can be assumed that the main hypothesis of this research, which claimed that: "Drivers generally rely on information on the road to gain situation awareness, and only access the information on the HMI in cases of transitions of control, to check the system status. Adding more information on the interface won`t necessarily increase the system's perceived usability." was partially reproved. It was confirmed that the moment of higher assessment of system information exactly during the transition of control, and people generally do not look down to monitor/supervise the automation in its normal state. It also was confirmed that drivers generally rely on the road to gather situation awareness, as it is the main source of information. Regardless those two confirmations, the research was unable to define proper model for the way drivers sample information, specially when it comes to the access of the information on the HMI. The access of information provided by the HMI is highly dependent of what activities are being held over to the driver, during the transition of control, and also to the amount of information present on the interface. Drivers will not only look to the HMI to check system status. If the system provides accurate active information about the task to be performed, drivers will access it, and it will benefit the take-over. Regarding the system usability, it is arguable that an improvement on drivers' performance would signify a better usability, in terms of efficacy, but it was not perceived by the users.

7 Conclusion

The motivation for this master's research dissertation came from the stablished challenge on the literature on human factors and ergonomics for autonomous vehicles. It is a hard task to enhance human performance during take-over situations, when the driver has to come back to the loop but is completely unable to do so.

As much as the state of the art on HAV technology is developing towards lvl 5 vehicle automation, we are still far away from fully autonomous vehicles (NHTSA, 2017). That being said, previous studies (Carsten et al.,2012; Merat et al., 2014) have shown that drivers after continuous exposure to vehicle automation tends to be gradually removed from the decision-making loop, which in that case might end up compromising their capabilities to hand over control in a possible time of need (Gold et al., 2013; Louw et al., 2017; Louw & Merat,2017).

Some authors believe that generally, people do not have enough time to gather all the information they need in order to make an ideal transition of control (Endsley, 1995a; Wickens, 1981). So, drivers end up adopting a satisficing, rather than an ideal decision-making model (Boer, 1999; Goodrich & Boer, 2003; Boer & Hoedemaeker, 1998). According to this satisficing decision-making theory drivers must have one specific threshold of specific information necessary for them to take-over control of the vehicle automation.

With this in mind, this research focused on the human decision-making process, and how drivers acquire information in order to regain situation awareness and resume control. It is believed that by understanding human information acquisition process on those situations, it is possible to generate insights about how to develop more efficient system interfaces, tailored to aid the driver according to their needs (Goodrich & Boer, 2003). Previous studies in the field (Schieben et al., 2014; Dziennus et al., 2015) showed that efficient ways to provide information to the drivers, through well designed system-interfaces can enhance their responses during transitions of control. It must be noted that, as a master's dissertation in Design, the focus of this research was to understand human behaviour, but in order to use this information for the conception of human-machine interfaces and how to promote a better interaction with the product (HAV).

The main goal of this research was to categorize drivers' reliance on information provided by Highly Automated Vehicles' HMI based on their behaviour patterns during transition of control. To achieve this goal, the research counted with a meta-analytical literature review, for exploratory reasons, followed by one *Post hoc* eye tracking analysis of a lane-change driving simulator experiments (Madigan et al., in press), followed another driving simulator experiment, tailored specifically for the purposes of this research. Both experiments were developed as part of the EU funded AdaptiVe project, which the researcher's participation on the studies occurred through a partnership between PUC-Rio and the University of Leeds. Each of the experiments measured the impact of the levels of automation and interface design modalities on drivers' eye gaze behaviour, trying to depict different patterns and factors that might interfere on this process. The results of this research showed several factors that might affect drivers' gaze behaviour during transition of control. The hypothesis of the study was partially reproved, and the following implications and key findings will be discussed on this chapter.

Regarding the factors that might influence the way drivers sample information to acquire situation awareness during take-over, the research found that the information sources people look at to be aware of the environment is highly dependent to the task in hand. As different tasks have different demands for information, it is natural that drivers will look to distinct sources on each scenario. When people are trying gather situation awareness about the system, research found that their gaze behaviour is highly influenced by the nature of the task that is been held over. For instance, activities such as speed control might require different interface information, when compared lane position control.

Regarding the information that is accessed on the HMI during resumption of control in vehicle automation, the research found out that system status is a very important information, as it is required to confirm if the transition occurred correctly. Also, the HMI is the main source of that kind of information, as there is no other reliable way for the driver to figure out how the system is behaving rather by direct output of the interface. Another information that seems to be important for the driver on the HMI during take-over is active support, informing/suggestion how they should act in each specific scenario. This approach synthetises the information, and ultimately increases drivers' attendance to the HMI and enhance their decision-making process by making it faster.

Both findings produce insights that may lead to direct implications in terms of interface design. Considering this issue, some design recommendation can be made in order to improve transitions of control in vehicle automation:

- If the task in hand plays a major role on driver's information prioritization, but there are different sorts of situations that may lead to different requirements in terms of information, system designers should be aware of the most common scenarios, and understand which information is most relevant for each situation, in order to actively present it during the take-over request.
- If the transition of control is required, it is most likely that drivers will need to check for the system status during the take-over process. As there is no other reliable way to acquire this information rather by looking to the HMI, this information must be always clear and present, available on every possible scenario.
- Drivers generally look on the interface to update their awareness about the items that will be held over by them, also, active information about how they should act enhances their response time. For that reason, when the system detects that the situation will issue a take-over request, the information on the HMI must be totally focused on actively present information about what driver should do to regain control of those specific activities, and do not inform irrelevant/abstract information (such as prioritize one overtaking suggestion, rather than inform the headway distances of the surrounding vehicles).

By the end of the whole process it is important to consider the limitations of this research, and what can be done in the future to cover it and develop the state of the art on the field. The first thing that must be noted is that all the empirical data gathered for this research was generated through driving simulator experiments. As drivers were not submitted to real-world situations with their habitual vehicles, it is possible that the observed behaviour is not accurately representing how would be their information acquisition process on the real life, due a matter of perceived safety, or even by system immersion, due a certain lack of fidelity, when compared to a real-world scenario. Even though, the University of Leeds Driving Simulator (UoLDS) is one of the most advanced simulators in the world, and several studies have already proven the efficacy of this technique in studies in Human Factors for transport studies (Merat et al., 2014; Louw, 2017; Khul et al., 1995).

Another point that must be regarded is that both experiments that generated data for this research looked only for lane change scenarios. As one of the main findings of the studies was the importance of the performed task, one key limitation of this research is the impossibility to model drivers' gaze behaviour in any other scenario. New studies are needed in order to create an accurate model for information prioritization during transitions of control in vehicle automation.

Also related to the task studies, both experiments' scenarios were non-critical ones, composed by rather simple activities. This approach was opted in order to observe how drivers would ideally look for information. Previous research (Chapman et al., 1998; Crundall et al., 2003) has proven that during critical situations, drivers tend to focus their eyes on the hazard ahead, which would might have caused biases on the data. To evaluate drivers' visual scanning behaviour in critical situations without inducing gun focus (Crundall et al., 2003) is still a challenge that needs to be tackled in future methodological research on the field of human factors in vehicle automation.

The research's experiment (which dealt with HMI design) have not also changed the graphical nature of the interface design, but rather focused on vary the information presented. For future research, it is believed that experiments focused on innovative information communication approaches, such as sound interfaces or even HUD (Head-Up Displays) design might be beneficial for the field and bring valuable insights for the development of new systems.

Based on the study's limitations pointed out above, this research purpose some possible opportunities for future research aiming to improve the state of the art on the field of Human Factors and Ergonomics for Autonomous vehicles:

- As said above, little effort has been made towards innovative interface approaches, such as HUD, or any other graphic design study. It is believed that studies from the field of user experience and interface design/usability can be truly beneficial for the state of the art on this field;

- This study identified a strong relationship between the nature of the task and drivers' gaze behaviour during transitions of control. Even though, few studies were found that systematically varied the take-over task to evaluate drivers' gaze behaviour. Based on this, it is suggested here that new studies, focused on specific take-over scenarios should be developed in order to better model drivers' gaze behaviour in different situations.

- This research reinforces that it is still a challenge to measure effectively human performance during transitions of control, especially when it comes to safety critical situations. Based on this, it is important to develop new methodological-oriented research to support new field studies on the area, providing better ways to tackle the studied problems and achieved more accurate findings.

8
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Appendix A – Bibliographic corpus [1]

Article number	Author's name	Title	Year	Observed factors	Commets
1	Zeeb, K.; Buchner, A.; Schrauf, M.	What Determines Take-Over Time? An Integrated Model Apporoach of Driver Take-Over After Automated Driving.	2015	Atividades secundárias, Apresentação de informação, Experiência anterior, Ambiente externo	Ele chega a citar outros fatores, como a fadiga, complexidade da situação e experiência, mas não declara a partir de estudo. Comprovado empiricamente, ele confirmou apenas a questão da atividade secundária.
2	Loon, R. J.; Martens, M.H.	Automated driving and its effect on the safety ecosystem: How do compatibility issues affect the transition period?	2015	Compatibilidade de interface (com direção manual); Ambiente externo; Previsibilidade; Confiança/Aceitação	Um artigo de revisão teórica que defende um estudo maior de padrões de direção humana tanto para ser aplicado na maquina como para reconhecer os outros. Fala muito sobre compatibilidade, affordance e aceitação e previsibilidade.
3	Lu, Z.; Winter, J.C.F. de	A review and framework of control authority transitions in automated driving	2015	Autoridade do sistema; Nível de automação; Carga de trabalho (complexidade do controle); volume de informação; Apresentação de informação; Engajamento do motorista; Transparência do sistema; tempo de resposta (informação antecipatória)	" The development of HMIs and controllers for smoothly and safely transferring control authority between automation and human is amajor challenge for human factor researchers in automated driving." Sumariamente é um artigo de revisão de literatura sobre Take Over action. Vale apena guardar este tópico.
4	Strand, N.; Nilsson, J. ;Karlson, I.C.M.;Nilsson, L.	Semi-Automated versus Higly Automated Driving in Critical Situations Caused by Automation Failures	2014	Nível de automação, Experiências anteriores; Reliability; Affordance (percepção ou clareza do erro)	Eles simplificaram uma aproximação para usar uma anova, mesmo não sendo uma normal; uma pesquisa experimental de design fatorial.

[1] This table used for the meta-analysis was written in Portuguese, as it was part of the beginning of the research.

5	Terai, H.; Okuda, H.; Hitomi, K.; Bando, T.; Miyajima, C.; Hirayama, T.; Shinohara, Y.; Egawa, M.; Takeda, K.	An experimental study on the difference in drivers' decision-making behavior during manual and supported driving	2015	Nível de automação, Ambiente de condução, Percepção de risco,	Experimento com algumas falhas, mas media a questão da percepção de risco e o uso de automação para a tomada de decisão ao volante. Os autores acreditam que quanto maior a periculosidade do ambiente externo, mais cauteloso e menos complacente será o condutor.
6	Payre, W.; Cestac, J.; Delhomme, P.	Intention to Use a Fully Automated Car: Attitudes and a Priori Acceptability	2014	Ambiente externo, Experiência do usuário com sistemas, Engajamento, Fadiga, Controlabilidade	Questionário sobre a aceptabilidade de HAD, e quais fatores levam a isso.
7	Gold, C.; Körber, M.; Hohenberger, C.; Lechner D.; Bengler, K.	Trust in automation – Before and after the experience of take-over scenarios in a highly automated vehicle	2015	Experiência do usuário, Idade, Reliability, controlabilidade, workload (?), engajamento	Pesquisa experiental que porava que maior trust e uma experiencia mto positiva e "tediosa" com HAD pode levar a complacência
8	Banks, V.A.; Stanton N.A.	Discovering driver-vehicle coordination problems in future automated control systems: Evidence from verbal commentaries	2015	Experiência do usuário, Idade, HMI, Transparência, Repetição/monotonia/ consistência, Engagement,	Pegar refs 12, 13, 14 dele. Estudo de declaração verbal que basicamente diz que pessoas mais exp tendem a ser mais complacentes por tédio, porém menos complacentes por noção de causa e consequência, e o oposto para inexperientes. Fichar depois.
9	Aziz, T.; Horiguchi, Y.; Sawaragi, T.	An empirical investigation of the development of driver's mental model of a Lane Departure Warning system while driving	2013	Exp do usuário, Atividades secundárias, aprsentação de informação, workload, ambiente externo	Estuo experimental com simulador que atesta que pessoas inexperientes não pecebem/têm a capacidade de interpretar um sistema a partir de sua comunicação por estarem ocupadas com outras atividades

					relativas à condução. Corrobora com minha hipótese.
10	Brookhius, K.A.; Waard, de D.	Monitoring Drivers' Mental Workload in Driving Simulators Using Physiological Measures	2009	Ambiente externo, Workload	Um estudo muito maior sobre a possibilidade do uso de uma técnica (monitoramento fisiológico), do que efetivamente sobre complacência em si.
11	Maltz, M.; Shinar, D.	Imperfect In Vehicle Colision Avoidance Warning Systems Can Aid Distracted Drivers	2007	Reliability, atividades paralelas	Um artigo que defende que um sistema muito efetivo em sua acertividade acaba deixando os usuários complacentes, e que uma experiência negativa pode ajudar a mantê-los no loop.
12					Cortado por inadequação ao tema
13	Sena, P.; D'Amore, M; Brandimonte, M.A.; Squitieri, R.; Fiorentino, A.	Experimental framework for simulators to study driver cognitive distraction: brake reaction time in different levels of arousal	2016		Cortado por inadequação ao tema
14	Madigan, R.; Louw, T.; Dziennus, M.; Gaindorge, T.; Ortega, E.; Graindorge, M.; Merat, N.	Acceptance of Automated Road Transport Systems (ARTS): an adaptation of the UTAUT model	2016	Reliability, Previsibilidade/Transparência,	Cortado por inadequação ao tema
15	Mulder, M.; Abbink,D.A.	Sharing Control with Elderly Drivers: Haptic Guidance during Curve Negotiation	2010	Idade, Apresentação de informação, Informação antecipatória, Frequência da comunicação	
16					Cortado por inadequação ao tema

