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ENGINEERING AND THE ENVIRONMENT

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Human Factors Considerations in the Design and Development of Highly Automated Driving Systems

by

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ABSTRACT

ENGINEERING AND THE ENVIRONMENT

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HUMAN FACTORS CONSIDERATIONS IN THE DESIGN AND DEVELOPMENT OF HIGHLY AUTOMATED DRIVING SYSTEMS

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Increasing levels of automation within the driving task has seen the driver's role change from an active operator to one of a passive monitor. However, systems design has been plagued by criticism for failing to acknowledge the new role of the driver within the system network. To further our understanding of the driver's role within an automated driving system, the theory of Distributed Cognition was adopted. Distributed Cognition provides a useful framework for the investigation of task partitioning between multiple system agents. A novel Systems Design Framework has been developed as part of this thesis that utilises both qualitative and quantitative research methodologies within the Distributed Cognition paradigm. The framework is divided into two phases, the first phase requires an understanding of how individual system agents function to create models that show how these components share information using Operator Sequence Diagrams whilst empirical methods were used to validate these models in the second phase (e.g. Verbal Protocol Analysis and Network Analysis). These extension methodologies were useful in highlighting a number of design weaknesses, beyond the modelled technological components, that required modification to improve overall system design. The Systems Design Framework has been successfully applied to assist Systems Engineers with a foundation to design and conduct research into the human factors implications of different levels of automation within driving.

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DECLARATION OF AUTHORSHIP

I, VICTORIA A. BANKS, declare that this thesis entitled

Human Factors Considerations in the Design and Development of Highly Automated Driving Systems

and the work presented in it are my own and has been generated by me as the result of my own original research.

I confirm that:

1. This work was done wholly or mainly while in candidature for a research degree at this University;
2. Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated;
3. Where I have consulted the published work of others, this is always clearly attributed;
4. Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work;
5. I have acknowledged all main sources of help;
6. Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself;
7. Parts of this work have been published as:

Journal Papers

Banks, V. A., Stanton, N. A., & Harvey, C. (2014). Sub-systems on the Road to Vehicle Automation: Hands and feet free but not 'mind' free driving. *Safety Science, 62,* 505-514.

Banks, V. A., Stanton, N. A., & Harvey, C. (2014). What the drivers do and do not tell you: Using verbal protocol analysis to investigate driver behaviour in emergency situations. *Ergonomics*, *57*(3), 332-342.

Banks, V. A., & Stanton, N. A. (2015). Contrasting Models of Driver Behaviour in Emergencies using Retrospective Verbalisations and Network Analysis. *Ergonomics*,*58*(8), 1337-1346.

Banks, V. A., & Stanton, N. A. (2015). Keeping the Driver in Control: Automating automobiles of the future. *Applied Ergonomics. 53*(B), 389-395.

Banks, V. A., & Stanton, N. A. (2016). Driver-Centred Vehicle Automation: Using Network Analysis for agent-based modelling of the driver in highly automated driving systems. *Ergonomics.* DOI: 10.1080/00140139.2016.1146344

Conference papers

Banks, V. A., Stanton, N. A., & Harvey, C. (2013). What the crash dummies don't tell you: The interaction between driver and automation in emergency situations. *Proceedings of the IEEE Intelligent Transportation Systems for All Transport Modes 2013, The Hague, The Netherlands, 6-9 October 2013.*

Banks, V. A., & Stanton, N. A. (2014). Does ADAS create as many problems as it solves? *ITS International.* Available at: http://www.itsinternational.com/categories/location-based-systems/features/does-adas-create-as-many-problems-as-it-solves/ [Accessed 12/10/2015].

Banks, V. A., & Stanton, N. A. (2014). Hands and feet free driving: Ready or Not? *Proceedings of the 5th International Conference on Applied Human Factors and Ergonomics AHFE 2014, Kraków, Poland 19-23 July 2014.*

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Signed: ....

Date:...

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For Caitlin, my most rewarding achievement to date.

List of abbreviations

AEB	Autonomous Emergency Brake
DDMiE	Driver Decision Making in Emergencies
DSA	Distributed Situation Awareness
EAST	Event Analysis of Systemic Teamwork
Euro NCAP	European New Car Assessment Programme
HMI	Human Machine Interface
NHTSA	National Highway Traffic & Safety Administration
OSD	Operator Sequence Diagram
SUDS	Southampton University Driving Simulator
VPA	Verbal Protocol Analysis

Chapter 1: Introduction to the thesis

1.1 Background

Interest in "vehicle automation" dates back to the 1950's stemming from the Defence Advanced Research Project Agency (DARPA). The agency drove research and development into autonomous vehicles for military missions (Rouff & Hinchey, 2012) as it was recognised that highly automated vehicles could be used to gather intelligence, be used in surveillance operations and for target acquisition and reconnaissance. The agency placed emphasis on maintaining technological superiority and security as well as reducing the number of personnel required on the ground. DARPA is most famously recognised for its Grand Challenges (2004, 2005) and Urban Challenge (2007) that invited teams to build and design fully autonomous vehicles. The first Grand Challenge in 2004 aimed to show that autonomous vehicles could undertake resupply missions in unfamiliar desert terrain. Although no vehicles completed the course, success was finally achieved in 2005, demonstrating that unmanned vehicles could navigate across remote environments, on a variety of road surfaces with different obstacles and with limited or no global positioning satellites (Rouff & Hinchey, 2012). The 2007 Urban Challenge was designed to test the ability of autonomous vehicles to navigate safely and effectively through populated areas to simulate supply missions whilst adhering to normal driving laws. At this point, safety was of utmost importance and all vehicles had to be equipped with a form of "E-Stop" – autonomous emergency braking – to maintain the safety of DARPA employees and spectators. It is these advancements that fuelled research and innovation within the automotive industry as the capabilities of automated vehicles to improve the safety of the roads and its occupants had been recognised.

In line with the advancements facilitated by DARPA, the introduction of automated driving features into 'civilian' life has gradually risen since 2000. The main purpose of automated driving features from a marketing point of view is to continue the trend of safe, comfortable, efficient and enjoyable personal travel as well as bring about improvements to traffic efficiency and fuel consumption (e.g. Ward, 2000; Khan et al. 2012).

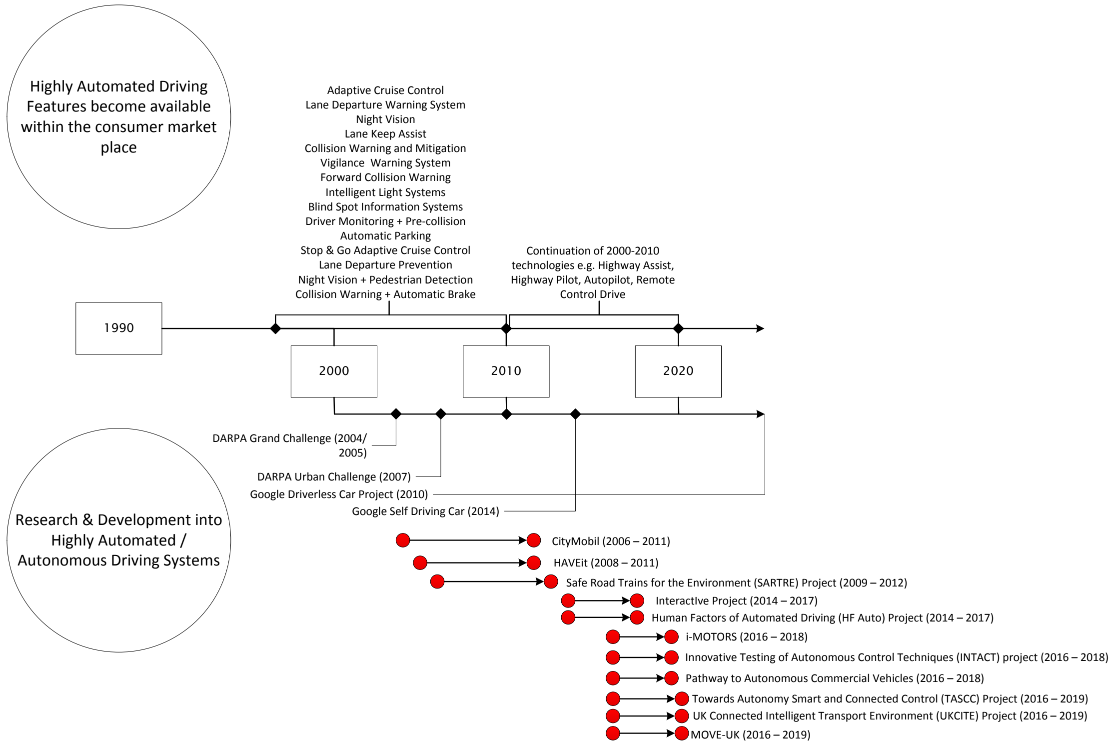


Figure 1.1. Timeline of automation deployment in the consumer market place and the continuing research and development programmes that have underpinned market implementation since 2000.

Whilst fully autonomous vehicles (i.e. vehicles requiring no human operator) were developed for the DARPA Challenges and more recently by Google in 2014, automation in the automotive industry requires an acknowledgement of Human Factors in the design of automated driving features because the driver remains an active participant within the driving task to some extent. Although over recent years in particular technological advancements have meant that vehicles have become increasingly capable of performing the same functions as the driver to a much greater degree, there continues to be a stipulation within the law that drivers must remain in overall control of their vehicle (e.g. Article 8 of the Vienna Convention, 1968). A recent amendment to the convention in 2014 (introduced in 2016) states that driverless cars are allowed on the road as long as they can be overridden by a human driver. This means now more than ever, the driver needs to remain capable of regaining control of an automated vehicle and be supported to do so following prolonged exposure to periods of highly automated driving where boredom and fatigue may become increasingly problematic. Many of the research and development activities shown in Figure 1.1 are specifically looking into how control may be transferred between the driver and automated systems, secondary task engagement and V2X communication, the research presented in this thesis offers one of the first acknowledgments of how the role of the driver within an automated system begins to change of the level of automation within the driving task increases using task analysis modelling techniques. The aim therefore was not to deliver specific data about "how" to manage a transfer of control in autonomy but to identify and increase our understanding of the new role of the driver within the totality of the driving system.

1.2 Research motivation

Safety research suggests that driver inattentiveness and a lack of timely response to unpredictable or incomplete information are the most common driver errors that result in vehicular accidents (Amditis et al. 2010; Cantin et al. 2009; Donmez et al. 2007; Khan et al. 2012; Stanton & Salmon, 2009). These external factors are typically random events that evolve to form complex interactions between driver and vehicle (Khan et al. 2012). Without automated assistance, the driver may be underprepared or lack the skill required to respond to the situation accordingly. For this reason, highly automated vehicles have great potential to improve the safety of our roads and in turn reduce the economic burden of any cumulative effect as a result of an accident such as sick pay through injury and impact to businesses if roads are closed. To put this into focus, the World Health Organisation (WHO) has stated that if current road traffic accident trends continue, the annual fatalities as a consequence of such accidents will increase to 2.34 million by 2020 (Khan et al. 2012). In 2012, the WHO declared that approximately 1.3 million people per annum die as a result of road traffic accidents. Nearly half of these (46%) are considered to be "vulnerable road users". Deaths resulting from road traffic accidents are the leading cause of injury mortality, offering a clear justification for investing time into the field of vehicle automation. If the benefits of automation outweigh potential costs, then automation may prove to be beneficial in economic, societal and environmental terms (Stanton & Marsden, 1996; Young et al. 2011; Khan et al. 2012). However, despite the expectation that automation will bring about enhancement of road safety, such hypotheses require further validation (Stanton & Marsden, 1996). Further research is needed to assess the degree to which automation can reduce the overall number of driver errors that are often implicated as the cause of many vehicular accidents.

Since 1997, the European New Car Assessment Program (Euro NCAP) has continued to encourage vehicle manufacturers to exceed the minimal safety requirements that are required by law. It also aims to ensure that stringent guidelines and testing protocols are rigorously enforced to ensure that potential new customers are given transparent safety information through use of its internationally recognised Five Star Rating Scheme. By rewarding technologies, Euro NCAP pushes vehicle manufactures to accelerate their standard fitment of key automated safety technologies such as Blind Spot Monitoring, Lane Support Systems, Speed Alert Systems, Autonomous Emergency Braking, Automatic Emergency Call and Pre-Crash Systems.

There are of course other reasons why automation may be beneficial. For example, automated driving may not only improve road safety, but also reduce traffic congestion, exhaust gas emissions and fuel consumption according to the European Commission (2011). Interest in automated driving as a form of "Traffic Management System" continues to grow as demonstrated through the 9th Intelligent Transport Systems European Congress (2013) which included a special interest session that looked specifically at the future of highly automated vehicles (including highway trucks and vehicle platooning) as well as automated urban transportation. Although air quality has been an environmental concern for some time, transport is currently a major source of air pollution within the UK and with car use set to increase further, more needs to be done to tackle the problem of congestion and its associated impacts both economically and environmentally (Fagnant & Kockelman, 2015). There are a number of approaches that can be used to improve air quality and new vehicle technologies can play an important role in addressing these environmental issues further.

1.3 Research aims

With systems design plagued by criticism for failing to adequately define the role of the human operator, there is concern amongst the Ergonomics and Human Factors community that automated subsystems in driving may create more problems than they solve. Failing to acknowledge the role of the driver in an automated driving system may lead to undesirable behavioural adaptation as a result of inadequately anticipating the changing role of the driver within the system. This is likely to become even more problematic as multiple vehicle subsystems, operating at different levels of automation are interacting. It is also a very important area of study given recent legislation that requires the driver to be capable of regaining control of an automated vehicle.

This research attempts to address concerns surrounding driver behavioural adaptation in three main ways:

1. *Increase the awareness of Human Factors in the design of automated aids by focussing on the interaction that occurs between the driver and other system agents*

With growing concern that the role of the driver is not being fully recognised in the design of automated driving systems, it is important to focus upon the interaction that occurs between the driver and system agents at differing levels of autonomy. This allows for exploration of the diminishing role of the driver with regard to direct vehicle control as more control is transferred from the driver to the automated subsystems.

2. *Assess the appropriateness of automation deployment and context of use*

Human Factors would argue that even though it may be possible to fully automate a vehicle, it may not always be appropriate given the limits of human attention needed to execute a required response. An automatic braking system, for example, could relinquish driver control over a critical safety function. This may be appropriate to do so in scenarios whereby the driver has not got the capacity to respond, such as 500ms prior to a collision. Such an autonomous feature however may cause drivers to become more reliant on its presence. This may result in increased reaction times and stopping distances as drivers 'wait' for system engagement.

3. *Provide design guidance on automated features based upon experimental evidence*

   Being able to provide systems design guidance to vehicle manufacturers is extremely important to ensure that the functionality of driver-vehicle interaction is optimised as far as is reasonably practicable.

1.4 Outline of thesis

Chapter One: Introduction to the thesis

This initial chapter introduces the area of driving automation and outlines the aims and objectives of the research. It also includes a summary of each chapter and indicates the contribution to knowledge.

Chapter Two: On the Road to Full Vehicle Automation

This chapter introduces the concept of automation and the different levels at which it can be introduced into a system thus altering the role of the human operator within it. Multiple automation taxonomies are discussed that have sought to better define "who" is doing "what" at varying levels of automation. This chapter serves to compare and contrast the most commonly used frameworks within industry and how they relate to traditional taxonomies available within the literature. What all automation taxonomies have in common is that at higher levels of automation, the level of control that the human operator has over a system is reduced. However, this does not mean that they become completely removed from the system altogether. Instead, they remain to some extent within the control-feedback loop. This is because they continue to receive feedback from the automated system and their wider environment. In terms of driving, the driver will continue to receive feedback from the automated system via the Human-Machine-Interface (HMI) within the vehicle in addition to feedback from the wider road environment even when the vehicle is capable of performing much of the driving task autonomously. This means that driver *responsibilities* continue to change as the level of automation increases. Assessing whether drivers are able to adhere to these changing responsibilities requires an acknowledgement of key Human Factors considerations. Chapter two reviews the literature relating to four key Human Factors concepts; situation awareness, driver workload, trust and skill and concludes that automation can have both positive and negative effects on each of these dimensions.

Chapter Three: Adopting a Systems Engineering View

Past research into automation has traditionally been *either* Technology-Focused or Human-Centred. However, this chapter adopts an increasingly popular sociotechnical view that takes into consideration both the strengths and weaknesses of all system agents (both human and non-human). With the allocation of system function being key to understanding how automation may affect the role of the driver within the system network, chapter three introduces the concept of Distributed Cognition (Hutchins, 1995a). This paradigm aims to better define how tasks can be partitioned between system agents. The application of Distributed Cognition to driving is a new and unexplored medium yet there appears to be great benefit in doing so. This is because it enables system engineers and designers to acknowledge the *new* role of the driver in an automated driving system. Chapter three introduces a two-phase Systems Design Framework that applies Distributed Cognition to driving. The first 'modelling' phase uses a well-established and popular Ergonomics technique (Operator Sequence Diagrams; Brooks 1960, Kurke, 1961) to represent the interactions that take place between system agents. The second 'experimental' phase aims to validate these system models through the collection and analysis of empirical data. Chapter three demonstrates the first phase of this framework using an example of Pedestrian Autonomous Emergency Brake (AEB).

Chapter Four: Exploring the use of Verbal Protocol Analysis as a tool to Analyse Driver Behaviour

Although the representations that are afforded by system modelling provide an insight into the behaviour and interaction that occur between multiple system agents, they are unable to represent the underlying cognitive behaviour of the driver. Chapter four explores the use of Verbal Protocol Analysis (VPA; Ericsson & Simon, 1993) as a tool to both validate and extend the visual representations of automated driving systems. VPA is a direct observation method that can capture the underlying processes that mediate behavioural outcomes that are often represented by hard data alone. In this case, hard data was supplemented by the analysis of driver verbalisations relating to driving emergencies experienced using the Southampton University Driving Simulator. The study in chapter four was a pilot study that resulted in a number of practical recommendations for future research being put forward. These recommendations contribute to a methodological advance in using retrospective verbal protocols.

Chapter Five: Contrasting models of Driver Behaviour in Emergencies using Retrospective Verbal Protocols

This chapter introduces models of Driver Decision Making in Emergencies (DDMiE) to investigate how the level and type of automation may affect driver decision making and subsequent responses to critical braking events. Network Analysis was used to interrogate retrospective verbalisations making it possible to quantitatively analyse driver decision-making processes. Four DDMiE models representing different levels of automation were developed as a result. The findings suggest that whilst automation does not alter the decision making pathway (e.g. the processes between hazard detection and response remain similar), it does appear to significantly weaken the links between information processing nodes. This reflects an unintended yet emergent property within the task network that could mean that we may not be improving safety in the way we expect.

Chapter Six: The Effect of Systems Design on Driver Behaviour

Chapter six builds upon the work presented in chapter five by analysing the performance data generated by the Southampton University Driving Simulator during the same study in light of evidence within driver verbalisations. Data was analysed with a view to assess the appropriateness of systems design and context of use at varying levels of automation within driving emergencies. This was based upon the suggestion that a “silent” and “invisible” AEB system would be less likely to lead to negative behavioural adaptation on behalf of the driver. Chapter six explores whether this was actually the case. Despite significant improvements in road safety, the data suggested that systems design had a direct effect on driver-vehicle interaction patterns with drivers being more likely to relinquish control of the braking effort to a warning based system of AEB than a non-warning based system of AEB. This means that whilst we may be improving the safety of other road users, we may not always improve the safety of our drivers.

Chapter Seven: What's next for Vehicle Automation? From Design Concept through to Prototype

To the average driver, the concept of automation in driving infers that they can become completely "hands and feet free". This is a common misconception however, one that has been shown through the application of Network Analysis to new Cruise Assist technologies that may feature on our roads by 2020. This chapter introduces the concept of Driver-Initiated Automation, an approach that will be implemented in next generation automated highway features. Chapter seven uses Phase 1 of the Systems Design Framework introduced in chapter three to show how the role of the driver remains an integral part of the driving system using Distributed Cognition. This implicates the need for designers to ensure that drivers are provided with the tools necessary to remain actively in-the-loop despite being given increasing opportunities to delegate their control to the automated subsystems.

Chapter Eight: Discovering Driver-Vehicle Coordination Problems in Early Stage System Development

Chapter eight discusses a case study that was designed to investigate possible functionality issues of a Driver-Initiated Command and Control System of Automation. Verbalisations and subjective reports of mental workload and stress revealed evidence of different driver-vehicle coordination problems (i.e. mode confusion and automation surprise) depending upon the level of driver familiarity with the system.

Chapter Nine: Driver-initiated Design: An Approach to Keeping the Driver in Control?

Automated automobiles will be on our roads within the next decade but the role of the driver has not yet been formerly recognised or designed. Rather, the driver is often left in a passive monitoring role until they are required to reclaim control from the vehicle. Chapter nine discusses a study that tested the idea of Driver-Initiated Automation, in which the automation offered decision support related to an automatic overtake that could either be accepted or ignored. Despite putting the driver in control of the automated system by enabling them to accept or ignore behavioural suggestions (e.g. overtake), there were still issues associated with increased workload and decreased trust. These issues are likely to have arisen due to the way in which the automated system was designed. Recommendations for improvements to systems design were made that should improve ratings of trust and make the role of the driver, with regards to their authority over the automated system, more transparent.

Chapter Ten: Conclusions and Future Work

The final chapter summarises the research objectives in light of the findings presented in this thesis and considers the contributions made to knowledge. An evaluation of the research approach highlights that whilst qualitative research methodologies are often criticised for their lack of objectivity, they provide researchers with an insight into 'how' and 'why' drivers use automation in the way that they do. Relying upon quantitative data alone would have resulted in an incomplete representation of the issues relevant to driving automation. Consideration is also given to the theoretical, methodological and practical implications of the research based upon the development of the Systems Design Framework and the tools it uses in extending our understanding of the role of the driver within an automated driving system. Finally, areas of further academic enquiry are identified.

1.5 Contribution of knowledge

The work presented in this thesis contributes to our understanding of Distributed Cognition (Hutchins, 1995a) in driving. Whilst traditionally, descriptions of Distributed Cognition have been solely narrative, this thesis has further developed our understanding of the allocation of system function by modelling Distributed Cognition using well established Ergonomics techniques. This thesis proposes that a comprehensive understanding of Distributed Cognition in driving can be achieved by following a six step multi-method framework that gives rise to the opportunity to highlight design weaknesses or areas for consideration and provide design solutions based upon experimental data through which model validation can be achieved. The thesis proposes that Distributed Cognition can be modelled using Operator Sequence Diagrams (OSD; Brooks, 1960). These have been widely used as a means to explore system function since the 1960's (Kurke, 1961). They represent how information is 'expected' to flow within a system network and how information is 'expected' to be shared between individual subsystem components. In this way, it is possible to see how system components interact with one another. Following on from this, Verbal Protocol Analysis (VPA; Ericsson & Simon, 1993) has been identified as a useful extension methodology to validate these system models and extend our understanding of these models further using driving simulator and on-road investigations.

A number of methodological contributions have also been made. The main stimulus to obtain driver verbalisations were questions from the Critical Decision Method (Klein et al. 1989). Whilst this is traditionally a retrospective interview, findings from this research project highlight issues of retrieval failure. To overcome this, a 'freeze probe' technique (described in section 4.3.1) was adopted and it was found to be more successful in delivering richer insights into driver decision-making. A novel application of Network Analysis to these driver verbalisations was successful in showing how the processes underpinning driver decision-making are affected by different levels of automation.

The findings of this research project have not only contributed to our understanding of Distributed Cognition in driving but also provided a platform to explore and identify system design weaknesses that may have undesirable consequences on driver behaviour. These insights have formed a pivotal role in influencing design revisions for a new system of Driver-Initiated Automation design currently under development (described in section 9.5).

Chapter 2: On the Road to Full Vehicle Automation

2.1 Introduction

The driving task is made up of hundreds of individual subtasks of driving (McKnight & Adams, 1970; Walker et al. 2015). This means that automation can be applied to different aspects of 'driving' with differing levels of autonomy simultaneously (Endsley & Kaber, 1999). Traditional driving tasks, such as emergency braking and decision making may be delegated, fully or partially, to automated systems with an aim to reduce driver mental workload and improve overall safety and performance. This suggests that different levels of automation progressively alter system operation from manual operation to fully automated operation.

2.2 Levels of automation

A recent review of the literature by Vagia et al. (2016) states that since the 1950's, a total of 12 automation taxonomies have been developed. One of the oldest and most widely cited taxonomies was developed by Sheridan & Verplanck (1978). This comprehensive ten-level automation taxonomy specified which system functions were the responsibility of the human operator and which were the responsibility of the computer system. It ranged from full manual control (Level 1) to full automation control (Level 10) with intermediate levels combining differing levels of human and computer control. A later automation model by Endsley & Kaber (1999) sought to better define these intermediate levels by identifying "who" was doing "what" at each level of automation. The advantage of Endsley & Kaber's 10-level taxonomy is the explicit nature in which system monitoring, strategy generation, decision making and response execution has been assigned to both human *and* computer or as single entities, either human *or* computer. It meant that it had wider applicability to real time control tasks such as air traffic control, piloting and teleoperation (Vagia et al. 2016). Later on in 2000, Parasuraman et al. began to emphasise that different aspects of human-computer interaction could be automated. The authors proposed that four cognitive functions could be used as input functions, of which, automation could be applied independently. These input functions were defined as information acquisition (the task of sensing, recognising and monitoring information), information analysis (the task of processing, predicting and analysing), decision selection (the task of action selection between different alternatives) and action implementation (the task of responding). Whilst they did not identify levels of automtion in the same manner of former taxonomies, they did suggest that automation within each function could range between "low" and "high".