17	Cummings, M. L.; Marquez, J.J.; Roy, N.	Human-Automated Path Planning Optimization and Decision Support			cortado por inadequação ao tema
18	Weyer, J.; Fink, R.D.; Adelt, F.	Human-Machine Cooperation in Smart Cars. An Empyrical Investigation of The Loss-of-Controll Thesis	2014	Experiência do usuário, Informação Antecipatoria, Apresentação de informação, Nível de automação, Reliability, workload/ comforto, reliability	Artigo mostra a partir de um questionário a percepção de usuários sobre causas de loss of control com sistemas autônomos. Autor tem uma perspectiva optimista de full automated driving ser pouco prejudicial (na visao dos usuários). Quanto menos no controle estão os usuários, mais eles atentam para o caminho.
19					Cortado por inadequação ao tema
20	Desmond, P.A.; Matthews, G.	IMPLICATIONS OF TASK-INDUCED FATIGUE EFFECTS FOR IN-VEHICLE COUNTERMEASURES TO DRIVER FATIGUE	1997	Fadiga, workload, Comunicação do sistema.	Artigo que mostra por meio de um simulador que quanto maior a fadiga, mais desatentos e incapazes de perceber coisas ficamos, logo, a comunicação deve ser mais explícita.
21	Rudim-Brown, C. M.; Parker, H. A.	Behavioural Adaptation to Adaptative Cruise Control (ACC): Implications for Preventive Strategies	2004	Nível de automação, Reliability, Experiência do usuário, Atividades secundárias	Artigo impirico que mostra que quanto maior o nível da automação e mais reliable, mais as pessoas ficam complacentes e engajam com atividades secundárias, o que pode agravar o processo.
22	Balfe, N; Sharples, S.; Wilson, J.R.	Impact of Automation: Measurements of Performance, Workload and Behaviour in a complex control Environment	2015		Cortado por inadequação ao tema
23					Cortado por inadequação ao tema

24	Beggiato, M.; Pereira, M.; Petzoldt, T.; Krems, J.	Learning and Development of Trust, Acceptance and Mental Model of ACC. A Longitudinal On-Road Study	2015	Experiência do usuário	Um artigo que alega que quanto mais tempo se usa o sistema, melhor se fica com ele, mas acaba iniciando complacencia.
25	Hancock, P.; Parasura man, R.	Human Factors and Safety in the Design of Inteligent Vehicle-Higway Systems (IVHS)	1992		Cortado por inadequação ao tema
26					Cortado por inadequação ao tema
27					Cortado por inadequação ao tema
28					Cortado por inadequação ao tema
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45					Cortado por inadequação ao tema

46	De Visser, E.J.; Legullon, M.; Freedy, A.; Freedy, E.; Weltman , G.; Parasura man, R.	Designing an Adaptive Automation System for Human Supervision of Unmanned Vehicles: A Bridge from Theory to Practice	2008		Cortado por inadequação ao tema
47	Jamson, A. Merat, N. Carsten, O.M.J, Lai, F.C.H.	Behavioural changesin drivers experiencing higly-automated vehicle control in varying traffic conditions	2013	Nível de automação, Influência do ambiente externo	ver comentário em planilha da rev um
48	Louw, T. Kountour iotis, G. Carsten, O. Merat, N.	Driver Inattention During Vehicle Automation: How Does Driver Engagement Affect Resumption Of Control?	2015	Nível de automação, Influência do ambiente externo	ver comentário em planilha da rev um
49	Daniele Rusciob, Maria Rita Ciceria, Federica Biassoni	How does a collision warning system shape driver's brake response time? The influence of expectancy and automation complacency on real-life emergency braking	2014	Confiabilidade, Experiência do operador, Informação antecipatória, Transparência do sistema	ver comentário em planilha da rev um
50	Winter, J. Happe, R. Martens, M. Stanton, N.	Effects of adaptative cruise control and higly automated driving on workload and situation awareness: A review of empirical evidence	2014	Nível de automação, Influência do ambiente externo	ver comentário em planilha da rev um
51	Larson, A. Kircher, K. Hultgen, A.J.	Learning from experience: Familiarity with ACC and responding to a cut-in situation in automated driving	2014	Esperiência do operador, Confiabilidade	ver comentário em planilha da rev um
52	Schiben, A. Griesche, S. Hese, T. Fricke, N.	Evaluation of three different interaction designs for automatic steering intervention	2014	Informação antecipatória, Confiabilidade, Transparência do sistema, Influência do ambiente, Apresentação de	ver comentário em planilha da rev um

	Bauman n, M.			informação, Intermitência do sinal	
53	Victoria A. Banks*, Neville A. Stanton	Keep the driver in control: Automating automobiles of the future	2014	Autoridade, Transparência do sistema, Confiabilidade	ver comentário em planilha da rev um
54	Banks, V.A. Stanton, N.	Sub-systems on the road to vehicle automation: Hands and feed free but not 'mind' free driving	2013	Nível de automação, Confiabilidade, Idade do operador	ver comentário em planilha da rev um
55	Sonja Stockert, Natalie Tara Richards on, Markus Lienkam p	Driving in an increasingly automated world – approaches to improve the driver-automation interaction	2015	Influência do ambiente, Nível de automação	ver comentário em planilha da rev um
56	Hitoshi Teraia, Hiroyuki Okudab, Kentaro Hitomic, Takashi Bandoc, Chiyomi Miyajima b, Takatsug u Hirayam ab, Yuki Shinohar ac, Masumi Egawac, Kazuya Takedab	An experimental study on the difference in drivers' decision-making behavior during manual and supported driving	2015	Carga de trabalho, Nível da automação	ver comentário em planilha da rev um
57	Joel Gonçalve s, Klaus Bengler	Driver State Monitoring Systems– Transferable knowledge manual driving to HAD	2015	Nível da automação, Complexidade do sistema, Informação antecipatória	ver comentário em planilha da rev um
58	Sebastia n Hergeth, Lutz Lorenz, Roman Vilimek,	Keep Your Scanners Peeled: Gaze Behavior as a Measure of Automation Trust During Highly Automated Driving	2016	Influência do ambiente, Nível de automação	ver comentário em planilha da rev um

	Josef F. Krems				
59	Sijun Shen and David M. Neyens	Assessing drivers' performance when automated driver support systems fail with different levels of automation	2014	Carga de trabalho, Nível da automação, Complexidade do sistema	ver comentário em planilha da rev um
60	Payre, W.; Cestac, J.; Delhome , P.	Fully Automated Driving: Impact of Trust and Practice on Manual Control Recovery	2016	Experiência do usuário, Nível de automação, informação Antecipatória, Reliability, "transparência (vinda de experiência)"	Um artigo de cunho experimental que defende a ideia de que condutores de HAD mais experientes são menos complacentes por ter uma maior noção de causa e consequência das coisas. Também foi confirmado que quanto mais confiam em um sistema, maior a complacência cega." This negative impact was mitigated in the elaborate practice condition. ", ou seja, a exp releva a complacência por overtrust. Drivers should be taught how to use FAD. • In simple practice conditions, a high level of trust can have a negative impact on emergency MCR reaction time. • Elaborate practice mitigates the negative impact of overtrust on emergency MCR reaction times.
61	Parasura man, R.; Manzey, D.H.	Complacency and Bias in Human Use of Automation: An Attentional Integration	2010	Atividades secundárias, Apresentação de informação, Engajamento do operador, Reliability, Contexto/Ambiente,	Este é um artigo teórico de referência nos estudos de complacência e HAI, apresenta um framework geral de como ocorre a coisa, DEVE SER USADO DE BASE PARA TODO O ESTUDO. Muita coiisa para fundamentar minha dissertação quando fala sobre

					atividades paralelas. ELE DEFENDE INTERFACE LOGO NO INICIO DAS CAUSAS DA COMPLACENCIA.
62	Wickens, C. D.; Clegg, B. A.; Vieane, A. Z.; Sebok, A. L.	Complacency and Automation Bias in the Use of Imperfect Automation	2015	Reliability, Experiência do usuário, Frequência de comunicação, transparência, apresentação de informação, atividades secundárias, Workload.	Artigo de base do wickens que alega que alertar errado é pior do que não alertar para a complacência. Fala sobre transparência. Não comunicar gera complacência, comunicar errado gera bias, e Bias>complacência.
63	Ma, R.; Kaber, D. B.;	SITUATION AWARENESS AND DRIVING PERFORMANCE IN A SIMULATED NAVIGATION TASK	2006	Reliability, atividades paralelas	Artigo que estuda os impactos da reliability do sistema na capacidade do motorista de entender o mesmo (S.A.). Artigo raso e fraco
64	Saffarian, M.; de Winter, J.C.F.; Happee, R.	Automated Driving: Human-factors issues and design solutions	2012	Engagement, Reliability, Experiência do usuário, complexidade do sistema, informação antecipatória, transparência, apresentação de informação, intermitência do sinal,	Este artigo faz uma espécie de taxonomia teórica da relação humano automação em carros. Reler para pegar os critérios dele. Ele fala dos motivos para take-over tbm,
65	Neubauer, C.; Matthews G.; Saxby, D.	THE EFFECTS OF CELL PHONE USE AND AUTOMATION ON DRIVER PERFORMANCE AND SUBJECTIVE STATE IN SIMULATED DRIVING	2012	Atividades paralelas, nível de automação, driving engagement, fadiga.	Pesquisa experimental que testa o impacto do uso de celular na complacência do motorista de carro autônomo. Os autores alegam que quanto mais distraído com o ambiente e com a passividade do sistema , maior o tempo de resposta.

66	Beller, J.; Heesen, M.; Vollrath, M.	Improving the Driver–Automation Interaction: An Approach Using Automation Uncertainty	2013	Reliability, Transparência, apresentação de informação, intermitência de sinal.	Um artigo experimental que alega que quando mostramos os boundaries de limitação do sistema para o controlador, ele fica menos complacente. "Ver This situation has been discussed in the literature as the cry-wolf effect (Breznitz, 1983)". Results showed that informing participants about the system reliability level allowed them to rely more appropriately on the aid, leading to an improved performance.
67	Mulder, M.; Abbink,D .A.; Boer, E.R.	sharing control with Sharing Control With Haptics: Seamless Driver Support From Manual to Automatic Control	2012	Apresentação de informação, Nível de automação, engagement	Um artigo que propõe um novo modelo de interação que prega "shared control" com sistemas hapticos. Ver: Norman (1990, p. 2) put forward four automation design criteria: “Appropriate design should [1] assume the existence of error, [2] it should continually provide feedback, [3] it should continually interact with operators in an effective manner, and [4] it should allow for the worst of situations". o artigo defende que quando você mantêm o motorista no loop de decisão, mas com o sistema constantemente comunicando sua atividade, ele mantêm o controlador mais estável.