What all taxonomies have in a common is a consensual view that the human operator is expected to carry out all tasks at lower ends of the automation taxonomy, whilst at the higher end of the taxonomy, automated systems can take on the majority of these tasks. Other transportation domains (e.g. automated metro lines) have typically used reduced representations of the taxonomies outlined above. For example, Georgescu (2006) proposed three operational models for automated metro lines that share similarities with Endsley & Kaber's (1999) definitions;

1. Semi-automatic (reflects shared control)
2. Driverless train operation (reflects supervisory control)
3. Unattended train operation (reflects full automation)

For complex task environments, Endsley & Kaber (1999) suggest that the level of automation can vary between manual control, supervisory control and full automation. With this in mind, it is possible that the same automation pathway could be applied to driving. However, it seems plausible that the jump from manual to supervisory control is likely to be too rapid. This is because drivers need time to understand the effects of the automated systems and how they behave (Stanton et al. 2007a). Rather, the level of driving automation may vary somewhere between manual control (Level 1), decision support (Level 4), automated decision making (Level 8), supervisory control (Level 9) and full automation (Level 10) using Endsley & Kaber's (1999) definitions. The addition of decision support gives the driver an opportunity to develop their awareness of system state. It is thus analogous to a "safety gantry" ensuring that the driver builds an awareness of system capabilities and limits.

However, the taxonomies described above are rarely used within industrial practice. Instead, more emphasis is placed upon the National Highway Traffic Safety Adminstration (NHTSA; 2013), BASt Expert Group (Gasser & Westhoff, 2012) and SAE International Standard J3016 (2015) definitions of automation. The SAE framework is a six level taxonomy ranging from zero ('No Automation') to five ('Full Automation'). According to this framework shown in Figure 2.1, the driver only need monitor the external environment independently between levels zero and two. From level three onwards (Conditional Automation), the automated systems are able to monitor the road environment. Conditional automation recognises that automated systems are not able to cope with all possible driving eventualities (Norman, 1990) and therefore the driver may be requested to regain control under certain circumstances. It is officially defined in the SAE Standard J3016 (2015) as

> "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"*

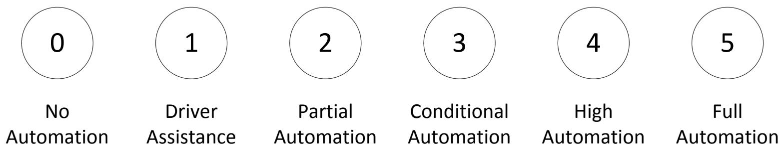


Figure 2.1. SAE Automation Taxonomy (2015)

In contrast, the BASt Expert Group identify five levels of automation ranging from 'Driver Only' to 'Full Automation' (Figure 2.2). This framework suggests that the driver is no longer required to monitor the road environment when the vehicle is highly automated (which represents level three automation if 'driver only' is considered level zero).

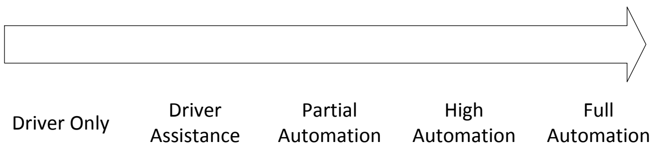


Figure 2.2. BASt Expert Group Automation Taxonomy (2012)

NHTSA (2013) also identifies five levels of automation (Figure 2.3) ranging from level zero ('No Automation') to level four ('Full Self-Driving). Again, the driver is not expected to continuously monitor the road environment from level three automation.

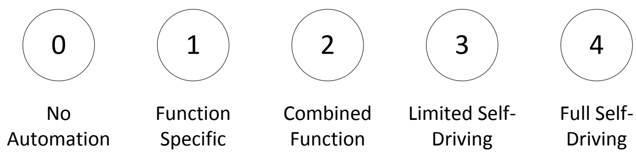


Figure 2.3. NHTSA Automation Taxonomy (2013)

With so many automation taxonomies available within the literature, it should come as no surprise that the mere definition of automation can cause confusion. Table 2.1 shows how primary driving subtasks are allocated between the driver and automation using the SAE International Standard J3016 (2015) as the basis

2.3 Types of automation in driving

In terms of automation implementation, there are two main strategies that can be adopted; soft or hard automation. ‘Hard automation’ essentially prevents human error because the system can override human inputs (Young et al. 2007). In driving, technologies such as Traction Control and Anti-Lock Braking Systems can be seen as examples of hard automation as they cannot be switched off and are always active. In contrast, ‘soft automation’ can be overridden by the human operator and it is this strategy that many automated technologies employ. The debate surrounding the use of soft or hard automation originates in the field of aviation. Whilst Airbus uses hard automation on board their aircraft, Boeing has opted for a soft approach. Both strategies use the same set of sensors and control devices but to very different ends (Young et al. 2007). Even so, both approaches have inherent vulnerabilities of varying degrees across aircraft type, manufacturer and operator (FAA, 1996). The difficulty of automating the driving task is that there is a great level of variability within the driving environment (Harris & Harris, 2004). Automating an open-loop system involving both human and computer control elements will therefore be extremely challenging to coordinate. The risk that driving automation poses is that it may lead some drivers to assume a passive role rather than maintaining an active role within the driver-system control loops (Kaber & Endsley, 2004). During the intermediate phases of automation, this type of behaviour will pose one of the greatest challenges to systems designers who must ensure that the driver is capable of regaining control of the vehicle. In this way, the research presented in this thesis is primarily concerned with “soft” automation as the driver still interacts with most automated systems within the vehicle. This ensures it remains aligned with the new amendment to the Vienna Convention (2014) in that automated systems must be capable of being overridden.

With this in mind, it is important to consider the types of automated systems that fall under the definition of soft automation within driving.

Table 2.1. Allocation of function between the driver and automation across automation taxonomies (adapted from Smith, 2013)

<table>
<tr><th>Level of Automation
(SAE)</th><th>Longitudinal and Lateral Control</th><th>Monitoring of the Environment</th><th>Operational & Tactical Tasks</th><th>Strategic Tasks</th><th>BASt Level</th><th>NHTSA Level</th><th>Endsley & Kaber (1999)</th><th>Types of Features</th></tr>
<tr><td>0 – No Automation</td><td>D</td><td>D</td><td>D</td><td>D</td><td>Driver only</td><td>0</td><td>1</td><td>Warnings e.g. Blind Spot Information Systems</td></tr>
<tr><td>1 – Driver Assistance</td><td>D / A</td><td>D</td><td>D</td><td>D</td><td>Driver Assistance</td><td>1</td><td rowspan="2">4</td><td>Adaptive Cruise Control</td></tr>
<tr><td>2 – Partial Automation</td><td>A</td><td>D</td><td>D</td><td>D / A</td><td>Partially Automated</td><td>2</td><td>Integrated Cruise Assist</td></tr>
<tr><td>3 – Conditional Automation</td><td>A</td><td>A</td><td>D</td><td>D / A</td><td rowspan="2">Highly Automated</td><td>3</td><td>7</td><td rowspan="2">Highway Pilot</td></tr>
<tr><td>4 – High Automation</td><td>A</td><td>A</td><td>A</td><td>D / A</td><td rowspan="2">3/4</td><td>9</td></tr>
<tr><td>5 – Full Automation</td><td>A</td><td>A</td><td>A</td><td>A</td><td>Fully Automated</td><td>10</td><td>Google Self-Driving Car</td></tr>
</table>

Key. D = Driver; A = Automation; D/A = Driver and Automation capable of completing function.

2.3.1 Lateral support systems

Lateral support systems support tasks associated with the sideward direction of driving such as lne position (Hermann, 2004). Examples include;

- Lane Departure Warning Systems

These systems are designed to warn the driver when the vehicle begins to unintentionally move out of its lane. The driver remains fully responsible for maintaining lateral control of the vehicle (Patten, 2013).

- Lane Keeping Assist

These systems work on the same principles as a Lane Departure Warning System but actively take steps to ensure that *unintentional* lane deviations do not occur by automatically using steering or torque inputs (Patten, 2013).

- Lane Centring

These systems use lane geometry to calculate how much torque is required to keep the vehicle within the centre of a lane. These systems are capable of autonomously maintaining lateral control of the vehicle without input from the driver.

2.3.2 Longitudinal support systems

Longitudinal support systems support tasks associated with the forward direction of driving such as speed or headway keeping (Hermann, 2004). Examples include;

- Speed Sign Recognition

Speed Sign Recognition can notify and warn the driver of current speed restrictions. The driver remains fully responsible for maintaining the speed and headway of the vehicle.

- Cruise Control

When a driver engages Cruise Control, they simply set a maximum cruise speed. The automated system will then hold this speed. At this level of automation, the driver is responsible for maintaining the headway of the vehicle whilst the automation is responsible for maintaining the speed of the vehicle.

- Adaptive Cruise Control

An extension to traditional Cruise Control, these systems can adjust vehicle speed in order to maintain a safe distance to the vehicle in front (Patten, 2013). This means that the vehicle will slow down when approaching a vehicle ahead and accelerate back up to the pre-set speed when the lead vehicle either increases its speed or is no longer in front of the host vehicle. At this level of automation, the automation is responsible for maintaining both the speed and headway of the vehicle.

- Stop & Go Adaptive Cruise Control

Stop & Go Adaptive Cruise Control can be viewed as an extension of Adaptive Cruise Control. It is based upon the same principles of Adaptive Cruise Control but is able to bring the vehicle to a complete stop when necessary (Stanton et al. 2011). As with Adaptive Cruise Control, the automation is responsible for maintaining both the speed and headway of the vehicle.

2.3.3 Combined function systems

These systems support tasks associated with both the forward and sideward direction of driving (i.e. longitudinal and lateral control). Combined Function systems represent the newest forms of automated driving features within the consumer marketplace that use extensions of Adaptive Cruise Control and Lane Keeping Assist.

Examples include;

- Traffic Jam Assist / Traffic Jam Pilot (used in low speed traffic scenarios only (TRW Automotive, 2013)
- Integrated Cruise Assist
- Autopilot

2.4 Human factors considerations in using automation

From the discussion above, it is clear to see how automation implementation within the driving task affects the role of the driver and the level of control that they have in performing traditional driving tasks. Despite their level of control reducing, drivers continue to receive feedback from the vehicle and their wider environment. This means that although their *responsibilities* have changed, they remain to some extent within the control-feedback loop. This means that the level and type of automation implementation is an important consideration in the design and development of automated technologies because it has an effect on the ways in which the driver can exercise their authority and control (Builder et al. 1999).

It is helpful to think of the control loop as a circular process that consists of a goal (desired state), strategy (to achieve the desired state) and feedback (to establish whether the chosen strategy satisfies the desired state). When the driver is in the loop, they are actively engaged in all three processes. However, as soon as automation is engaged, the driver is potentially relegated from one or more of these stages meaning they could become out of the loop (Stanton et al. 2007a). However, to think of the driving loop as a single process does not fully reflect the nature of the complex interactions that occur throughout the driving task. Rather than a single driving loop, there would appear to be many more given that individual system components can both hold and share data. For example, the driver may build their awareness of their environment through coordinating their behaviour with automated systems, the information presented within the vehicle via the Human Machine Interface and also information obtained from the road environment. In contrast, the automated system will use driver inputs as well the vehicles response to those inputs to develop its awareness of the current situation in addition to information fed into the system directly from sensors and radar. With each control loop working concurrently across and independently from one another, the information that flows between them relies heavily upon the maintenance of the links that lie between them. However, the introduction of automation into the driving system is likely to change the nature of these interactions and may even see the disintegration of loops between the driver and vehicle systems becoming more evident as vehicles become increasingly intelligent (Stanton et al. 1997; 2007a).

To better understand the functionality of the driver-vehicle interactions in using automation, research has typically focussed upon the operationalization of the following concepts (Sheridan et al. 2008; Saffarian et al. 2012);

2.4.1 Reduced situation awareness

Situation Awareness (SA) is a multi-dimensional concept that can describe how individuals (Endsley, 1995), teams (Salas et al. 1995) and systems (Stanton et al. 2006) both develop and maintain their awareness during task performance. Endsley (2006) formerly described Situation Awareness (SA) 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 in the near future" (p.529).*

In a dynamic driving environment, individual SA on behalf of the driver is built through the monitoring of critical variables such as speed, road positioning, behaviour of own and other vehicles as well as weather conditions (Walker et al. 2008). SA explains how drivers use this information to combine their long-term goals (e.g. navigation) with short-term goals (e.g. avoiding collisions with other road users) in real time (Walker et al. 2008) whilst predicting how these variables will continue to change in line with the environment (Gugerty, 1997). Driver SA therefore can be seen as activated knowledge (Salmon et al. 2012) – knowledge that relates to the driving task, at a specific time, within the road environment.

Essentially this means that there can sometimes be a failure to notice change in the external environment due to some form of distraction or interaction with other in-vehicle devices. Whilst it is hoped that vehicle automation will have the desirable benefit of improving the monitoring ability of drivers as they will have more attention devoted to the task at hand, the literature is littered with instances where automation has proven to be problematic as an individual's ability to monitor the visual scene efficiently may actually decrease under automated driving conditions since automation leads to changes in levels of vigilance and complacency (Kaber & Endsley, 2004). For example, on February 12, 2009, a Colgan Air Flight 3407 crashed near to Buffalo, New York. A synopsis by the National Transportation Safety Board (2010) reported that the co-pilot incorrectly programmed information into the onboard computers causing the plane to slow down to an unsafe speed triggering a stall warning. The captain had not noticed that the plane had slowed down indicating a lack of SA and responded incorrectly by repeatedly pulling back on the controls which overrode two safety systems. The correct procedure would have been to push the control yoke forward. An investigation later concluded that there were no mechanical or structural problems that would have prevented safe flight if the pilot had responded correctly to the original problem. All passengers and crew were killed.

A loss of situation awareness was also implicated in the Air France 447 accident in 2009 killing all people on board (Salmon et al. 2016). A major investigation by the Bureau d'Enquêtes et-d'Analyses (2012) concluded that the fatal incident was a result of a series of events following the disconnection of autopilot as a result of frozen pitot tubes in adverse weather. This led to the plane stalling and crashing into the Atlantic Ocean. The report scrutinized the aircrews lack of awareness of situation, inability to establish the correct procedure to follow in such an event and an overall failure to control the aircraft.

Whilst aviation is considered to be one of the safest forms of transport, "human error" is considered to be one of the principle threats to flight safety according to the Civil Aviation Authority (1998). Interestingly, what many incidents occurring within aviation have in common is that functioning automated safety systems are either overridden or ignored placing perfectly serviceable vehicles in otherwise dangerous situations (Stanton & Salmon, 2009). There are two primary forms of error that have been associated with automation in aviation (Stanton & Marsden, 1996). These are mode error (Endsley & Kiris, 1995) and automation surprises (Sarter et al. 1997). Mode errors on modern flight decks started being reported in the late 1980's (Sarter, 2008). A mode error in aviation is typically a result of mode confusion and is characterised by the pilot performing an action that is appropriate for the *assumed* state rather than the *actual* state of the system (Mumaw et al. 2001). Numerous studies have shown that pilots can become confused about both the system state and behaviour of flight deck automation (e.g. Sarter & Woods, 1995). Automation surprises are closely linked with pilot mode errors. This is because the pilot perceives that the automation is engaged in activities that were not commanded or engaged (Mumaw et al. 2001). In this way, an automation surprise on the flight deck represents a miscommunication between the automation and human operators leading to a gap in the pilots understanding of what the system is doing / going to do (Sarter & Woods, 1995; Sarter et al.1997). These forms of error are not however limited to the aviation domain and it seems highly likely that similar errors will occur within driving automation. In fact, the occurrence of both mode confusion and error in driving with automation is already documented (e.g. Stanton et al. 2011). For example, Andre & Degani (1997) discuss a common error that drivers make when using cruise control. In their paper, they discuss a situation whereby a driver overrides cruise control and increases their speed (in this case slow moving traffic as a consequence of poor weather increased speed once the weather had improved). When they chose to exit the highway, the driver had forgotten that cruise control was still active (thus meaning that the driver experienced mode confusion) and once the vehicle had fallen below the initial set speed, a sudden "jolt" of acceleration had led them to losing control of the vehicle. Similar errors may also occur when using Adaptive Cruise Control whereby a driver may follow behind a slow moving vehicle (i.e. travelling below their desired set speed) when wanting to exit the highway. As soon as the driver moves the car onto the exit road, the vehicle will increase its speed to reach the pre-set desired speed, It is at this point however, that drivers will want to slow their vehicle for the upcoming junction or intersection. Thus, performance impairment may be attributed to a failure to recognise and match external environmental demands.

2.4.2 Erratic changes to driver mental workload

Mental workload can be described as the relation between the attentional resources demanded by the task and the resources actually available to complete the task (Sheridan et al. 2008; Singleton, 1989) which echoes the philosophy underpinning Resource Theory. Much of the research available on mental workload comes from the field of aviation and it has provided some worrisome results with many pilots reporting that use of automated systems actually increases mental workload when it is needed most (Bainbridge, 1983; Sheridan et al. 2008). Reinartz & Gruppe (1993) suggested that automation may simply shift driver attention to other tasks such as system monitoring resulting in little reduction in workload.

An alternative perspective comes from Malleable Attentional Resource Theory (MART; Young & Stanton, 2002). MART proposes that there are separate attentional pools but far from having a fixed capacity, these attentional pools remain robust and are capable of adapting depending on task circumstances. This means that task demand can affect the size of the attentional resource available to complete a task and therefore it can be possible to both overload and underload human controllers. It is possible that high levels of driving automation may lead drivers to become cognitively underloaded (Young & Stanton, 2004) especially in routine situations (Ma & Kaber, 2005; Stanton & Young, 2005). This may resonate as 'highway hypnosis', a form of drowsiness or fatigue that can lower driver alertness (Wertheim, 1978). This altered state may lead to drivers who are unable to respond to changes within their environment in the same way, implicating the concept of SA. The general consensus is that mental workload optimisation is crucial to maintaining effective task performance (e.g., Wilson & Rajan, 1995). Such optimisation inevitably involves a balancing act between demands and resources of both task and operator. However, optimising systems performance during transitional automation would require the driver to remain an active, rather than passive, supervisor of the system. Strategies to maintain the driver in-the-loop are therefore an important area of investigation because overall driver workload has been shown to reduce as both the physical and cognitive tasks associated with driving become automated. This workload shift sees the driver transitioning from an active operator to more of a passive monitor (Kaber & Endsley, 2004) which conflicts with the desire to optimise system performance.

2.4.3 Trust, overreliance and complacency

The concept of trust surrounding vehicle automation has largely derived from the idea of complacency (e.g. Parasuraman et al. 1993; Lee & See, 2004; Young & Stanton, 2002). If automation is perceived by the driver to be highly reliable, the driver may not monitor the system as closely as perhaps is warranted and therefore may not expect occasional failures. Thus, the perception of increased reliability instils trust and drivers may become complacent. de Waard et al. (1999) reported that 50% of drivers failed to regain control following system malfunction in a driving simulator study on an automated highway system due to the belief that the system would intervene despite the system being compromised. Although the reality of system failure is small in most cases due to an extensive testing phase, operational failings such as the inability to automate all aspects of the driving task, leaves the driver vulnerable to the need of intervention whether it is prompted by the system or not (Larsson, 2012).

Overreliance on automation has been highlighted as a possible cause for several aviation accidents. For example, the National Transportation Safety Board (1994) determined that a pilot who demonstrated low confidence in their manual flying ability was too reliant on automation and failed to monitor aircraft speed during a final approach in a snowstorm causing them to crash land short of the runway near Columbus, Ohio. The Air Transport Administration (1989) and the Federal Aviation Administration (1990) have both expressed concern over pilots reluctance to regain control from automated systems. Worryingly, Riley (1994) found that whilst novice pilots would turn off automation when it failed, almost half of the experienced pilots did not.

With trust and acceptance emerging as key concepts within the automobile industry, there is a growing body of literature into this area as manufacturers strive to design automated systems that will be widely accepted and adopted.

2.4.4 Skill degradation

Skill development and maintenance remains a lasting concern within the field of driving automation, especially if drivers become “hands and feet free”. This is because automation may hinder the learning potential of future drivers or lead to a loss of skill due to lack of manual input (Parasuraman, 2000; Lavie & Meyer, 2010; Miller & Parasuraman, 2007). Reaching an appropriate level of automation is therefore extremely important to ensure that drivers can maintain an appropriate level of driving experience (Patten et al. 2006). However, a number of studies have indicated that performance under increased levels of automation can decline suggesting that automation can negatively impact driving performance through skill degradation. For example. Jameson (2003) reported that individuals perform manual tasks less efficiently once they have acclimatised to the system performing the task on their behalf.

However, this may only be a problem in the short term whilst increasing levels of automation are introduced into the driving system. Once automated vehicles are fully integrated into our transportation network, issues relating to skill degradation may become less problematic. Even so, whilst we remain in the intermediate phases of automation, skill degradation is a real concern.

2.5 Conclusions

Taking a systems view, it seems that the mediation of activity may be better coordinated if an augmented approach is taken. The design of technology that can integrate our own cognitive ability and can be used to further extend our capabilities is achievable if the interactions between individuals, environment and other media are explored.

It is clear to see that regardless of the automation framework that is adopted (e.g. theoretical or practical), the terminologies used within them remain fairly similar. It is essential that agreement can be reached on the appropriate 'label' assigned to automated systems and that its usage remains consistent throughout the design process to avoid confusion about system limitations and functional boundaries. Even so, it seems that at least for the interim period between transitional automation and full vehicle automation, control transitions will continue to be made between the driver and automated system due to issues surrounding practicability, liability and individual preferences of the driver (SMART, 2010). For this reason, the driving task can be best described as shifting somewhere on a continuum between manual and fully automated driving. Thus, rather than being either strictly manual or automated, the driving task is shared between the driver and automated system. In essence, what this means is that the whole driving system can involve the automation of different processes at different levels simultaneously. Until drivers become completely "Hands and Feet Free", serious concerns remain with regard to out-of-the-loop performance problems (Billings, 1988; Endsley & Kiris, 1995; Endsley & Kaber, 1997) and the ability of the driver to detect and resolve errors in their *new* supervisory role (Endsley & Kiris, 1995).

2.6 Future directions

The allocation of function between the driver and automation within an automated driving system appears to be key in understanding how the role of the driver will be affected by automation implementation. However, our understanding of network dynamism is limited to the definitions outlined by SAE, BASt and NHTSA whom fail to capture changes to the control-feedback loops of driving. Whilst automation taxonomies go some way in describing the workload shift between the driver and automation, more explicit modelling is required to truly understand how the driver's role within the driver-vehicle control loops is impacted by automation implementation. Chapter three builds upon chapter two by introducing the concept of Distributed Cognition (Hutchins, 1995a; 1995b). This approach recognises that interactions can occur between human and non-human agents. Modelling the communication patterns that exist between these agents will further extend our understanding of a) how these systems function and b) the relationships that exist between multiple system agents.

Chapter 3: Adopting a Systems Engineering View in the Design of Automated Driving Features

3.1 Introduction

Systems Engineering can be seen as an interdisciplinary approach to the field of engineering that integrates both technical and human-centred approaches to look more closely at work processes, optimisation and risk management. This holistic approach is concerned with how the functioning and performance of a joint cognitive system can be best described and further understood. The driving task is an example of a joint cognitive system (Salmon et al. 2008); one that comprises of the driver and the devices with which they engage. This viewpoint stems from the belief that every 'agent' within a system plays a critical role in the successful completion of a task and more importantly, 'agents' can be both human and non-human (Stanton et al. 2006; Salmon et al. 2008). It therefore provides an analytical framework that can be used in the design of adaptive automation (Hollnagel & Woods, 1983). Artman & Garbis (1998) suggested that cognition is achieved through close coordination of the elements or agents involved in the system, and in a vehicle, both the driver and in-vehicle devices are seen as 'agents'. It appears to be team cognition that is the binding mechanism that produces coordinated behaviour (Cuevas et al. 2007). Although early research into automation seemed to focus most heavily upon autonomy, current research now focusses upon satisfying the requirements of joint activity, including human-machine teamwork (Klein et al. 2004).

An interdisciplinary approach such as this is extremely complex because the 'behaviour' or interaction that occurs between system components is not always well defined or understood. The aim of Systems Engineering is to better define and characterise subsystems and the interactions that occur between them. In terms of vehicle automation, questions remain over whether or not automated subsystems fundamentally change the driving task by affecting the ways in which the driver interacts with vehicle systems. In order to address these concerns, a Distributed Cognition approach is adopted (Hutchins, 1995a). Unlike traditional theories, Distributed Cognition goes beyond the individual and encompasses the interactions that take place between humans, resources and materials within their environment across space and time (Hollan et al. 2000; Hutchins, 1995a) and therefore fits nicely within the Systems Design paradigm. It has been recognised that both human and non-human agents are vital to the flow of information (Griffin et al. 2010).

With vast amounts of information exchange between multiple agents within a system, the ability to sense changes within these representational states, understand them and then perform some form of computation to deal with these changes implicates SA (Endsley, 1995) and describes the essence of Distributed Cognition. Although the study of SA originated within the aviation domain (Stanton et al. 2001), Endsley (1995) identified SA as a critical component in driving.

The Distributed Cognition approach has been most famously applied to description of task partitioning in a pilot's cockpit (Sorensen et al. 2011) and there appears to be no reason why it cannot be applied to driving. From a Distributed Cognition perspective, SA is formulated through a myriad of individual components and cannot be predicted based solely upon one of these individual components or the mere combination of individual SA from different agents (Salas et al. 1995). This idea is particularly relevant to vehicle automation because the driver uses assistive aids to help build a 'picture' of what is happening in the world (Walker et al. 2010). It is possible therefore to apply Endsley's (1995) three-stage model of SA to a system (e.g. Stanton et al. 2006). There is a need to move away from traditional notions of SA (Endsley, 1995) that dominate Ergonomics at present to one that focuses upon entire systems (Gorman et al. 2006; Salmon et al. 2008; Sorensen et al. 2011; Walker et al. 2010). This is because there are very few complex tasks that can be performed on a completely individualistic basis (Perry, 2003; Walker et al. 2010). Distributed Situation Awareness (DSA; Stanton et al. 2006; Stanton et al. 2015) offers a compatible approach that assumes SA is a system level phenomenon rather than individual-orientated (Salmon et al. 2008; Stanton et al. 2006). DSA outlines that SA can be held by human and non-human agents, that different agents view their environment differently and that at an individual level SA overlap will be dependent upon the goals of each agent. DSA also recognises that communication can be non-verbal and that SA loosely holds systems together whereby one agent has the ability to compensate for degraded SA in another (Stanton et al. 2006; Stanton et al. 2015).