68	Bashiri, B.; Mann, D.D.	DRIVERS' MENTAL WORKLOAD IN AGRICULTURAL SEMIAUTONOMOUS VEHICLES	2013	Reliability, complexidade do sistema, Engagement, Influência do ambiente, level da automação,	Artigo que alega que o uso de automação em um ambiente agrícola automotivo aumenta o workload do kra, devido ao fato dele ter que "interpretar o sistema", e ficar em constante vigilância, além de cuidar do próprio trabalho.
69	Xiong, H.; Boyle, L.N.; Moeckli, J.; Dow, B.R.; Brown, T.L.	Use Patterns Among Early Adopters of Adaptive Cruise Control	2012	Experiência do usuário; apresentação de informação	Artigo que busca investigar perfís de experência de motoristas com automação e achar seus problemas. Segundo os autores, quanto mais novato, mais erros ocorrerão, porém quanto mais experiente, mais complacente. Também alega que o fator informação fornecida pelo sistema influencia neste comportamento.
70	Young, M.S.; Stanton, N.A.	JOURNEY' S END: WILL VEHICLE AUTOMATION MAKE SKILLED DRIVERS REDUNDANT?	2000	Experiência do usuário, Nível de automação, complexidade do sistema, ambiente da condução	Um artigo que testa a experiência do usuário na capacidade de retomar controle durante uma falha de automação
71	Matthews, G.; Newman, R.; Joyner, L.A.	AGE AND GENDER DIFFERENCES IN STRESS RESPONSES DURING SIMULATED DRIVING	1999		Cortado por inadequação ao tema
72	Fletcher, L.; Zelinsky, A.	Driver Inattention Detection based on Eye Gaze–Road Event Correlation	2009	Fadiga, "engagement", informação antecipatória, Exp do usuário, Driving environment, intermitência do sinal, apresentação de informção,	Um aritog que estuda a possibilidade de um sistema que identifique a awareness do motorista para a tarefa de conduzir. Ele conclui que é possível inferir sobre o wl do motorista e alertar antecipatoriamente o mesmo sobre o seu estado.how do we combine the behavior of the two controlling agents?. Catar a tabela 1 deste artigo. teste

					com carro instrumentado.
73	Wickens, C.D.; Parasuraman, R.; Manzey, D.; Bahner-Heyne, J.E.; Meyer, J. Bliss, J.B.; Lee, J.D.; Rice, S.	Current Concepts and Trends in Human-Automation Interaction	2009	ver o artigo de qualquer forma	Cortado por inadequação ao tema
74	Hoff, K.A.; Bashir, M.	Trust in Automation: Integrating Empirical Evidence on Factors That Influence Trust	2015	Pegar os métodos dele	Cortado por inadequação ao tema
75	Cummings, M. L.; Gao, F.; Thornburg, K.M.	Boredom in the Workplace: A New Look at an Old Problem	2016		Cortado por inadequação ao tema
76	Kennedy, K.D.; Bliss, J.P.	Inattentional Blindness in a Simulated Driving Task	2016		Cortado por inadequação ao tema
77					Cortado por inadequação ao tema
78	Allahyar, M.; Becic, E.; Chappell, S.; Fisher, D.; Lohrenz, M; Monk, C.; Philips, B.	The Evolving Role of Automation in Transportation: Human Factors Lessons Learned from the Different Modes	2016	Transparência, Experiência do usuário, Level de automação, complexidade do sistema, apresentação de informação, Driving engagement, "reliability", ambiente de condução, autoridade,	Panorama teórico sobre o futuro da HAD. Conduzido a partir de um estudo naturalístico.

79	Young, M.S.; Stanton, N.A.	Malleable Attentional Resources Theory: A New Explanation for the Effects of Mental Underload on Performance	2002	Ambiente externo, apresentação de informação, level de automação, Driving engagement, Complexidade do sistemma, fadiga	Pesquisa que visa encontrar vantagens em métodos alternativos de apresentação de informação e recursos de atenção em HAD. Ao fim, a pesquisa defende que saliências paralelas de atenção são úteis para manter o foco do usuário na vigília do sistema, ao mesmo tempo que o nível de automação e a complexidade da tarefa secundária se impõem como barreiras. Evidence is accumulating that simply reducing demand is not necessarily a key to improving performance.
80	Chien, S.Y.; Lewis, M.; Hergeth, S.; Semnani-Azad, Z.; Sycara, K.	Cross-Country Validation of a Cultural Scale in Measuring Trust in Automation	2016	Complexidade do sistema, Reliability, cultural heritage, Apresentação de informação, transparência	Um artigo que alega que diferentes culturas reagem melhor a diferentes formas de comunicação em HAD. Artigo de cunho experimental quantitativo.
81					Cortado por inadequação ao tema
82					Cortado por inadequação ao tema
83	Parasuraman, R.; Sheridan, T.B.; Wickens, C.D.	Situation Awareness,Mental Workload,and Trust in Automation:Viable,Empirically Supported Cognitive Engineering Constructs	2008	Rever este artigo depois	Cortado por inadequação ao tema
84	Roirva, E.; Parasuraman, R.	Transitioning to Future Air Traffic Management: Effects of Imperfect Automation on Controller Attention and Performance	2010	Rever este artigo depois	Cortado por inadequação ao tema

85	Chancey, E.T.; Bliss, J.P.; Proaps, A.P.; Madhavan, P.	The Role of Trust as a Mediator Between System Characteristics and Response Behaviors	2015	Gostei da definição dele de trust	Cortado por inadequação ao tema
86	Sanchez, J.; McLean.	Conceptual Model of Human-Automation Interaction	2009	Pegar este artigo para revisão de literatura	Cortado por inadequação ao tema
87	Blair, K.; Sandry, J.; Rice, S.	An Expansion of System Wide Trust Theory Using In-Vehicle Automation	2012	Reliability, Experiência do usuário,	ele está falando sobre uma perspectiva mais abrangente de vários sistemas de auxílio, de forma que imperfeições em um podem comprometer o outro.
88	Schaefer, K. E.; Chen, J. Y. C.; Hancock, P.A.	A Meta-Analysis of Factors Influencing the Development of Trust in Automation: Implications for Understanding Autonomy in Future Systems	2016	RELER DEPOIS, MUITO IMPORTANTE; Usar os parâmetros estatísticos que foram usados	Cortado por inadequação ao tema
89	Hoc, J.M.; Amalberti, R.	Cognitive Control Dynamics for Reaching a Satisficing Performance in Complex Dynamic Situations	2016		Cortado por inadequação ao tema
90	Lyons	Trust-Based Analysis of an Air Force Collision Avoidance System			Cortado por inadequação ao tema
91	Wohlleber, R.W.; Calhoun, G.L.; Funke, G.J.; Ruff, H.; Chiu, C.Y.P.; Lin, J.; Matthews, G.	The Impact of Automation Reliability and Operator Fatigue on Performance and Reliance	2016		Cortado por inadequação ao tema
92					Cortado por inadequação ao tema
93				Pode ser interessante ler depois	Cortado por inadequação ao tema
94					Cortado por inadequação ao tema

95					Cortado por inadequação ao tema
96				Reler depois	Cortado por inadequação ao tema
97					Cortado por inadequação ao tema
98					Cortado por inadequação ao tema
99				parece interessante	Cortado por inadequação ao tema
100	Sheridan, T.B.	Human supervisory control of aircraft, rail and highway vehicles	1999	Nível de automação, apresentação de informação, atividades externas, engagement, experiência do operador, complexidade do sistema, fadiga, autoridade, transparência, reliability, intermitência do cinal	O artigo faz um panorama geral sobre o uso de automação em diferentes meios de transporte. No final ele faz um apelo ao design de interface. Reler dps a parte final sobre problemas
101					Cortado por inadequação ao tema
102					Cortado por inadequação ao tema
103					Cortado por inadequação ao tema
104					Cortado por inadequação ao tema
105					Cortado por inadequação ao tema
106					Cortado por inadequação ao tema
107					Cortado por inadequação ao tema
108					Cortado por inadequação ao tema
109					Cortado por inadequação ao tema
110					Cortado por inadequação ao tema
111					Cortado por inadequação ao tema
112					Cortado por inadequação ao tema
113			2008		Cortado por inadequação ao tema
114					cortado por inadequação ao tema

Factors:	**Frequency**	**Sample P**	**Z Low**	**Z Medium**	**Z High**	**Influence level**	**Critical Z**
Influence of the environment	25	0.53	9.87	3.47	0.44	High	-1.96
Automation level	22	0.47	8.41	2.51	-0.44	High	
System reliability	20	0.43	7.44	1.88	-1.02	High	
Experience with the system	19	0.40	6.95	1.56	-1.31	High	
Information presentation	19	0.40	6.95	1.56	-1.31	High	
System Transparency	16	0.34	5.49	0.60	-2.19	Medium	
Driving engagement	14	0.30	4.52	-0.03	-2.77	Medium	
Workload	13	0.28	4.04	-0.35	-3.06	Medium	
System complexity	11	0.23	3.06	-0.99	-3.65	Medium	
Anticipatory information	9	0.19	2.09	-1.62	-4.23	Medium	
System repetition	8	0.17	1.60	-1.94	-4.52	Low	
System Authority	4	0.09	-0.34	-3.21	-5.69	Low	
Driver elderliness	2	0.04	-1.31	-3.85	-6.27	Low	
Cultural heritage	1	0.02	-1.80	-4.17	-6.56	Null	
N total	47						
Critério Low	0.1						
Critério medium	0.3		Pareto				
Critério High	0.5		**Parâmetro**	**Freqência**	**Freq Acumulada**	**Percentagem**	**Percent Acumulada**
Descritiva			Influência do ambiente externo	25	25	13.66	*13.66*
			Nível da automação	22	47	12.0218579	25.68
Média	13.07142857		Reliability	20	67	10.9289617	36.61
Erro padrão	2.025833937		Experiência com o sistema	19	86	10.3825137	46.99
Mediana	13.5		Apresentação de informação	19	105	10.3825137	57.38
Modo	19		transparência do sistema	16	121	8.7431694	66.12
Desvio padrão	7.579976514		Driving engagement	14	135	7.6502732	73.77
Variância da amostra	57.45604396		Fadiga	13	148	7.10	80.87
Curtose	-1.044407746		Complexidade d o sistema	11	159	6.01	86.89
Assimetria	-0.182378303		Informação antecipatória	9	168	4.92	91.80
Intervalo	24		Intermitência de sinal	8	176	4.37158	96.17
Mínimo	1		autoridade	4	180	2	98.36
Máximo	25		Idade do operador	2	182	1	99.45
Soma	183		Diferença cultural	1	183	0.5464481	100.00
Contagem	14						
Alpha	0.05	-1.645					

Appendix B – Driving simulator experiment paperwork

UNIVERSITY OF LEEDS DRIVING SIMULATOR

UNIVERSITY OF LEEDS

Participant Information Sheet

Before deciding to take part in this study please read the following information about the experiment.

Background to this experiment

This study aims to examine drivers' interaction with automation in vehicles. The experiment will involve you driving the University of Leeds Driving Simulator. You will be required to interact with an automated system, switching it on and off, as well as driving the simulator in manual mode (i.e. without automation).

The simulator

The University of Leeds Driving Simulator is a controlled and safe environment in which to study driver behaviour. From the outside, the two major items that can be seen are the motion system and the large, white projection dome. Inside, is a Jaguar S-type vehicle cab. All the controls in the simulator work as expected and the instrument panel also operates displaying speed, and various warning lights.

Entry to the simulator dome is via a boarding platform and you will be accompanied into the simulator by the researcher.

The drives

Practice Drive

You will first have the opportunity for a practice drive, to allow you to become familiar with the simulator. The researcher will explain all of the driving controls of the Jaguar prior to your practice drive and remain with you throughout. Only when you feel comfortable will you be asked to continue. Please feel free to ask any questions that you may have. This should last around 20 minutes. For this experiment there will be a second practice drive later in the experiment to enable you to practice with the automated system which will be used.

The simulator has a motion system which recreates the dynamic forces we feel as we drive a vehicle. Your first drive may feel a little odd, especially when accelerating, braking or cornering. However, don't worry, this is true for everybody who drives the simulator for the first time and these feelings usually subside after a few minutes of driving.

Experience has shown us that new simulator drivers tend to set off too quickly, making control of the car difficult. Please start slowly and gradually increase your speed during the practice drive. You may also have the impression that the steering is over-sensitive and tend to over-steer at first. Use the normal "self-centring" of the steering wheel to help keep the car straight. You may find that it is easier to straighten the simulator after a curve by letting the steering wheel slip through your hands. Apply only small inputs to the steering wheel.

For a small percentage of people, the initial "odd" or "unsteady" feelings do not subside and they begin to feel a little unwell. This usually manifests itself in the form of a feeling of motion sickness. **If you do feel unwell or nauseous, please do not be embarrassed to withdraw from the study. We would rather this than make you feel ill! Simply inform the researcher that you are not feeling well and we will stop the simulation immediately.** The researcher will take you back to the briefing area.

The Main Drives

After the practice drive you will complete three experimental drives, the order of which will be different for different drivers. All the drives will happen in a 3 lane motorway, and all you have to do is follow it until the end. Please, try to stay on the middle lane as much as possible and keep your speed around 70 mph.