Importantly, there appears to be very limited research available on human-machine cooperation within a driving domain (Hoc et al. 2009) which is somewhat surprising when considering that cooperation is intimately linked with driver support (Hoc et al. 2009). However, Hoc & Blosseville (2003) offered a number of modes of cooperation that can occur between a driver and automation. For instance, the perception mode is generally restricted to the presentation of symbolic information on dashboards or road signs (Hoc & Blosseville, 2003). These are rigorously enforced by International Standards (e.g. BS ISO 2575:2010+A1:2011 for control symbols). Mutual control refers to driver and system sharing a degree of control whilst the function delegation mode refers to the driver delegating some vehicular control to an automated sub-system. For example, cooperation between a driver and an automated sub-system such as Adaptive Cruise Control (ACC) (Rajaonah et al. 2008) is based within the control and function delegation modes. Drivers can choose to delegate their longitudinal control to the ACC as long as they can reclaim control depending upon the context, the actions required and 'who' is the most suitable 'agent' to perform these actions (Rajaonah et al. 2008). This indicates that the driver-ACC system is very adaptable. There is a clear need then to consider the interactions that occur between multiple agents as being "cooperative" because automated systems can become "vital non-human" agents within the task under the right circumstances (e.g. Cuevas et al. 2007, p. B64). According to Cuevas et al. (2007), a human-automation team can be defined as the coupling of both human and automated systems that must work both collaboratively and in coordination to successfully complete a task, for instance; driver and ACC (Rajaonah et al. 2008; Rudin-Brown & Parker, 2004). It is important that the principle of complementarity is adopted, with the allocation of tasks serving to maintain control whilst retaining human skill (Grote et al. 1995). As with Free Flight (Langan-Fox et al. 2009), driving automation poses many challenges with regards to the interaction between humans and automation including operational functionality and system management. There may be confusion over whom (the driver or automated sub-system) has authority over 'which' vehicular controls as the level of automation increases.

3.2 Distributed cognition in driving

Distributed Cognition in driving provides a means to employ Human Factors insights into the early phases of the design process (Jenkins et al. 2009; Walker et al. 2015). It aims to provide a clearer understanding of task partitioning between the driver and automated subsystems and recognises that the cognitive processes normally completed by the driver can be shared across this system (Hollnagel, 2001; Stanton, 2014) to achieve a common goal (Hoc et al. 2009). Up until now, it is an approach that has been successfully applied to a number of domains including ship navigation (Hutchins, 1995b), airline cockpits (Hutchins & Klausen, 1996), engineering practice (Rogers, 1993), search and rescue (Plant & Stanton, 2016) and air traffic control (Halverson, 1995). The application of Distributed Cognition to driving is a new and unexplored medium yet there appears to be great benefit in doing so in terms of automation development and system safety.

The Distributed Cognition approach makes use of a number of exploratory methods including detailed analysis of real life events, network simulations and laboratory experiments (Rogers, 1997). The following section offers a step-by-step approach to applying Distributed Cognition to driving. The author proposes that in order to achieve a comprehensive understanding of Distributed Cognition in driving, the following steps should be taken;

Step 1: Design Idea, Concept or Prototype

The first step of applying Distributed Cognition to driving involves determining which specific driving task the investigator is interested in. With this in mind, it is possible to modify and extend current vehicle technologies and/or develop future automated driving systems. Focus group discussions or mind-map exercises are a useful starting point.

Step 2: Allocation of Function

The allocation of system function should be viewed as a high level task analysis giving that aims to give a general impression of the workload shift between system agents from manual to fully automated control in a descriptive manner to allow further exploration and discussion between researchers, systems designers or engineers. With the driving task consisting of so many subtasks (see Walker et al. 2001; 2015), automation can be applied to different aspects of 'driving' at differing levels of autonomy (Endsley & Kaber, 1999). Once automated subsystems are activated within the driving task, the driver assumes that a degree of control has been assigned to the system. This can change the nature of driver-vehicle interactions as a division of labour occurs. Echoing the viewpoint of Endsley & Kaber (1997), it must be ensured that the driver knows exactly "who" is expected to do "what" during the driving task. Thus, in order to design a human-centred product, the designer should augment the task which the product is designed for. In this way, it is possible to establish "who" can do "what" at differing levels of automation. Much like Hutchins (1995a) described two roles within a pilot's cockpit (Pilot Flying and Pilot Not Flying), the driving system contains two primary actors capable of controlling the vehicle (Driver and Automation). At this point, we are not seeking to define individual subcomponents (e.g. sensors, radars) or how information flows between them.

A mapping exercise (e.g. Table 3.1) can achieve the desired output using a matrix of adapted information processing functions outlined by Endsley & Kaber (1999) and Parasuraman et al. (2000). Importantly, the allocations assumed within Table 3.1. are descriptive rather than normative but offer a useful starting point in thinking about how allocation of function may be shared between the driver and automated systems. In addition to the functions outlined in previous taxonomies, the author proposes an adaptation to previous automation taxonomies to make them more applicable to driving. Firstly, an anticipatory phase takes into consideration the feed-forward mechanisms that occur within the driving task. For the driver, much of this will be based upon prior experience but feed-forward information can also come from other system agents. Secondly, a recognition phase takes into account the distinction between object detection and object recognition within the driving task. For example, the identification of a pedestrian stepping out or a car joining the carriageway can only be recognised if they are first detected. In the recognition phase, a greater degree of attention is devoted to an object of interest. This means that potential hazards within the visual scene are allocated additional attentional resources so that they can be identified and either confirmed or discarded. This pattern of behaviour is important for later decision making and strategy generation processes. What this means is that drivers monitor and acquire information relating to their environment and anticipate likely events and interactions that may occur (Endsley & Kaber, 1999; Parasuraman et al. 2000); when an event or interaction does occur, the driver must firstly detect it and recognise the salient features of the event; based upon this recognition, the driver must then decide on strategies for dealing with the event (Endsley & Kaber, 1999), select the most appropriate strategy (Endsley & Kaber, 1999; Parasuraman et al. 2000) and perform a response to implement this strategy (Endsley & Kaber, 1999; Parasuraman et al. 2000).

However, what these cognitive functions mean for automated systems within the driving task needs further clarification. The following descriptions provide narrative examples of how automated systems use information within the environment to support decision-making and response execution.

- *Parking Aid - Benjamin wants to park his car in a parking lot. He drives around the parking lot in search of a space. He notices a gap ahead of him and at closer inspection realises that it is a free space. He looks at the environment around him and decides that it is big enough to park his car safely and that he would also like to reverse into it. Pulling his car forward ahead of the parking space, Benjamin checks his mirrors and selects the appropriate gear. Using his previous experience, Benjamin is able to reverse safely into the gap. However, he is unable to see the back wall clearly due to poor lighting. His Parking Aid begins to "beep" which must mean that he is getting close to the wall. In this example, the Parking Aid has been monitoring its environment and detected that the distance between the extremities of the car and obstacles within in the environment are becoming reduced. It has alerted Benjamin to such obstacles using an auditory signals, of which will become more panicked the closer he gets to the wall.*

- *Adaptive Cruise Control - Susan is driving her car along a highway. She engages Adaptive Cruise Control – a form of intelligent cruise control that can slow down or speed up depending upon the traffic situation ahead. The driver sets a maximum speed which the vehicle is now responsible for maintaining. Whilst Susan is still* *expected to monitor her surroundings and anticipate the movements of other road users in case she may need to override the system, the Adaptive Cruise Control system must also monitor the roadway ahead and detect vehicles any obstructions in the path of the vehicle. It uses radar sensors to monitor the traffic ahead and can "lock" on to a vehicle ahead in lane and maintain a 2-4 second gap depending on driver preferences. Sometimes, recognition of a vehicle ahead is shown within the Human Machine Interface. If the lead vehicle slows down, or another vehicle enters the lane ahead, radar headway sensors detect the object and digital signal processors send signals to the engine or braking system to decelerate. This deceleration signal is to preserve the safe gap between vehicles. Once the road is clear, or the vehicle ahead speeds up, the sensors will send signals to reaccelerate to the set speed.*

Table 3.1 shows how the driver and automated subsystems can work in parallel or independently of one another in current marketable subsystems. Using this representation, it becomes clear that many of these subsystems operate at an enhanced level of automation as they are capable of performing all seven information processing functions. However, it is important to note that there appears to be a greater difference in the level of automation between assistive technologies (e.g. Collision Warning Systems) and the level of automation demonstrated by controlling technologies (e.g. Collision Avoidance). In addition, the level of assistance that the driver receives between individual subsystems in these broad categories of 'Assistive' and 'Controlling' technologies varies greatly. For example, a Parking Aid provides assistance in only one function whereas Collision Warning and Lane Departure Warning Systems (LDWS) can assist the driver in multiple functions. In contrast, controlling technologies such as Adaptive Cruise Control and Park Assist have been designed to perform all seven information processing functions so that a greater degree of control transfer can occur between the driver and automated subsystems. In terms of Distributed Cognition, controlling technologies assume responsibility for all seven processes. The increasing frequency of 'A' in Table 3.1 indicates that the driver is gradually removed from the control-feedback loop and is likely to take on a supervisory role within the system network. This means that the driver can essentially become hands and feet free because the locus of control shifts from the driver to the automated sub-system.

Table 3.1. Distributed cognition of Information Processing Functions within the Driving System when systems are active (intended to be descriptive rather than normative)

DCOG / TECH	Monitor	Anticipate	Detect	Recognise	Decide	Select	Respond
Parking Aid (Sensors / Beeps)	D/A	D	D/A	D	D	D	D
Power Steering	D	D	D	D	D	D	D/A
Night Vision	D/A	D	D	D	D	D	D
Lane Departure Warning System	D/A	D	D/A	D/A	D	D	D
Collision Warning	D/A	D	A	D/A	D	D	D
Blind Spot Information System	A(D)	D(A)	A	D	D	D	D
Pedestrian Detection System	A(D)	D(A)	A	D/A	D/A	D/A	D/A
Automatic Braking	A(D)	D(A)	A	A	A	A	D/A
Intelligent Light System	A(D)	D(A)	A	A	A	A	A
Intermittent Windscreen Wipers	A(D)	D(A)	A	A	A	A	A
Collision Avoidance	A(D)	A	A	A	A	A	A
ABS	A(D)	A	A	A	A	A	A
Traction Control	A(D)	A	A	A	A	A	A
Adaptive Cruise Control	A(D)	D(A)	A	A	A	A	A
ACC Stop & Go	A(D)	A	A	A	A	A	A
Lane Keep Assist	A(D)	A	A	A	A	A	A
Park Assist	A(D)	A	A	A	A	A	A
Driver Monitoring	A(D)	A	A	A	A	A	A

Key. D = Driver; A = Automation; D/A = Driver and Automation can perform function; D(A) = Driver should ideally perform function but subsequent automation involvement has been designed to overcome driver inactivity in this function; A(D) = Automation capable of performing function but the driver is still expected to continue active monitoring of both sub-system behaviour and events in the driving environment.

However, subsystems acting alone (i.e. without driver monitoring) are unlikely to create safer driving environments due to their functional limitations (Stanton et al. 2011) which perhaps explains why in recent years it is becoming more prevalent to use multiple automated subsystems simultaneously. In the case of active hazard detection for instance, combined Pedestrian Warning/Detection Systems (Pedestrian AEB), Collision Warning Systems and Active Braking will bring about enhanced levels of automation (SMART, 2010). However, subsystem synergies such as this mean that the level of assistance provided to the driver across the entirety of the driving system will become increasingly complex (Stanton et al. 2011). This is because the level of automation is technology specific and the driver will need to remain aware of multiple system states simultaneously (Cuevas et al. 2007; Dehais et al. 2012; Walker et al. 2009).

The mapping of Allocation of Function should not be viewed as a mandatory exercise when applying Distributed Cognition to driving. Instead, it should be viewed as an opportunity to discuss with peers what individual system agents may be responsible for during automated driving. It should not be viewed statically because in dynamic environments such as driving, allocation of function is likely to change depending upon context (Hancock & Scallen, 1996).

Step 3: Operator Sequence Diagrams

We have already seen from the matrix in Table 3.1 that as vehicles become increasingly 'intelligent', they become better able to take over elements of the driving task traditionally performed by the driver (Dingus et al. 1997; Walker et al. 2001). The matrix alone does not reflect the interactions that occur between the driver and vehicle subsystems. To further our understanding of Distributed Cognition in driving, it is vital that these interactions are modelled to ensure that the introduction of automation does not negatively impact upon the functionality of the driving system (Hoc et al. 2009). Being able to analyse and evaluate the activity of these agents provides an opportunity to establish how drivers may recover in the event of system failure. This becomes increasingly important as technologies become more intelligent (Shorrock & Straeter, 2006) due to their potential to play an important role in detection, problem-solving and decision-making functions that would otherwise be completed by the driver under manual conditions. Thus, step 3 should be viewed as the opportunity to explore a task network with more situational context.

For the early stages of system development, the application of Operator Sequence

Diagrams (OSD's; Brooks, 1960, Kurke, 1961) provide a novel way to investigate Distributed Cognition within automated driving systems through clear, easy to read, graphical representations (see pages 40-43 for examples). Since the 1960's, the method has been widely used in Systems Engineering and has been applied successfully to a wide range of domains including air traffic control (Walker et al. 2005), rail (Walker et al. 2006), energy distribution (Salmon et al. 2004), nuclear industry (Kirwan & Ainsworth, 1992) and most famously, to a pilots cockpit (Sorensen et al. 2011). It is one of the most cost effective ways to simulate a complex system (Chapanis, 1995) and can be described as a paper-based methodology that can be easily implemented at different stages of the design process from a design concept to prototype.

Outputs seek to contribute to the design of feedback systems that may help to overcome any communication breakdown between system agents. This is because OSD's provide a means to assess weak links between agents and communication flows (Griffin et al. 2010; Kurke, 1961). The OSD methodology originally sought to concurrently indicate human-machine interactions throughout the development and design of complex weapons systems (Brooks, 1960). Graphical representations enabled the analyst to identify essential interactions that took place between system agents in addition to identification of weak links within the system network prior to deployment. This is essentially the aim of applying them to automated driving systems.

According to Wallace et al. (2000), OSD's must adequately capture and represent the subtasks and operations required to complete the task including subevents, decisions, capabilities and the ordinal or temporal flow of control and information by using standard geometric figures (see Table 3.3, page 40). These figures are individually coded to denote different elements of the operational sequence (Kurke, 1961).

Although OSD's can be criticised for being task specific and therefore not capable of representing the true complexity of work, this also serves as a benefit if the analyst is interested in simulating a "specific" subtask conducted in a complex system. According to the Hierarchical Task Analysis of Driving (Walker et al. 2015), there are approximately 1600 identifiable driving subtasks of varying complexity. This means that within the driving domain, the OSD methodology could be used to simulate individual subtasks of driving that make use of additional hardware and automated technology. This makes it possible to identify how the driving task may change as a result of technology introduction (pre- versus post- automation) and be a useful mechanism in comparing and contrasting different technological formats (e.g., display units). OSD's therefore offer an easy way of visualising the interrelationships and communications that occur between different agents providing an inexpensive alternative to mock-ups and prototypes that attempt to address the same purpose.

Step 4: User Trials

Although task analysis and its associated methods such as those outlined in the preceding steps, are a popular and widely used method to assist in the design and development of automated technologies (Putkonen & Hyrkkänen, 2007), it remains a challenge to capture both the cognitive and behavioural elements of a task and there is still some debate over whether they represent cognition adequately (Patrick, 1992). In terms of driving, it seems reasonable to suggest that the cognitive processes involved in completing the driving task play the most important role in performance, especially when considering that it is cognition that shapes subsequent behaviour. Although Annett (2004) argues that task analysis does involve cognition and behaviour, Shepherd (2000) suggests that we should begin to consider 'how' this can be represented. Allocation of function matrices and OSD representations are not capable of doing this so, to understand the effects of automation on driver cognition, other methodologies such as Verbal Protocol Analysis (Ericsson & Simon, 1993) are required to explore this further.

Driver-vehicle interaction can be further explored in driving simulator, closed circuit and on-road settings. There are of course a number of advantages and disadvantages associated with each of these strategies. Most driver behavioural studies are conducted in driving simulators as they provide the safest environment (de Winter et al. 2012). This is because there is no danger to the driver or other road users. It is therefore possible to investigate driver behaviour in critical driving scenarios. There are also other advantages to using driving simulation including the ease of data collection and versatility. Computer systems provide on-line data processing, storage and automatic arrangement of data. Investigators can choose parameters of interest meaning that they can collect as much or as little data as they see fit (Nilsson, 1993; Godley et al. 2002; Bella, 2008). They can also be easily configured to simulate a variety of research scenarios (Blana, 1996). This makes it possible to evaluate viable system approaches from numerous alternatives before field testing occurs at a relatively low cost. Vehicle characteristics, such as steering ratios and brake calibrations, can be changed quickly allowing for immediate testing. However, whilst driving simulation can be tightly controlled (i.e. every driver experiences exactly the same testing scenario), the extent to which behaviour corresponds to what would actually happen in real life is questionable (Blana, 1996). This is because the social and economic factors that often influence driving behaviour are absent and Greenberg & Park (1994) suggested that this alters behaviour substantially. Even so, this is difficult, if not impossible, to achieve in the real world (Bella, 2008; Blana, 1996; de Winter et al. 2012; Nilsson, 1993; Moroney & Lilienthal, 2009). A further weakness associated with the use of driving simulators is the risk of simulator induced motion sickness. Oron-Gilad & Ronen (2007) predict 10% of people will experience some level of sickness.

Closed circuit or test-track studies represent a step closer to real-world driving (NHTSA, 1997). However, the extent to which they represent real driving behaviour depends upon the nature of the study (NHTSA, 1997). The presence of other vehicles on the test track for example can introduce the risk of real consequence (e.g. collision) and is likely to encourage realistic driving practice. Even so, test track studies offer a more controllable environment over on-road studies (Bach et al. 2009). Of course, on-road studies offer the highest level of fidelity and validity but are coupled with high risk, low versatility and low controllability (Bach et al. 2009; NHTSA, 1997).

Step 5: Identify Design Weaknesses

Upon analysis of the data generated during steps 3 and 4, it will be possible to highlight any potential systems design weaknesses that can negatively affect overall system functionality. For example, response time and stopping distance data may provide a useful insight into how the introduction of an automated feature into the driving system may affect overall system performance. Alternatively, focussing upon driver verbalisations may reveal issues related to systems design that would otherwise be missed from data collection.

Step 6: Propose Design Solutions

Recommendations for alternative strategies should be raised following the appraisal of results if required. Any change to systems design should adopt task augmentation, modelling and user trial strategies to ensure the success of later prototypes.

The step-by-step approach outlined above provides the basis for future exploration into the design and allocation of system function for both pre-existing technologies and the development of future automated systems within this thesis. It is pictorially represented in Figure 3.1 and shows how the application of Distributed Cognition to driving can be achieved in two distinct phases that combine traditional task analysis with qualitative research methods in a Systems Design Framework.

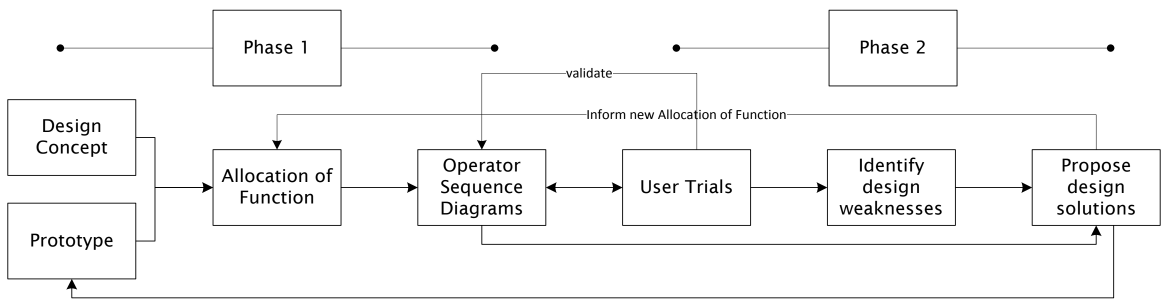


Figure 3.1. Systems Design Framework divided into two phases. Phase 1 essentially models system behaviour whilst Phase 2 seeks to both validate the assumptions made in these models and extend them where appropriate to do so

3.3 Example of applying distributed cognition to driving

In order to demonstrate the utility of the Systems Design Framework identified in Figure 3.1, a case study of driver-vehicle interaction at increasing levels of automation in driving emergencies has been selected for further exploration into the diminishing role of the driver as more physical control is transferred from the driver to automated systems. Notably, only the first phase of the framework was applied to assess its potential in describing system-level interaction occurring at varying levels of automation. The rationale behind the use of this example is discussed below and during step 1.

With driving requiring the driver to continually process the information presented to them in the environment (Fuller, 2005), the level of task demand is determined by a number of interacting factors including environmental (visibility, road markings, signals, camber angles and so on), social (other road users that may occupy critical areas in driver trajectory), operational (vehicle displays, lighting and control) and finally elements that the driver has direct control over such as speed and vehicle trajectory (Fuller, 2005). Access to this flow of information is based upon the availability of attentional resources, driver perception and the decision-making processes (Wickens & Holland, 2000) and will vary dependent upon the distribution of system complexity, rate and element of certainty (Fuller, 2005). Abnormal or atypical driving upsets this flow of information as it brings additional complexity into the driving task. This is because the driver is required to choose an appropriate strategy to cope with an otherwise 'uncertain' event that they may not have experience in dealing with. One way of coping with this additional complexity in driving is to design automated systems that are capable of improving the safety of both the driver and other road users in addition to traditional active safety technologies such as traction control that are always active.

Step 1: Identification of Design Concept

There has been growing concern surrounding the safety of vulnerable road users, particularly adults, over recent years (Parliamentary Advisory Council for Transport Safety commissioned report - Road Safety Analysis, 2013). Formerly, vulnerable road users are defined as;

> "non-motorised road users, such as pedestrians and cyclists as well as motor-cyclists and persons with disabilities or reduced mobility and orientation"
>
> *Intelligent Transport Systems Directive, 2014*

This may be attributed to the fact that vulnerable road users are in closer proximity to other road vehicles in urban environments and have significantly less protection. Although there are a number of mitigation strategies available to local authorities in urbanised developments such as dedicated cycle lanes, pedestrian zones and 20mph zones, road safety may also be improved through vehicle design (e.g. World Health Organisation, 2004).

It seems likely that vulnerable road users are likely to benefit indirectly by some form of 'intelligent' or 'adaptive' automation designed to promote road safety. Adaptive Headlights, Blind Spot Monitoring and Pedestrian Warning with Autonomous Emergency Brake (Pedestrian AEB) are just some of the technologies that Euro NCAP are introducing more stringent testing procedures for. Even so, there is still debate over whether the use of such systems fundamentally changes the driving task by affecting the ways in which the driver interacts with vehicle subsystems (Banks et al. 2014a). Much of the available research into active pedestrian safety focusses on the technical limits or aspects of automation rather than addressing Human Factors in systems design (e.g., Gandhi & Trivedi, 2007; Keller et al. 2011; Rosen et al. 2010). This means that the changing role of the driver is not always recognised. It is clear that there is a need to balance the indirect benefits for vulnerable road users with the potential performance impacts on the driver. If for instance automation simply removes the need for the driver to monitor their environment, vulnerable road users may benefit from technology fitment but the driver may not (see Stanton & Pinto, 2000, for a review on the possible ill-effects of risk compensation).

Pedestrian AEB has been identified by the Euro NCAP as a critical safety system to be widely deployed from 2016 onwards. From a Human Factors and Ergonomics point of view, this gives an opportunity to investigate the impacts of Pedestrian AEB on driver behaviour prior to mass production. Although an extensive amount of literature has been produced surrounding the safety and efficiency of AEB (e.g., Grover et al. 2008), very little research has emphasised Human Factors in its design. It is unclear how driver decision-making may be affected by the addition of this form of ADAS. For this reason, it has been identified as the concept of interest in this chapter.

Pedestrian AEB uses radar and camera based technology to monitor and detect objects that enter the path of the vehicle and warn the driver about potential collisions (Figure 3.2). Using pattern recognition and classification within image processing, the system can track pedestrian movements. If the system calculates that the risk of collision is high, it responds by initiating emergency braking and in some instances provides a warning to the driver.