All the three drives will include automated elements. The system used on this study has lane-keeping and adaptive cruise control functionality, but requires you to re-take manual control in order to overtake. You should use the right lane to overtake any vehicle which is travelling more slowly than you in the middle lane. The vehicle will decelerate automatically in the presence of a lead vehicle, and you will be able to perceive the change in speed. Please, overtake every slow-moving vehicle as soon as you feel safe to do so. You will get an opportunity to practice with the system prior to the experimental drives.

The automation system

How to turn automation on/off: The automated system can be turned on by pressing a button on the steering wheel. This button will be shown to you by the researcher during your practice drive. When you switch the controller on, please move your hands away from the steering wheel, and your right foot off the accelerator pedal. To turn the controller off, you can either press the button on the steering wheel, or move the steering wheel, or press on the brake or accelerator pedals (or a combination of these).

The information provided by the system's interface will vary across the 3 drives. You can see the current status of the automation by looking at the left dashboard.

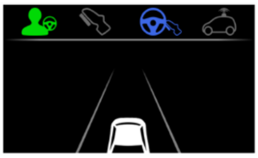
For the **no information condition**:

There will be no information on the interface to inform you about the system status. The only information you`ll receive is a beep warning that the system has switched on or off.

For the **System information condition**:

Blue Steering Wheel: Automation currently unavailable.

Green Steering Wheel: Automation is ON.



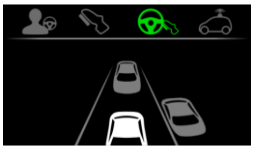
For the **Environment information condition**:

Blue Steering Wheel: Automation currently

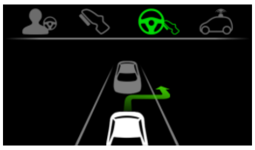
Unavailable.

Green Steering Wheel: Automation is ON.

Grey Car Icon on the middle lane: There is a vehicle ahead and the system will brake.



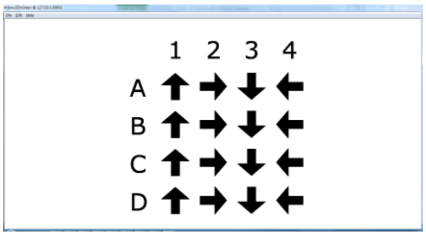
Grey Car Icon on the right lane: There is a vehicle close by in the right lane, and it is not safe to overtake. This system will be turned off for the left lane, because it is not required. Please note that this vehicle is just warns for the presence of an obstacle, and might not represent its real position on the environment.



Green arrow on the middle lane: There are no vehicles close by in the right lane, and it is safe to overtake.

Secondary task

Once the automation system is turned on for the first time, a screen on the console of the vehicle will display a mini task that you will have to perform while the automation is active. The screen will show several arrows pointing in different directions on a 4x4 grid, and only one of them will be pointing up. Your goal will be to locate the up arrow and click on it as fast as you can. Once you find and click on it correctly, a new set of arrows will be displayed. Please repeat this process every time the automation is on. At the end of the experiment, you will receive extra rewards based on the number of up arrows you have found.



Once the automated system starts to reduce speed due the presence of a slower vehicle ahead, you must stop looking to the arrows` screen. Up to this point, you must decide when to overtake. Once the deceleration begins, you won`t receive any points for clicking on arrows until you complete the overtaking manoeuvre and turn the system on again.

Evaluation questionnaire

After each drive, you will be asked to return to the briefing room to answer a very quick questionnaire related to the information you used to interact with the system and perform the task. Please answer the questions honestly. At the end of the experiment, you will be invited to talk about your experience and opinions on the situations you experienced in the simulator.

Experiment duration and payment

For this experiment it is expected that the total testing time will be approximately 2 hours. You will be given the chance for a break halfway through the experiment. For your kind participation in this study you will receive £18 as a token of our appreciation. You will receive extra £2 if you score more than 1000 arrows on the secondary task.

Ethics, safety and confidentiality

It is important for you to appreciate that we are ***not*** looking at your individual performance, or judging your abilities. We are solely interested in the behaviour of a group to draw collective conclusions. Please note that this study is subject to the strict ethical guidelines and the requirements of The Data Protection Act 1998. We would like to point out in particular:

- At no time now, nor in the future, will any information you provide be published that allows you as an individual to be identified.
- You are free to withdraw from this study at any time, without needing to give a reason for doing so. Although please note that in this case you will no longer be entitled to the £18/20 aforementioned.

If you would like more information or have any questions or concerns about the study please contact:

Mr Rafael Gonçalves	*Master`s student*	*tsrg@leeds.ac.uk*
Dr Tyron Louw	*PhD; Institute for Transport Studies*	*t.l.louw@leeds.ac.uk*
Dr Ruth Madigan	*Research Fellow; Institute for Transport Studies*	*r.madigan@leeds.ac.uk*
Prof Natasha Merat	*Professor; Institute for Transport Studies*	*n.merat@its.leeds.ac.uk*

Thank you for taking the time to read this information sheet.

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DRIVING SIMULATOR

UNIVERSITY OF LEEDS

Participant Consent Form

Thank you very much for agreeing to take part in this research. The purpose of this form is to make sure that you are happy to take part and that you know what is involved. Signing this form does not commit you to anything you do not wish to do.

If you suffer from any of the following medical conditions, unfortunately we will not be able to use you as a participant. Therefore, please let the experimenter know now if you suffer from:

- Fear of heights
- Epilepsy
- Serious mobility problems affecting the back, knees or hips
- Claustrophobia
- Feelings of disorientation
- Severe motion sickness

Please sign here if you suffer from none of the above ______________________

Have you read the participant briefing sheet? YES NO

Have you had the opportunity to ask questions and discuss the study? YES NO

If you have asked questions, have you had satisfactory answers? YES NO N/A

Do you understand that you are free to withdraw from the study at any time and without having to give a reason for withdrawing? YES NO

Do you agree to take part in the study? YES NO

Do you agree to not discuss/share the details of this study with people other than the researcher? YES NO

Name in block letters ____

Signature_______________________________________ **Date** ______________________

1. Date of Birth ___________

2. Gender? Male______ Female_______

3. Handedness? Left______ Right_______

4. Approximate Annual Mileage (miles)__________

5. No. of years holding a full UK driving license: ______________

6. Do you think you would find an automated driving system

trustworthy	☐	☐	☐	☐	☐	☐	☐	untrustworthy
unreliable	☐	☐	☐	☐	☐	☐	☐	reliable
not useful	☐	☐	☐	☐	☐	☐	☐	useful
hard to learn	☐	☐	☐	☐	☐	☐	☐	easy to learn

7. Please rate how you would expect to feel using a driving automation system:

unsafe	☐	☐	☐	☐	☐	☐	☐	safe
bored	☐	☐	☐	☐	☐	☐	☐	engaged
stressed	☐	☐	☐	☐	☐	☐	☐	relaxed
inattentive	☐	☐	☐	☐	☐	☐	☐	attentive

Final Questionnaire

1. Please show how often each of the following applies to you by ticking the box that you think applies. This will be used for research purposes only.

	Very infrequently or never	Infrequently	Quite infrequently	Quite frequently	Frequently	Very Frequently or always
Do you break the motorway speed limit?	☐	☐	☐	☐	☐	☐
Do you drive fast?	☐	☐	☐	☐	☐	☐
Do you become flustered when faced with sudden dangers while driving?	☐	☐	☐	☐	☐	☐
Do you remain calm when things happen very quickly and there is little time to think?	☐	☐	☐	☐	☐	☐
Is your driving affected by pressure from other motorists?	☐	☐	☐	☐	☐	☐
Are you happy to receive advice from people about your driving?	☐	☐	☐	☐	☐	☐
Do you dislike people giving advice about your driving?	☐	☐	☐	☐	☐	☐
Do you drive cautiously?	☐	☐	☐	☐	☐	☐
Do you find it easy to ignore distractions while driving?	☐	☐	☐	☐	☐	☐
Do you ignore passengers urging you to change your speed?	☐	☐	☐	☐	☐	☐
How often do you set out on an unfamiliar journey without first looking at a map?	☐	☐	☐	☐	☐	☐

Do you plan long journeys in advance including places to stop and rest?	☐	☐	☐	☐	☐	☐
Do you overtake on the inside lane of a dual carriageway if you have the opportunity to do so?	☐	☐	☐	☐	☐	☐
Do you ever drive through a traffic light after it has turned red?	☐	☐	☐	☐	☐	☐

2. Please indicate how much practical experience you have with these in-vehicle technologies (tick one box per line):

	None, never used	Some, brief experience	Prolonged experience
Cruise control (maintains a steady speed as set by the driver)	☐	☐	☐
Adaptive cruise control (automatically adjusts the speed to ensure the vehicle does not get too close to the one in front)	☐	☐	☐
Forward collision warning (monitors distance to the vehicle in front and alerts the driver when they are too close)	☐	☐	☐
Lane departure warning system (assists the driver in maintaining lane position, giving a warning if the vehicle crosses lane markings unintentionally)	☐	☐	☐

3. When it comes to trying a new technology product I am generally….

among the last	☐	in the middle	☐	among the first	☐

2. Please indicate which of the systems` interface you preferred by ticking the box next to your preferred:

	Preferred System
No information (When the screen was turned off)	☐
System information (Indicating the system status)	☐
Environmental information (With information about the vehicle ahead and overtake suggestion)	☐

3. In general I found the automated driving systems……

trustworthy	☐	☐	☐	☐	☐	☐	☐	untrustworthy
unreliable	☐	☐	☐	☐	☐	☐	☐	reliable
not useful	☐	☐	☐	☐	☐	☐	☐	useful
hard to learn	☐	☐	☐	☐	☐	☐	☐	easy to learn

4. While automation was on I felt…….

unsafe	☐	☐	☐	☐	☐	☐	☐	safe
bored	☐	☐	☐	☐	☐	☐	☐	engaged
stressed	☐	☐	☐	☐	☐	☐	☐	relaxed
inattentive	☐	☐	☐	☐	☐	☐	☐	attentive

Interview Plan:

Applied after all the runs:

1) "Tell me, step-by-step, what have you done, since the moment you felt the vehicle breaking until the point you completely overtook the vehicle, during the events on each run?"
    a. Whenever the interviewee talk about some information source (mirrors, road ahead, side window, speedometer or HMI), ask them why they have looked there and when.
    b. In case they finish talking and do not mention about of this information: 1) headway distance, vehicle on the right, speed, system status. Ask them "How about _____? Have you looked for it? How?"

2) "Now, tell me about the automated systems, what did you found about them?"
    a. "Have you felt any difference in the way you behave on different conditions?"
    b. "Have you felt something missing, or any problem?"

3) "Have you looked to the interface?"
    a. "Which information were you looking for? "
    b. "When?"
    c. "Why?"
    d. In case they say no, ask them why.
    e. "On the condition with system information, what is your opinion about the green arrow, suggesting you to overtake?"
    f. "In an ideal system, which information do you think that should be in there?"
    g. In case they suggest something that they can already access on the road, ask them why it should be on the HMI.

4) "Is there anything more you would like to add?"

System evaluation Questionnaire

Please tell us your opinion about each element presented below by ticking the box that you think is most appropriate. This will be used for research purposes only. Please, answer the questions considering your experience with the scenario you just drove **and the system`s interface presented to you during this specific run**. In the case of this condition, there was no visual interface, so please consider the sound alarms that you have heard during the run.

1. How important is the information provided by each of the sources below for the safe execution of your overtaking manoeuvres?

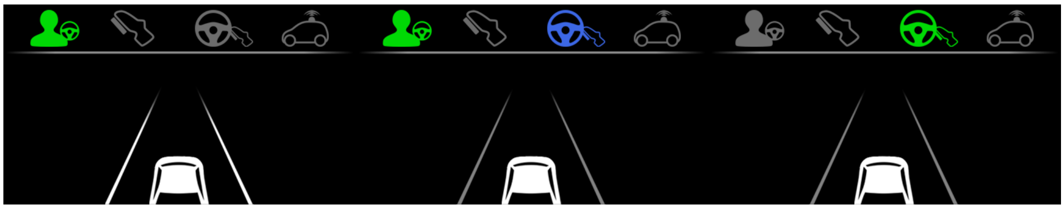
	Not Important				Very Important
Road ahead	☐	☐	☐	☐	☐
Speedometer/cluster	☐	☐	☐	☐	☐
System`s interface	☐	☐	☐	☐	☐
Rear view mirror	☐	☐	☐	☐	☐
Wing mirrors	☐	☐	☐	☐	☐

2. Which information did you look for on the system`s user-interface during the overtaking manoeuvres? (you can choose more than one option)

System status (On/Off/ Available)	Information about the road ahead (presence or absence of a vehicle ahead)	Overtaking suggestion (green arrow on the screen)	Didn`t look at the interface
☐	☐	☐	☐

System evaluation Questionnaire

Please tell us your opinion about each element presented below by ticking the box that you think is most appropriate. This will be used for research purposes only. Please, answer the questions considering your experience with the scenario you just drove **and the system`s interface presented to you during this specific run, as can be seen in the pictures below.**



1. How important is the information provided by each of the sources below for the safe execution of your overtaking manoeuvres?

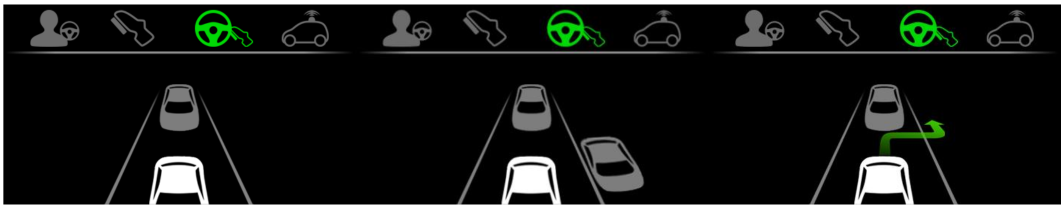
	Not Important				Very Important
Road ahead	☐	☐	☐	☐	☐
Speedometer/cluster	☐	☐	☐	☐	☐
System`s interface	☐	☐	☐	☐	☐
Rear view mirror	☐	☐	☐	☐	☐
Wing mirrors	☐	☐	☐	☐	☐

2. Which information did you look for on the system`s user-interface during the overtaking manoeuvres? (you can choose more than one option)

System status (On/Off/ Available)	Information about the road ahead (presence or absence of a vehicle ahead)	Overtaking suggestion (green arrow on the screen)	Didn`t look at the interface
☐	☐	☐	☐

System evaluation Questionnaire

Please tell us your opinion about each element presented below by ticking the box that you think is most appropriate. This will be used for research purposes only. Please, answer the questions considering your experience with the scenario you just drove **and the system`s interface presented to you during this specific run, as can be seen in the pictures below.**



1. How important is the information provided by each of the sources below for the safe execution of your overtaking manoeuvres?

	Not Important				Very Important
Road ahead	☐	☐	☐	☐	☐
Speedometer/cluster	☐	☐	☐	☐	☐
System`s interface	☐	☐	☐	☐	☐
Rear view mirror	☐	☐	☐	☐	☐
Wing mirrors	☐	☐	☐	☐	☐

2. Which information did you look for on the system`s user-interface during the overtaking manoeuvres? (you can choose more than one option)

System status (On/Off/ Available)	Information about the road ahead (presence or absence of a vehicle ahead)	Overtaking suggestion (green arrow on the screen)	Didn`t look at the interface
☐	☐	☐	☐

1. If there was any other information you were looking for on the system`s interface, please, write on the space below:

2. Did you look at the system`s interface while the secondary arrows task was on?

Yes ☐ No ☐

3. Thinking about the overall performance of the system`s interface you just used, please rate how strongly you agree or disagree with the following statements:

	Strongly disagree				Strongly agree
I think that I would like to use this system frequently	☐	☐	☐	☐	☐
I found the system unnecessarily complex	☐	☐	☐	☐	☐
I thought the system was easy to use	☐	☐	☐	☐	☐
I think that I would need the support of a technical person to be able to use this system	☐	☐	☐	☐	☐
I found the functions in this system were well integrated	☐	☐	☐	☐	☐
I thought there was too much inconsistency in this system	☐	☐	☐	☐	☐
I would imagine that most people would learn to use this system very quickly	☐	☐	☐	☐	☐
I found the system very cumbersome to use	☐	☐	☐	☐	☐
I felt very confident using the system	☐	☐	☐	☐	☐
I needed to learn a lot of things before I could get going with this system	☐	☐	☐	☐	☐
I found the information provided by the system useful	☐	☐	☐	☐	☐

Appendix C – Questionnaire Results

Demographic Data

Participant Number	Gender	Annual Milleage	License Time	Year of Birth	1 - Do you break the motorway speed limit?	1 - Do you drive fast?	1 - Do you become flustered when faced with sudden dangers while driving?	1 - Do you remain calm when things happen very quicly and there is little time to think?	1 - is your driving affected be pressure from other motorists ?	1 - are you happy to receive advice from people about your driving?
1	m	400	11	1987	6	6	3	4	4	5
2	m	50	6	1992	1	2	2	5	2	5
3	m	10880	5	1986	2	4	2	5	3	3
4	m	158	5	1989	4	4	2	5	4	5
5	m	263	10	1988	2	2	2	5	2	4
6	m	15000	17	1981	3	2	2	4	2	6
7	m	6000	9	1984	1	5	1	6	1	1
8	m	5000	5	1994	4	4	2	5	2	4
9	f	0	12	1964	4	5	3	4	4	3
10	f	50	4	1992	1	3	4	3	2	3
11	f	25000	30	1966	2	2	1	5	2	2
12	m	10000	10	1977	4	4	5	4	5	6
13	m	3500	2	1979	2	2	4	3	4	4
14	f	10000	16	1982	3	2	3	2	4	1
15	m	5000	4.5	1995	5	4	2	5	2	3
16	f	5000	26	1972	6	5	2	5	2	1
17	f	520	5.5	1994	6	6	1	6	2	2
18	f	7500	10	1990	5	3	2	4	4	2
19	m	2600	10	1979	2	2	2	5	2	2
20	m	10000	2.5	1986	4	4	3	4	3	4
21	m	6000	21	1978	3	3	3	4	4	4
22	m	2000	12	1988	1	2	2	5	2	3
23	m	12000	24	1975	2	2	2	5	1	5
24	f	0	3	1996	6	5	5	2	5	2
25	f	8000	33	1963	3	3	6	3	4	4
26	m	0	1	1992	5	5	1	4	2	1
27	m	6000	37	1956	4	3	2	5	2	6
28	m	8000	43	1955	1	1	1	1	1	6
29	f	10000	22	1975	1	4	2	5	4	2
30	m	10000	9	1989	2	1	2	5	2	4

Driving Profile

Do You dislike people giving advice about your driving?	1 - Do you drive cautiously?	1 - Do you find it easy to ignore distractions while driving?	1 - Do you ignore passengers urging you to change your speed?	1 - How often do you set out on an unfamiliar journey without first looking at a map?	1 - Do you plan long journeys in advance including places to stop and rest?	1 - Do you overtake on the inside lane of a dual carrigeway if you have the opportunity to do so?	1 - Do you ever driver through a traffic light after it has turned to red?	2 - Indicate how much practical experience do you have with thiese in vehicle technologies: Cruise control	2 - Indicate how much practical experience do you have with thiese in vehicle technologies: ACC	2 - Indicate how much practical experience do you have with thiese in vehicle technologies: forward collision warning
2	5	5	5	5	4	4	2	1	1	3
2	1	5	2	1	2	2	1	2	1	2
3	3	5	2	4	2	3	2	3	2	2
2	5	5	4	5	3	1	1	2	1	1
2	5	4	2	2	3	2	1	2	1	1
1	5	6	6	2	3	2	2	1	1	1
2	6	5	6	6	4	1	1	3	1	1
2	3	5	3	1	3	1	1	3	3	2
5	2	4	5	1	5	5	1	1	1	1
2	6	4	6	1	4	2	1	2	2	1
3	6	6	2	1	5	1	1	1	1	2
1	6	6	3	4	2	2	1	1	1	1
2	5	4	6	1	5	1	2	2	1	1
6	4	2	3	2	2	4	2	2	1	1
2	5	5	5	4	4	1	1	2	1	1
5	2	3	3	4	2	3	1	3	3	3
2	3	5	6	6	5	5	1	2	1	1
5	5	5	3	5	2	1	1	3	2	1
5	5	3	5	5	3	1	1	3	2	2
3	4	3	3	2	5	1	1	1	1	1
3	5	5	5	2	4	2	1	1	1	1
3	4	5	6	2	6	2	1	2	1	1
3	5	4	6	3	2	4	1	2	2	2
6	5	5	6	6	4	1	1	1	1	1
2	6	4	4	1	3	1	2	1	1	1
6	3	2	6	4	6	1	1	3	1	1
2	5	5	5	5	4	1	1	2	1	2
1	1	1	1	1	1	1	1	1	1	1
4	4	5	3	4	4	1	1	2	1	1
2	4	4	3	1	4	2	1	2	1	1

2 - Indicate how much practical experienc e do you have with thiese in vehicle technolog ies: Lane departure warning	3 - Ehrn it comes to trying a new technolog y product I am generally ...	4 - please indicate which of the systems' interface you prefered by ticking the box next to the prefered	5 In general I found the automate d driving systems Trustwort h	5 In general I found the automate d driving systems reliable	5 In general I found the automate d driving systems useful	5 In general I found the automate d driving systems easy to learn	6 - While automati on was on I felt Safe	6 - While automati on was on I felt engaged	6 - While automati on was on I felt Relaxed	6 - While automati on was on I felt Attentive
1	2	3	2	6	6	7	6	7	6	2
1	2	3	2	6	6	6	6	4	6	6
2	2	3	4	5	6	4	5	3	6	5
1	2	2	2	6	6	6	4	4	4	5
1	2	1	1	7	7	7	5	3	4	1
1	3	1	2	6	6	7	6	5	5	4
1	2	2	3	6	6	7	7	5	7	5
1	2	2	1	7	6	7	6	5	6	5
1	2	2	2	6	6	7	3	6	4	6
1	2	2	3	6	6	7	3	3	6	4
1	2	2	1	6	6	7	7	6	7	6
1	2	3	3	4	6	7	6	5	6	4
1	2	3	2	6	5	5	6	4	4	3
1	3	2	2	6	4	7	6	2	6	6
1	2	1	1	7	7	7	6	4	7	4
3	3	1	2	7	6	7	7	3	2	2
1	2	2	2	6	6	7	7	3	7	4
2	2	1	2	6	6	6	6	3	7	2
2	2	2	2	6	6	6	6	4	5	3
1	1	2	3	5	1	6	3	1	5	1
1	2	2	2	6	6	7	4	4	5	3
1	2	1	1	1	6	7	6	4	6	6
1	3	1	2	6	6	7	6	5	7	6
1	2	3	5	5	5	5	5	2	3	2
1	2	1	2	6	6	6	7	5	5	2
3	3	1	1	7	7	7	7	7	7	7
1	3	3	1	7	7	7	5	4	5	5
1	1	2	1	7	7	7	7	7	7	7
1	2	3	1	5	5	6	6	3	5	3
1	1	2	1	7	6	7	7	3	6	5

Eva

1 - How important is the informati on provided e by each of the sources below for the safe execution of your overtakin g manoeuv res? Road ahead	1 - How important is the informati on provided e by each of the sources below for the safe execution of your overtakin g manoeuv res? Soeedinet er / cluster	1 - How important is the informati on provided e by each of the sources below for the safe execution of your overtakin g manoeuv res?Syste m's interface	1 - How important is the informati on provided e by each of the sources below for the safe execution of your overtakin g manoeuv res? Rear view mirror	1 - How important is the informati on provided e by each of the sources below for the safe execution of your overtakin g manoeuv res? Wing mirrors	2 - which informati on did you look for on the system's user- interface during the overtakin g manoeuv res? System status	2 - which informati on did you look for on the system's user- interface during the overtakin g manoeuv res? Informati on about the road ahead	2 - which informati on did you look for on the system's user- interface during the overtakin g manoeuv res? Overtakin g suggestio n	2 - which informati on did you look for on the system's user- interface during the overtakin g manoeuv res? Didn`t loot at the interface	3 - if there was any other informati on you were looking for on the system's interface, please, write on the space below:	4 - Did you look at the system's interface while the secondar y arrows task was on?
5	1	1	4	5	0	1	0	0		1
5	3	5	4	5	0	1	1	0		1
5	3	2	4	5	1	0	1	0		0
5	4	4	5	5	1	1	1	0		1
5	2	1	4	5	0	0	0	1		0
4	3	1	4	4	1	1	0	0		1
5	5	5	4	5	0	0	0	1		0
4	5	2	4	5	0	1	0	0		0
5	1	4	3	5	0	1	0	1		1
5	5	5	4	5	0	0	0	1		1
4	5	5	4	5	1	1	0	0		0
3	3	2	4	4	0	0	0	1	know if the	0
3	3	2	2	5	0	0	0	1	sPEED	1
3	4	3	3	3	0	0	0	1		1
5	3	1	4	5	0	0	0	1		0
5	2	1	3	5	0	0	0	1	Lance cent	0
2	4	1	4	4	1	1	1	0		1
5	4	2	4	5	0	0	0	1	Errors or w	0
4	4	2	4	4	0	0	0	1	ACC kicking	0
4	4	4	4	4	0	1	0	1		0
5	4	2	4	5	0	0	0	1		0
2	4	1	3	5	0	0	0	1		0
4	3	1	2	5	0	0	0	1		0
5	5	2	4	5	1	1	1	0	Indicator	0
5	3	5	3	4	1	0	0	0		1
5	1	5	1	5	0	1	0	1		0
5	4	5	4	5	0	1	0	0	on/of indic	0
5	5	5	5	5	1	0	0	0		0
4	3	1	4	4	1	0	1	0	Any indicat	0
5	5	3	5	5	0	1	0	0	Confirmati	1