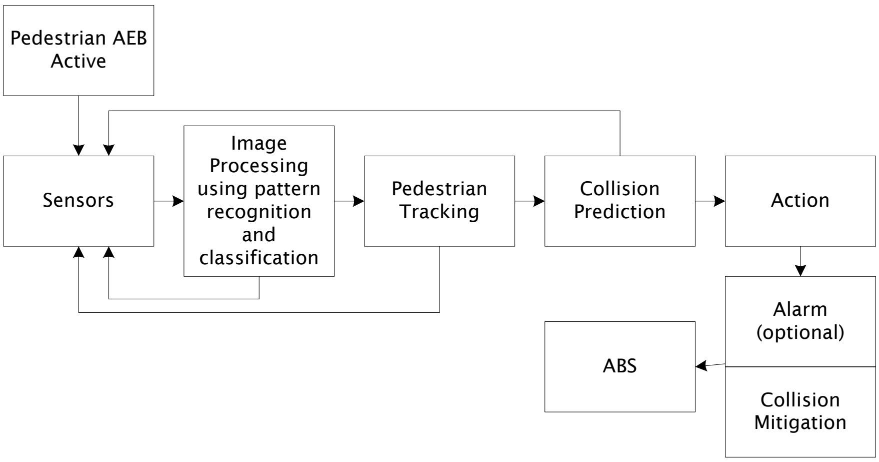


Figure 3.2. Functional Diagram of Pedestrian AEB (Adapted from: Gandhi & Trivedi, 2007)

Step 2: Allocation of Function

As a starting point, Table 3.2 offers useful insight into how increasing the level of automation of pedestrian detection may change the dynamism of driver-automation interactions and enables us to see how the workload begins to shift to the automated system. The levels of automation chosen here represent the hypothetical automation pathway that was identified using Endsley & Kaber's (1999) definitions in chapter two. In manual driving scenarios, the driver is responsible for completing all of the physical and cognitive work associated with the driving task. As the level of automation begins to increase, automation is able to assist and eventually control different aspects of the driving task. For example, an auditory warning (reflecting decision support) can assist the driver in detecting critical pedestrian events and facilitate or provide a response on behalf of the driver (e.g., braking support). This mapping exercise is however unable to relay the complex interaction that takes place between system agents to the reader. For this reason, we need a simple, easy to read graphical representation of Distributed Cognition so that the reader can quickly see how the level of automation impacts upon the dynamics of the driving system.

Table 3.2.Descriptive representation of distributed cognition of information processing functions involved in Pedestrian Detection

DCOG / Level of Auto	Monitor	Anticipate	Detect	Recognise	Decide	Select	Respond
Manual	D	D	D	D	D	D	D
Decision Support	D	D	D/A	D	D	D	D/A
Automated Decision Making	D/A	D	A	A	A	A	A
Full Automation	A(D)	A	A	A	A	A	A

Key. D = Driver; A = Automation; D/A = Driver and Automation capable of completing function; A(D) = Automation capable of completing function but driver still expected to take part.

Step 3: Operator Sequence Diagrams for Pedestrian Detection

To explore the utility of the OSD's for describing driver behaviour in an automated driving system, four OSD's were developed to represent the interaction that may occur at each level of automation as described in Table 3.2. These visual representations show the workload shift more succinctly and make use of standardised geometric features (Table 3.3).

Table 3.3. OSD Key showing the meaning of geometric shapes

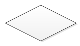
Geometric Shape	*Meaning*
	Process
	Sub-process
	Decision
	Terminator
	Manual input
	Delay
	Path of interaction

Figure 3.3 represents Level 1 automation (Manual Control) and shows that the driver is responsible for completing all the physical and cognitive tasks associated with driving. In this way, avoiding a collision with vulnerable road users is based upon driver attentiveness and the ability to adapt to the ever- changing road environment in the visual scene. In an ideal situation, a collision can be avoided if the driver is able to anticipate vulnerable road users coming into the path of the oncoming vehicle and to brake and/or steer away from them. Alternatively, if the driver decides that the pedestrian or vulnerable road user will move out of the vehicle path before reaching their location, they may choose to take no action.

Figure 3.4 represents Level 4 automation (Decision Support) and shows that the driver has principal control over the decision making and selection function but the automation is assisting the driver in the detection phase of information processing by providing an auditory and sometimes visual warning when a threat is identified. The use of an auditory signal allows the driver to become aware of a potential hazard in the vehicle path if they have not yet recognised a threat which signals the development of DSA (Stanton et al. 2006; Stanton et al. 2015). This is important because the driver and Pedestrian AEB collaboratively form DSA. Even so, it seems unlikely that driver workload will be reduced as the OSD suggests that the driver completes the same processing as before, although the complexity of the task with the addition of a warning appears to increase. Importantly, the addition of a warning is not capable of telling the driver where the 'threat' is located, however, it may increase the efficiency of the search and alert the driver to task-relevant information.

Figure 3.5 represents Level 8 automation (Automated Decision Making) and shows that in addition to an auditory warning, Pedestrian AEB systems also incorporate an element of collision mitigation. At this point, there is some overlap between Level 4 and Level 8 automation. This is because if the driver fails to intervene and a collision is considered to be imminent, Pedestrian AEB is capable of performing an emergency stop, thus automating the decision making process. This also confirms that the "automation pathway" is not a stepwise process. A combination of Endsley & Kaber's (1999) definition of Automated Decision Making and Supervisory Control sees Level 8 automation capable of generating, selecting and implementing strategies. For pedestrian detection, the nature of the interactions outlined in Figure 3.5 show that workload is weighted more heavily towards Pedestrian AEB rather than the driver. At Level 8 automation, the main role of Pedestrian AEB is to monitor the behaviour of the driver and intervene when collision risk thresholds have been reached. The main priority is to mitigate the effects of collision.

Although Pedestrian AEB as a single system will not be a candidate for full automation, it seems likely that a complex synergy of multiple subsystems may incorporate an element of hazard detection. Assuming that the blend of subsystems allows for the automation of braking and steering inputs, the OSD presented in Figure 3.6 may offer an insight into how "hands and feet free" driving may impact upon the interactions that take place across the driving system (representing Level 10 automation). Figure 3.6 represents Level 10 automation (Full Automation) of the pedestrian detection task. Unlike Level 8 automation, Level 10 automation sees the monitoring roles become reversed. Rather than the Pedestrian AEB being responsible for monitoring the behaviour of the driver, the driver's primary role within the driving system at Level 10 is to monitor the behaviour of Pedestrian AEB and the other systems in which the automation interacts. A fully automated pedestrian detection sub-system would essentially delegate the task of 'braking' and 'steering' in emergency situations to the automated subsystem. The driver would essentially become a passive monitor of vehicle sub-system behaviour and therefore become "out of the loop". However, in contrast to Endsley & Kaber's (1999) taxonomy, in which full automation signals that the human operator is not able to intervene, this concept is currently less pertinent to driving because the driver remains the key actor in overall system safety (Brookhuis et al. 2003; SMART, 2010). Driver intervention at this level of automation may be caused due to a conflict in subjective imminent hazard perception. Where Pedestrian AEB may deem it safe for the vehicle to continue on its trajectory, the driver may wish to intervene. In this way, it seems that Pedestrian AEB may increase driver workload in unintentional ways, through increased vigilance demands, lack of feedback and a wider range of decision options (Brookhuis & de Waard, 2010; Parasuraman et al. 2000). The monitoring function of the driver at Level 10 grows in importance because in the event that Pedestrian AEB fails to (a) detect a vulnerable road user; (b) misjudge pedestrian trajectory; (c) misjudge vehicle trajectory (d) travel above speed thresholds; the driver must respond accordingly to changes in their environment. If failure does occur, driver vigilance of system state will play a key role in whether or not automation failure will be overridden successfully. The driver must maintain an awareness of how the system is behaving and continue to monitor their surroundings to ensure that the Pedestrian AEB is effectively detecting and recognising potential hazards. However, with Pedestrian AEB completing all information processing tasks independently, the driver may become vulnerable to boredom and/or fatigue resulting in episodes of mental under-load (Young & Stanton, 2002; Dehais et al. 2012). One approach to addressing the disintegration of control-feedback loops is to add a visual display to maximise the level of feedback provided to the driver. This would be in an attempt to keep the driver in-the-loop to some extent and promote active engagement with the sub-system.

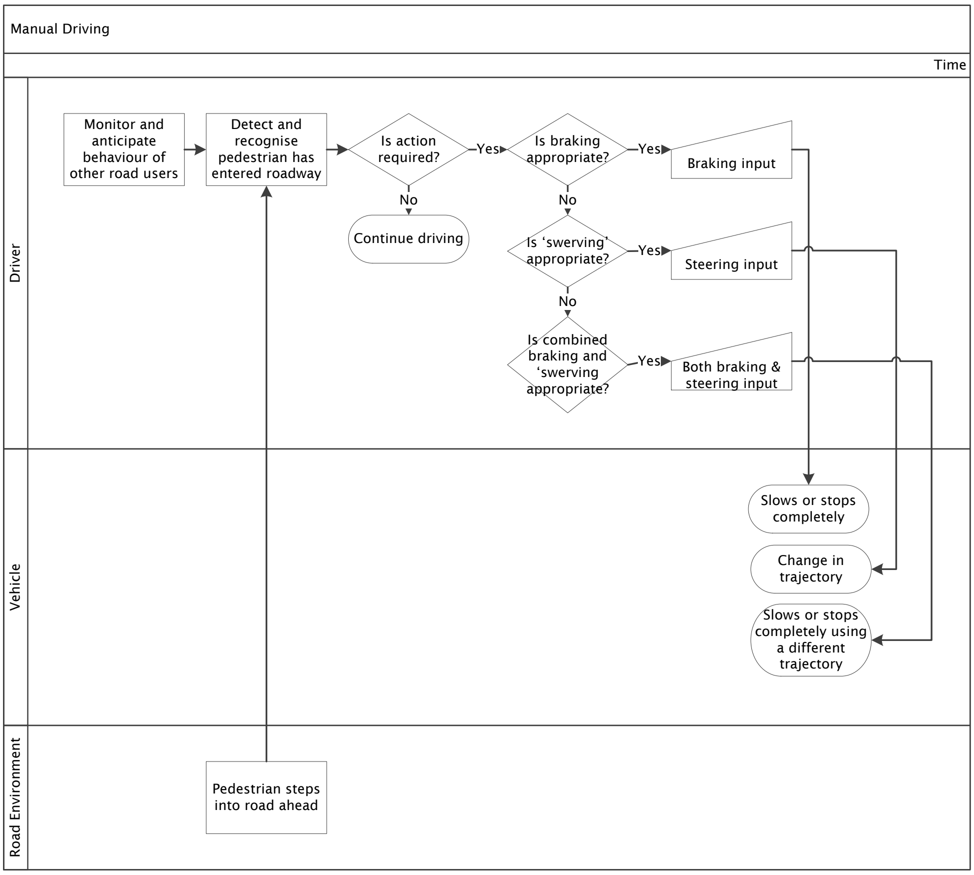


Figure 3.3. Manual Control of Pedestrian Detection (Level 1) assuming that the driver is alert and motivated.

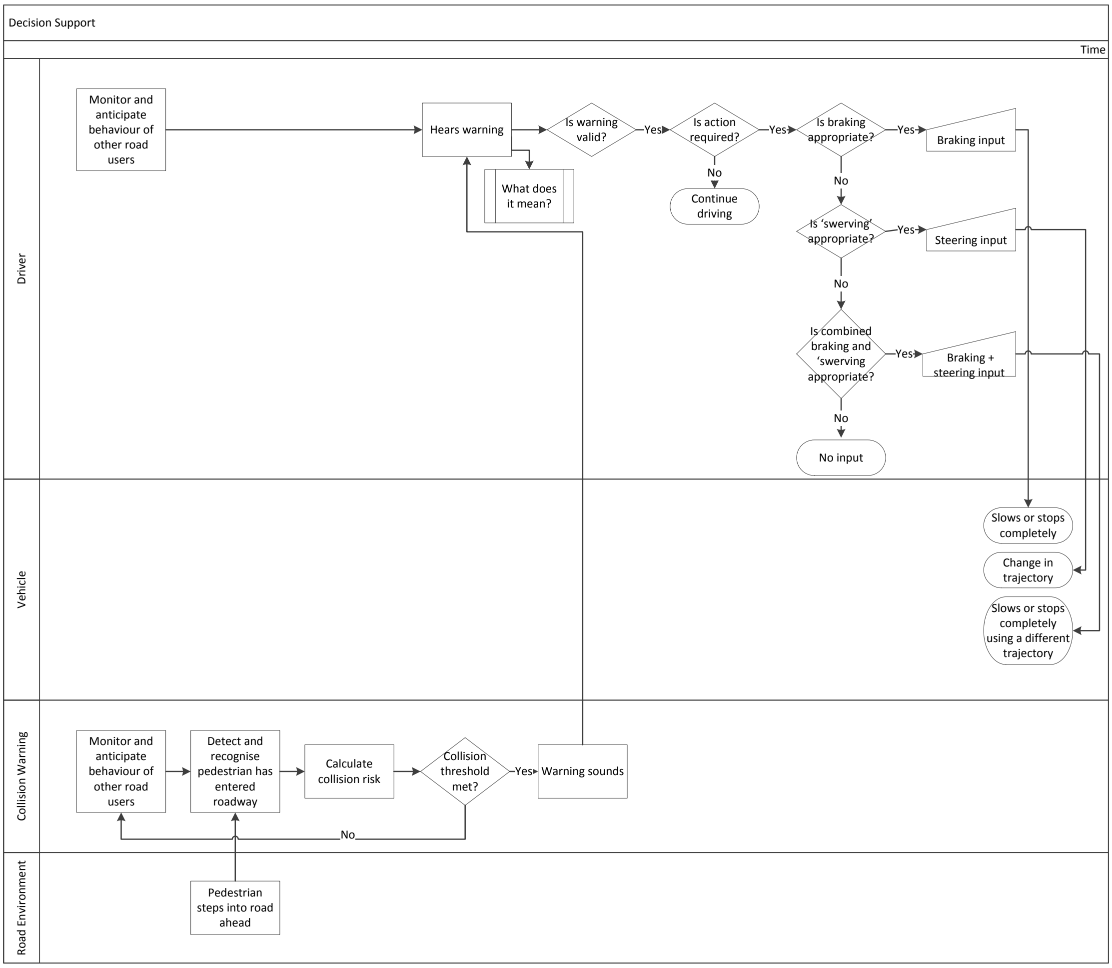


Figure 3.4. Decision Support in Pedestrian Detection (Level 4) assuming that the driver has failed to detect developing hazards