ıluation HMI 1

5 - SUS: I think that I would like to use this system frequently	5 - SUS: I found the system unnecessarily complex	5 - SUS: I thought the system was easy to use	5 - SUS: I think that I would need support of a technical person to be able to use this system	5 - SUS: I found the functions in ths system were wll integrated	5 - SUS: I thought there was too much inconsistency in this system	5 - SUS:I would imagine that most people would learn to use thus system very quickly	5 - SUS: I found the system very cumbersome to use	5 - SUS: I felt very confident using the system	5 - SUS: I needed to learn a lot of things before I could get going with this system	I found the information provided by the system useful
5	1	5	1	3	1	5	1	5	1	4
5	1	4	3	4	1	4	2	4	4	4
4	1	5	5	5	2	5	1	5	1	5
3	1	5	1	5	1	5	1	4	2	5
4	1	5	1	5	1	5	1	5	1	4
4	2	4	1	4	2	4	1	5	2	4
3	1	5	1	5	1	5	1	5	3	5
4	2	5	2	4	2	4	2	4	2	3
1	2	4	1	3	2	5	2	3	1	3
4	1	5	1	4	1	4	1	3	1	5
3	1	5	2	5	2	5	2	4	3	5
4	5	5	1	4	2	4	4	5	1	3
2	2	3	2	3	3	4	3	2	2	2
2	3	3	2	3	2	4	3	4	1	5
5	1	5	1	5	1	5	1	5	1	2
3	1	5	1	2	1	5	1	3	1	4
4	1	5	1	5	1	5	1	5	1	5
4	2	4	2	4	2	4	2	4	2	4
2	2	3	2	2	2	4	2	3	2	2
3	2	2	2	4	2	3	3	3	2	3
4	1	5	1	4	1	5	1	4	1	4
4	1	5	1	4	1	5	1	5	1	4
5	1	5	1	5	1	4	1	5	1	5
2	3	3	4	3	3	3	3	3	4	4
5	1	5	1	5	1	4	1	3	1	3
5	1	5	1	5	1	5	1	5	1	5
2	1	5	1	4	2	4	2	4	3	3
5	1	5	1	5	1	5	5	5	2	5
1	3	2	2	2	3	2	1	1	3	1
2	2	4	1	3	2	4	2	3	2	2

SUS score	1 - How important is the informati on provided e by each of the sources below for the safe execution of your overtakin g manoeuv res? Road ahead	1 - How important is the informati on provided e by each of the sources below for the safe execution of your overtakin g manoeuv res? Soeedinet er / cluster	1 - How important is the informati on provided e by each of the sources below for the safe execution of your overtakin g manoeuv res?Syste m's interface	1 - How important is the informati on provided e by each of the sources below for the safe execution of your overtakin g manoeuv res? Rear view mirror	1 - How important is the informati on provided e by each of the sources below for the safe execution of your overtakin g manoeuv res? Wing mirrors	2 - which informati on did you look for on the system's user- interface during the overtakin g manoeuv res? System status	2 - which informati on did you look for on the system's user- interface during the overtakin g manoeuv res? Informati on about the road ahead	2 - which informati on did you look for on the system's user- interface during the overtakin g manoeuv res? Overtakin g suggestio n	2 - which informati on did you look for on the system's user- interface during the overtakin g manoeuv res? Didn`t loot at the interface	3 - if there was any other informati on you were looking for on the system's interface, please, write on the space below:
95.0	5	1	2	4	5	0	1	0	0	Sighn of ve
75.0	5	4	3	4	5	1	1	0	0	HEADWAY
85.0	5	3	2	3	5	0	1	0	1	
90.0	5	4	4	4	4	1	1	1	0	
97.5	5	2	1	4	5	0	0	0	1	
82.5	4	4	3	4	4	1	1	1	0	
90.0	5	5	5	4	5	0	0	0	1	
77.5	4	5	3	5	5	0	1	0	0	
70.0	4	2	4	3	5	0	1	0	1	
87.5	5	5	5	5	5	1	1	0	0	
80.0	5	4	5	2	4	1	1	0	0	
72.5	1	4	4	5	5	0	0	0	1	aAudio inf
55.0	3	3	3	2	5	1	0	0	0	
62.5	3	4	3	2	4	0	0	0	1	
100.0	4	2	2	4	5	1	0	0	1	if the syste
82.5	5	2	2	3	5	1	0	0	0	Car approa
97.5	2	4	2	5	5	1	1	1	0	
75.0	5	4	2	4	4	0	1	0	0	
60.0	4	4	4	4	4	1	0	0	0	
60.0	4	4	4	4	4	0	1	0	0	Right lane
92.5	5	4	2	3	5	0	0	0	1	
95.0	3	4	3	3	5	1	0	0	0	
97.5	2	4	4	2	5	0	1	0	0	
42.5	5	5	5	4	5	1	0	0	0	
92.5	4	3	3	3	4	1	0	0	0	
100.0	5	1	5	1	5	1	1	1	0	
75.0	5	2	3	5	5	0	1	0	1	
87.5	5	5	5	5	5	1	0	1	0	
40.0	4	3	3	5	5	0	1	0	0	
67.5	5	5	3	5	4	0	1	0	0	

Evaluation HMI 2

4 - Did you look at the system's interface while the secondary arrows task was on?	5 - SUS: I think that I would like to use this system frequently	5 - SUS: I found the system unnecessarily complex	5 - SUS: I thought the system was easy to use	5 - SUS: I think that I would need support of a technical person to be able to use this system	5 - SUS: I found the functions in ths system were wll integrated	5 - SUS: I thought there was too much inconsistency in this system	5 - SUS:I would imagine that most people would learn to use thus system very quickly	5 - SUS: I found the system very cumbersome to use	5 - SUS: I felt very confident using the system	5 - SUS: I needed to learn a lot of things before I could get going with this system
1	5	1	5	2	4	1	4	1	4	1
0	5	2	2	3	4	1	4	1	4	2
0	4	2	5	2	4	3	5	3	4	2
1	4	1	5	1	5	1	5	1	5	1
0	3	1	4	1	4	1	4	1	3	1
1	4	4	5	1	4	2	4	2	4	1
0	4	1	5	1	4	2	5	2	5	2
0	4	2	5	2	4	2	5	1	4	1
1	4	1	5	2	4	2	4	1	4	2
1	4	1	5	1	4	1	4	1	4	1
1	4	2	5	1	4	2	5	3	4	2
0	4	5	5	1	2	2	4	4	5	2
1	3	2	4	2	3	2	4	2	3	2
0	2	2	4	2	4	2	4	3	4	2
0	4	1	4	1	5	1	5	1	5	1
0	2	2	4	1	2	1	3	2	4	1
1	2	4	1	1	5	1	5	1	5	1
0	4	2	5	2	4	2	4	2	4	2
0	4	2	4	2	4	2	4	2	4	2
0	3	2	3	2	4	2	3	3	4	3
0	4	1	5	1	4	1	5	1	3	2
0	3	1	5	1	4	2	4	1	4	4
0	4	1	5	1	4	1	3	1	5	1
0	2	3	3	2	2	3	4	3	4	3
1	3	2	4	1	4	1	4	2	3	1
0	4	1	5	1	5	1	5	1	5	1
1	4	2	4	1	5	1	3	1	5	2
0	5	1	5	1	5	1	5	5	5	5
0	2	2	3	2	3	2	2	2	3	1
1	3	2	4	3	3	1	4	2	2	1

I found the informari on provided by the system useful	SUS score	1 - How important is the informati on provided e by each of the sources below for the safe execution of your overtakin g manoeuv res? Road ahead	1 - How important is the informati on provided e by each of the sources below for the safe execution of your overtakin g manoeuv res? Soeedinet er / cluster	1 - How important is the informati on provided e by each of the sources below for the safe execution of your overtakin g manoeuv res?Syste m's interface	1 - How important is the informati on provided e by each of the sources below for the safe execution of your overtakin g manoeuv res? Rear view mirror	1 - How important is the informati on provided e by each of the sources below for the safe execution of your overtakin g manoeuv res? Wing mirrors	2 - which informati on did you look for on the system's user- interface during the overtakin g manoeuv res? System status	2 - which informati on did you look for on the system's user- interface during the overtakin g manoeuv res? Informati on about the road ahead	2 - which informati on did you look for on the system's user- interface during the overtakin g manoeuv res? Overtakin g suggestio n	2 - which informati on did you look for on the system's user- interface during the overtakin g manoeuv res? Didn`t loot at the interface
4	90.0	5	4	4	3	5	1	1	1	0
4	75.0	4	3	5	4	5	0	1	1	0
3	75.0	5	3	2	3	5	0	1	0	1
5	97.5	5	4	4	4	4	1	1	1	0
2	82.5	3	2	3	3	5	0	0	1	0
4	77.5	3	4	4	2	5	1	1	1	0
5	87.5	5	5	4	4	5	0	0	0	1
4	85.0	4	4	3	5	5	0	0	1	0
4	82.5	4	2	4	2	5	1	1	0	1
4	90.0	5	5	5	5	5	1	0	1	0
5	80.0	5	5	5	2	5	0	1	1	0
2	65.0	4	3	4	2	3	0	0	1	0
3	67.5	3	2	5	2	3	0	1	1	0
4	67.5	3	5	4	3	3	0	0	0	1
2	95.0	4	1	3	2	5	0	0	0	1
3	70.0	3	4	4	2	4	1	1	1	0
5	75.0	1	1	3	4	4	1	1	1	0
4	77.5	2	2	3	4	5	0	1	1	0
4	75.0	4	4	3	4	4	1	0	0	0
3	62.5	5	5	4	5	5	0	1	1	0
4	87.5	5	4	3	4	5	1	0	1	0
3	77.5	1	3	3	3	5	1	1	1	0
5	90.0	2	4	4	1	3	0	1	1	0
4	52.5	5	5	4	4	5	0	0	0	1
3	77.5	4	3	4	1	4	0	1	1	0
5	97.5	4	2	4	2	4	0	1	1	0
4	85.0	3	2	4	4	4	0	0	1	0
5	80.0	5	5	5	5	5	1	0	1	0
2	60.0	3	2	3	2	2	0	0	1	0
4	67.5	5	4	3	4	5	1	1	1	0

Evaluation HMI 3

3 - if there was any other information you were looking for on the system's interface, please, write on the space below:	4 - Did you look at the system's interface while the secondary arrows task was on?	5 - SUS: I think that I would like to use this system frequently	5 - SUS: I found the system unnecessarily complex	5 - SUS: I thought the system was easy to use	5 - SUS: I think that I would need support of a technical person to be able to use this system	5 - SUS: I found the functions in ths system were wll integrated	5 - SUS: I thought there was too much inconsistency in this system	5 - SUS:I would imagine that most people would learn to use thus system very quickly	5 - SUS: I found the system very cumbersome to use	5 - SUS: I felt very confident using the system
Sound, Tra	1	5	1	5	2	4	2	4	1	4
	1	5	1	4	2	4	1	5	1	4
	0	4	2	5	2	4	3	5	3	4
	1	4	1	5	1	5	1	5	1	5
	0	3	1	4	1	4	1	4	1	4
	1	4	4	5	1	4	2	5	2	5
	0	4	2	5	2	5	2	5	2	5
	0	4	2	5	1	4	2	5	2	4
	1	3	2	4	2	4	2	5	2	4
	1	3	1	5	2	4	1	4	1	4
	1	4	1	5	1	5	1	5	2	5
Audio Info	1	4	4	5	1	4	2	5	4	5
	0	4	2	4	2	4	2	4	2	4
	0	3	3	4	1	4	2	2	3	4
	0	3	1	5	1	5	1	5	2	4
Car approa	0	2	3	4	1	3	1	3	1	5
	1	4	1	5	1	4	1	5	1	5
	0	4	2	4	2	4	2	4	2	4
	0	4	2	4	2	4	2	4	2	4
	1	3	2	4	2	4	2	3	3	4
	1	4	1	5	1	4	1	5	2	4
	0	3	3	4	1	4	1	4	2	4
	0	4	1	5	1	5	2	3	1	4
	1	3	2	4	3	4	2	4	2	4
Speed	1	4	1	5	1	4	1	3	2	3
	0	4	2	4	2	4	2	4	2	4
	1	5	2	4	1	4	1	5	1	4
	1	5	1	5	2	5	1	5	5	5
	1	2	3	3	1	2	2	1	1	1
	1	3	2	4	2	4	2	4	2	3

Arros Score

5 - SUS: I needed to learn a lot of things before I could get going with this system	I found the information provided by the system useful	SUS score	Score 1	Score 2	Score 3
1	4	87.5	637	1130	1784
2	5	87.5	699	1331	2071
2	3	75.0	425		
1	5	97.5	530	1175	1780
1	3	85.0	677	1390	2130
1	4	82.5	713	1264	1800
1	5	87.5	431	843	1322
2	4	82.5	361	771	1178
2	4	75.0	468	984	1528
1	5	85.0	290	731	1249
4	4	87.5	543	1002	1384
1	4	77.5	563	1147	1783
2	5	75.0	616	1106	1648
2	4	65.0	198	375	637
1	3	90.0	144	634	1550
1	4	75.0	508	967	1415
1	5	95.0	257	459	691
2	4	75.0	372	763	
2	4	75.0	297	642	1036
2	2	67.5	272	523	962
1	4	90.0	627	1230	1775
1	3	77.5	358	759	1146
1	4	87.5	477	784	1347
3	4	67.5	166	335	497
2	5	80.0	331	668	1045
2	4	75.0	386	692	1045
2	4	87.5	624	1079	1500
1	5	87.5	189	404	643
1	2	52.5	233	510	
2	4	70.0	258	548	796

Annexes

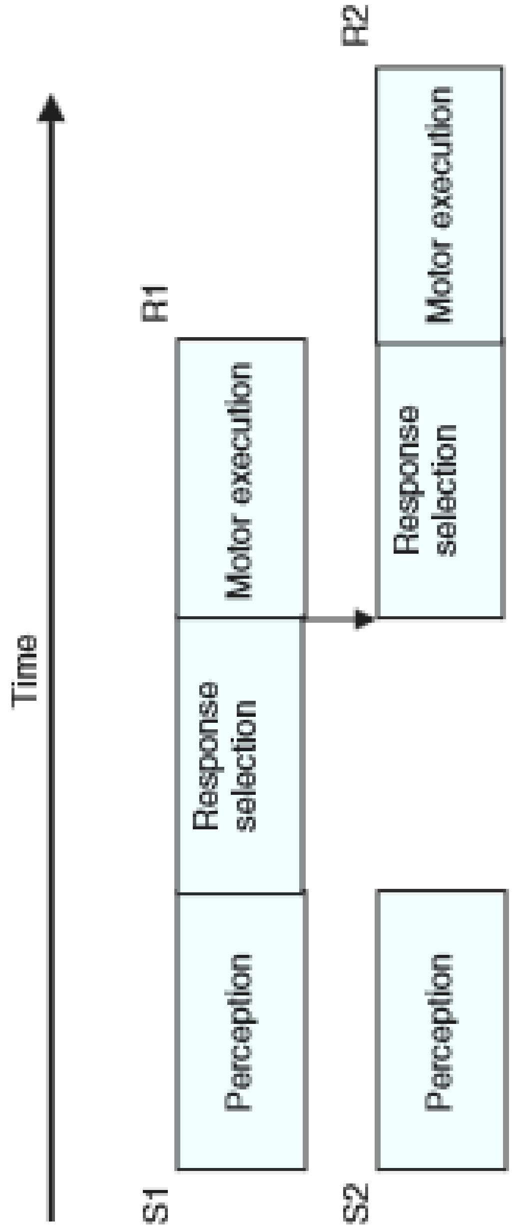


figure 2.1 – Interaction model Human-Task-Machine. Source: Proctor & Vu (2006)

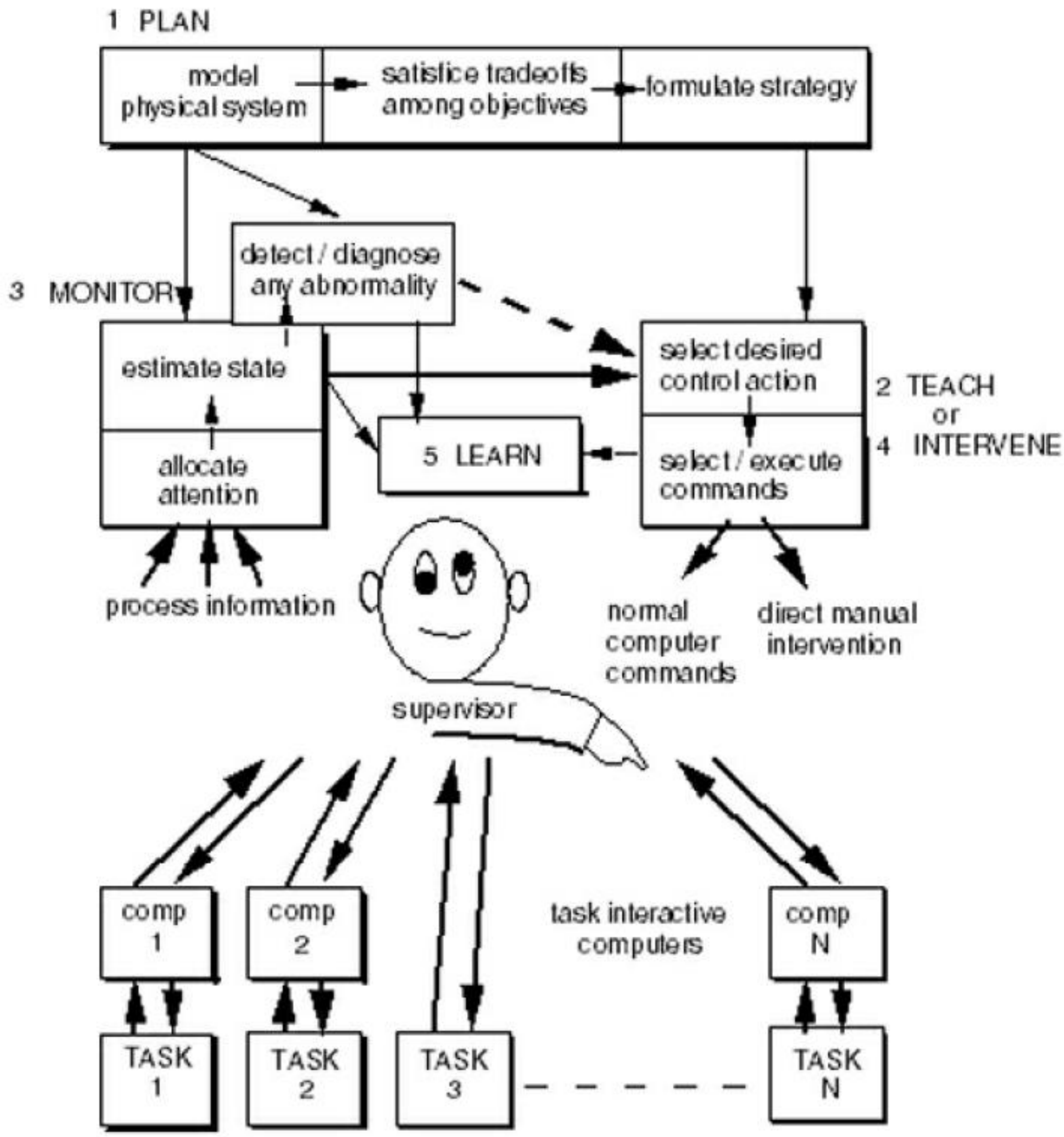


Figure 2.2 – Model for the supervisory control paradigm. Source: Sheridan & Parasuraman (2005)

LOA	Description
10:	Fully autonomous: The automation systems decide everything; act autonomously, yet collaborating with other automation systems, ignoring the human.
9:	The automation systems inform the human supervisor only if they decide to.
8:	The automation systems inform the human, only if asked.
7:	The automation systems execute autonomously and then necessarily inform the human supervisor.
6:	The automation systems allow the human supervisor a restricted time to *veto* before automatic execution.
5:	The automation systems execute that suggestion if the human supervisor approves.
4:	The automation systems suggest one decision action alternative.
3:	The automation systems narrow the decision choice selection down to a few.
2:	The automation systems offer a complete set of decision/action alternatives.
1*:	The automation systems acquire the data from the process and register them without analysis.
0*:	Fully manual: The automation systems offer no assistance: the human decides and acts.

Figure 2.3 – Levels of automation. Source: Parasuraman et al. (2000)

SAE level	Name	Narrative Definition	Execution of Steering and Acceleration/ Deceleration	*Monitoring* of Driving Environment	Fallback Performance of *Dynamic Driving Task*	System Capability *(Driving Modes)*
Human driver **monitors the driving environment**						
0	**No Automation**	the full-time performance by the *human driver* of all aspects of the *dynamic driving task*, even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a
1	**Driver Assistance**	the *driving mode*-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	Human driver and system	Human driver	Human driver	Some driving modes
2	**Partial Automation**	the *driving mode*-specific execution by one or more driver assistance systems of both steering and acceleration/ deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	**System**	Human driver	Human driver	Some driving modes
Automated driving system **("system") monitors the driving environment**						
3	**Conditional Automation**	the *driving mode*-specific performance by an *automated driving system* of all aspects of the dynamic driving task with the expectation that the *human driver* will respond appropriately to a *request to intervene*	System	**System**	Human driver	Some driving modes
4	**High Automation**	the *driving mode*-specific performance by an automated driving system of all aspects of the *dynamic driving task*, even if a *human driver* does not respond appropriately to a *request to intervene*	System	System	**System**	Some driving modes
5	**Full Automation**	the full-time performance by an *automated driving system* of all aspects of the *dynamic driving task* under all roadway and environmental conditions that can be managed by a *human driver*	System	System	System	**All driving modes**

Figure 2.4 – Levels of vehicle automation. Source: SAE (2014)

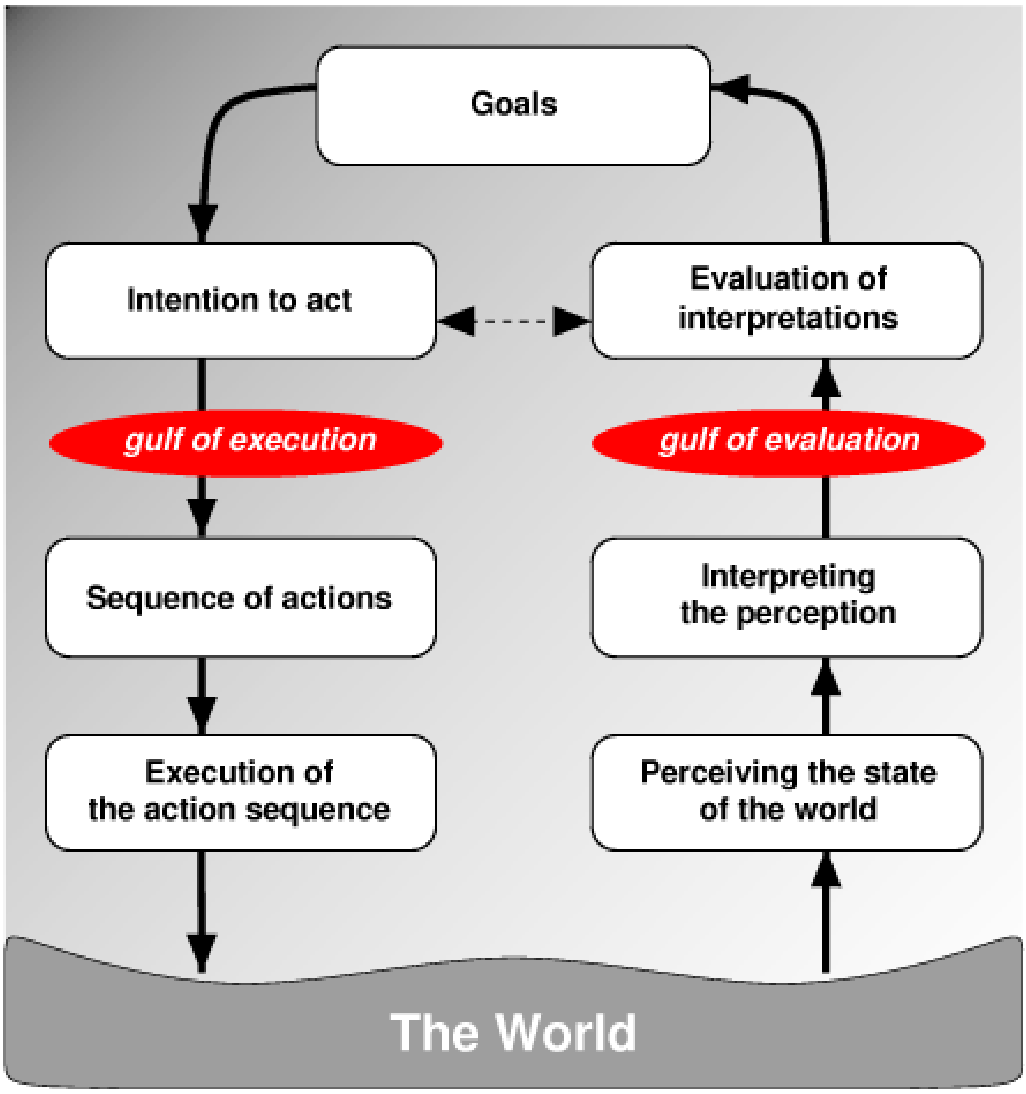


Figure 2.5 – System fallibility explanation model. Source: Norman

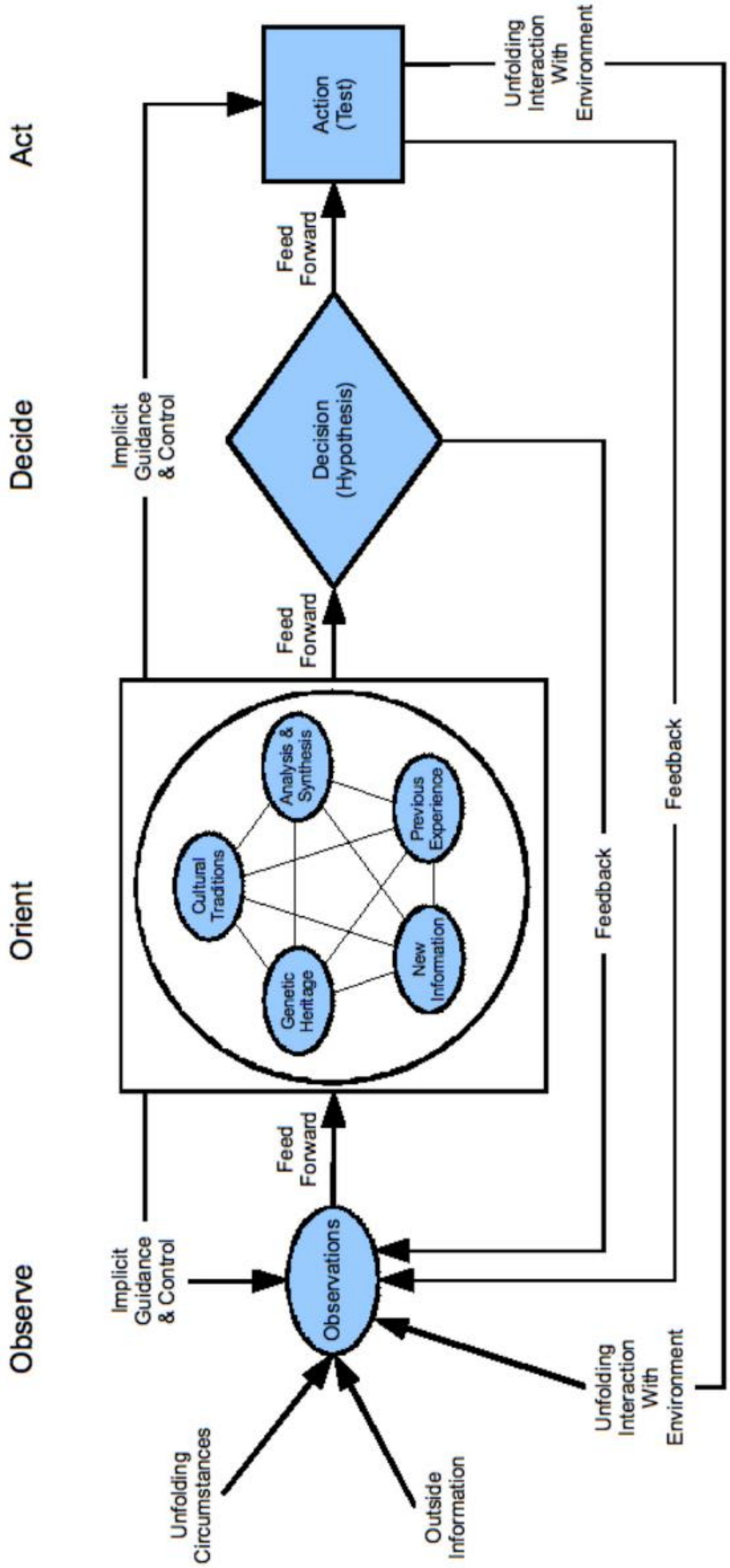


Figure 2.6 - OODA LOOP Model. Source: Thomas, 2001 apud. Gikkas (2012)

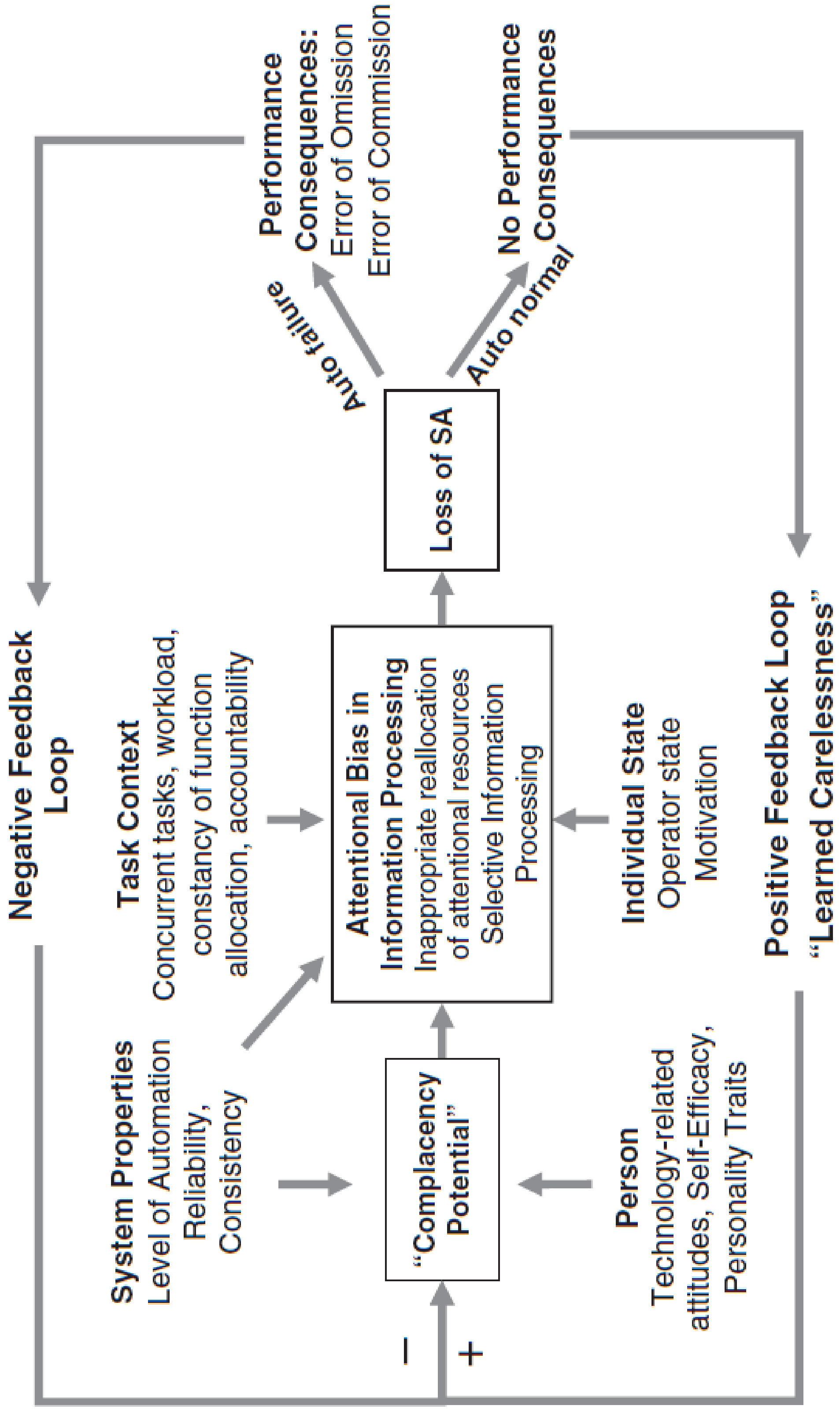


Figure 3.1 – Automation bias and complacency model. Source: Parasuraman & Manzey (2010)

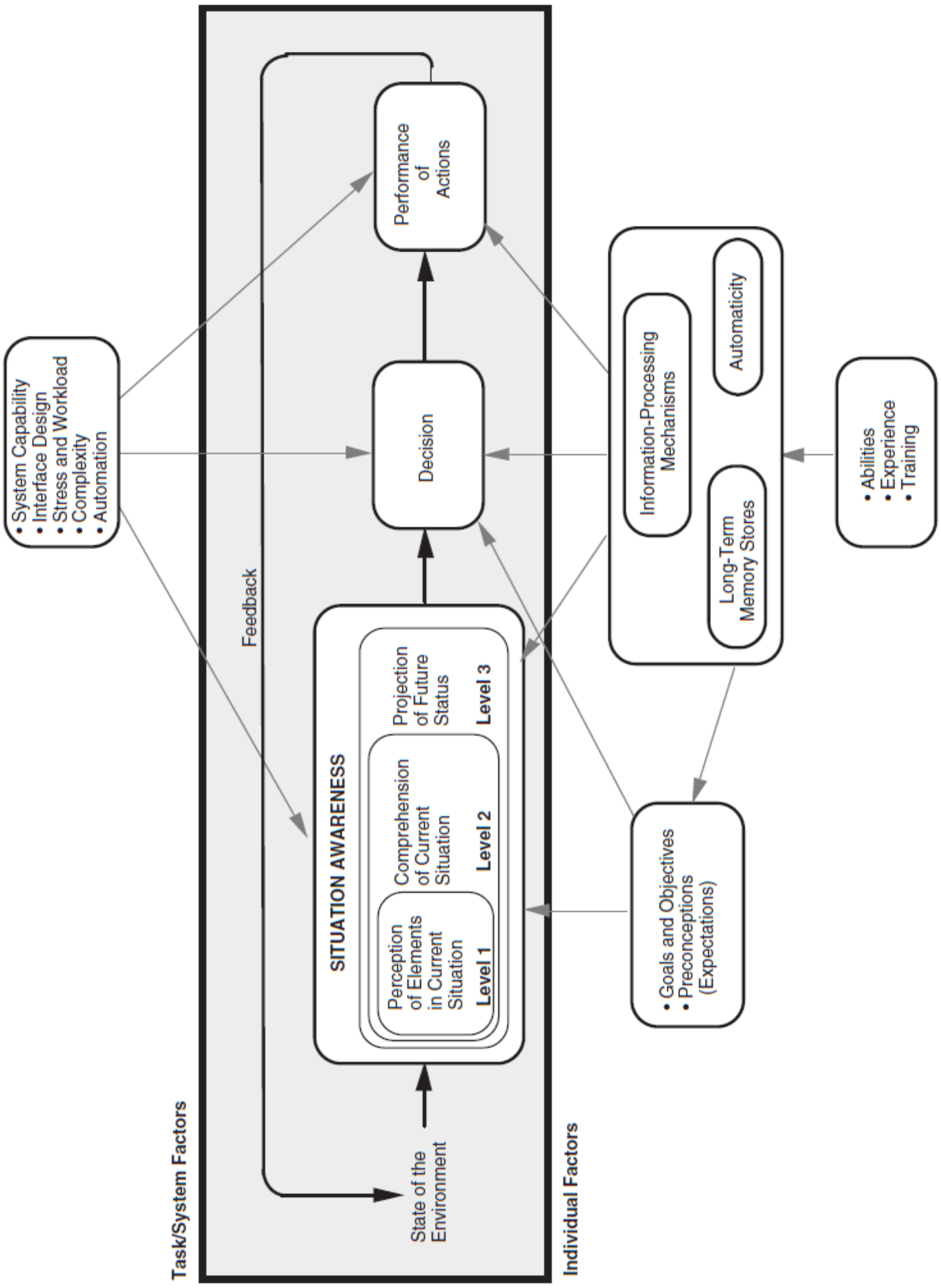


Figure 3.2 – Situation awareness acquisition model. Source: Endsley (1995a)