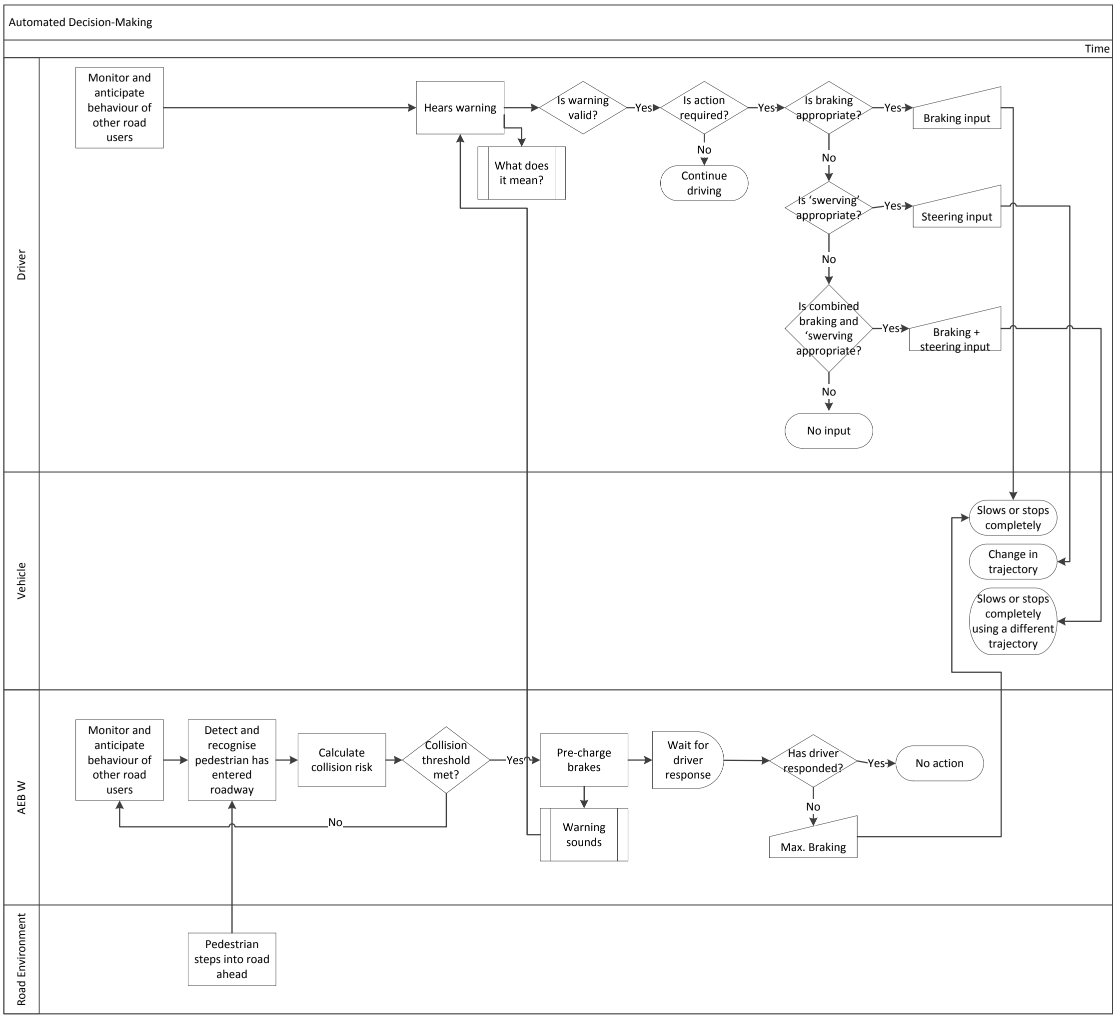


Figure 3.5. Automated Decision Making of Pedestrian Detection (Level 8) assuming that the driver has failed to detect developing hazards. Assumes AEB is coupled with an auditory warning

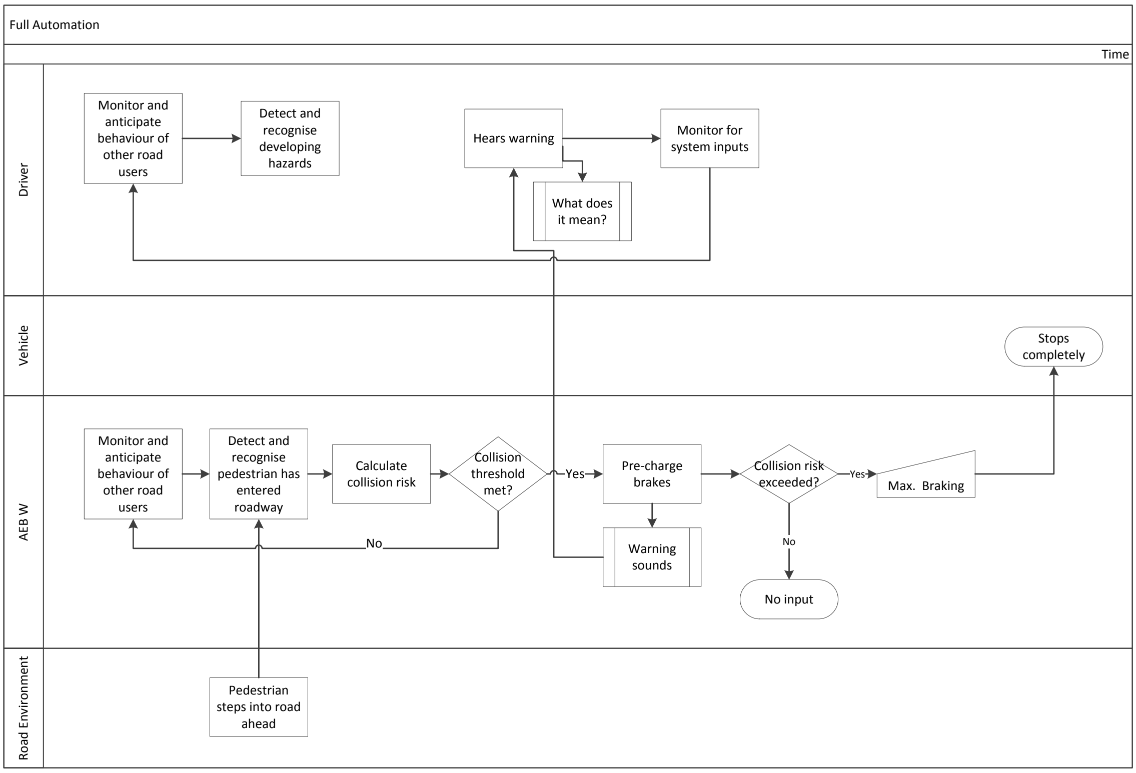


Figure 3.6. Hypothetical representation of full automation of Pedestrian Detection (Level 10)

3.4 Discussion

Although modelling exercises like this provide a useful insight into how introducing automation into the driving system may increase the complexity of the interaction that occurs within it, further investigation is required to establish 'how' this complexity is managed. In order to validate and extend the representation of OSD's, it is essential that these assumptions are experimentally tested through use of User Trials. Even so, OSD's are a valuable development tool that can offer a quick and effective way of visualising how a technology may impact upon overall system operation (Wallace et al. 2000). Although no one method is capable of representing the true complexity of the driving task, OSD's provide a good foundation for future investigation at the very early stages of system development.

Of course, with a rapidly changing and unpredictable environment, the interactions that take place are likely to be highly adaptable and not constrained to the processes outlined in this chapter and representational methods. Constraining complex behaviour into 'swim lanes' is of course limiting, yet offers reasonable approximation of Distributed Cognition within the driving system much like how Sorensen et al. (2011) dissected a cockpit environment. Although specific functionality issues were not represented due to its exploratory use of OSDs in representing Distributed Cognition in driving, as long as functionality issues are considered, OSD's may prove to be a useful Human-Machine Interface (HMI) design and allocation of system function tool in the development of future automated systems. What these methodologies do however demonstrate is that ironically, driver task loading does not appear to reduce with increased automation. Quite possibly workload will actually increase as the driver is required to monitor and anticipate the road environment, the behaviour of other road users in addition to the automated aspects of vehicle control synthesising the wider literature on malleable attention (Young & Stanton, 2002).

3.5 Future directions

System models are an invaluable resource but user trials are needed to validate them. With one of the greatest challenges remaining to be addressed surrounding whether or not the introduction of higher level automation into the driving task brings about any performance increments or decrements on behalf of the driver, chapter four focusses upon investigating the interaction that takes place between the driver and other system agents. This requirement is essential to ensure that automation implementation optimises overall system performance.

Chapter 4: Exploring the use of Verbal Protocol Analysis as a Tool to Analyse Driver Behaviour in Emergencies

4.1 Introduction

In order to improve the representation of Distributed Cognition in driving further, the OSD's presented in chapter three could make use of extension methodologies such as Verbal Protocol Analysis (VPA; Ericsson & Simon, 1993). Whilst OSD's can model the behaviour and interaction between system agents, VPA can offer a unique insight into the cognitive aspects of driver behaviour that could serve to validate the assumptions made within these OSD's. The purpose of this chapter is to identify processes and procedures that may be useful for future research in developing our understanding of the driver's role within the driving system. It therefore represents the link between Phase 1 (Modelling) and Phase 2 (Validation) of the Systems Design Framework (Figure 4.1).

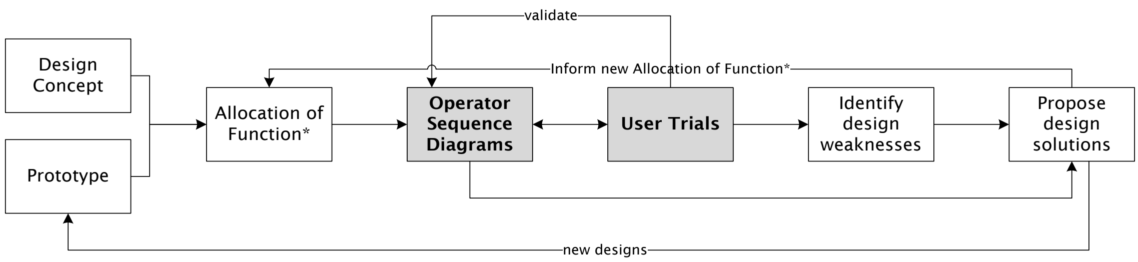


Figure 4.1. Aspects of the Systems Design Framework applied during chapter four as shown in grey

4.2 Analysing verbal protocols from drivers

Verbal reports offer a way to record the human thought process and are a key element in the analysis of decision-making (Ericsson & Simon, 1993). They have been widely used in a number of domains including nursing (e.g., Hoffman et al. 2009; Whyte et al. 2010), driving (e.g. Lansdown, 2002; Walker et al. 2011), software engineering (e.g., Hughes & Parkes, 2003) and the nuclear industry (e.g. Lee et al. 2012). When carried out using Ericsson & Simon's (1993) technique description, Russo et al. (1989) suggested that a rich dataset can be developed. In an extensive review of VPA methodology, Ericsson & Simon (1993) suggested that verbalisations give an insight into the contents of a person's working memory. Verbal reports therefore offer a way to reveal what a driver is thinking when they are completing a task, providing a real-time insight into the information that is used and the mental processes that are applied during the decision-making process (Hughes & Parkes, 2003).

There are two primary methods of VPA; concurrent think aloud and retrospective think aloud (Ericsson & Simon, 1993). Concurrent methods require the participant to provide verbal reports during their task performance whilst retrospective reporting is conducted immediately after a task is completed. Whilst concurrent data can be very interesting, Bainbridge (1999) argues that it still remains incomplete. Just because the subject fails to report something does not mean that they are unaware of it, or know about it. For this reason, retrospective verbal reports can be useful in supplementing concurrent protocol data by enabling direct exploration of the subjects' knowledge (Bainbridge, 1999). Both concurrent and retrospective protocols have their own benefits and drawbacks (van den Haak et al. 2003). These are summarised below;

Concurrent verbal protocols are often an attractive methodology given that it is unobtrusive and from an information processing perspective, concurrent verbalisation requires "inner language" to be expressed from short term memory (Taylor & Dionne, 2000). This direct style of reporting is thought to elicit valid and reliable data as individuals are not able to edit and change their responses (Ericsson & Simon, 1993). However, concurrent verbal protocols are increasingly prone to reactivity resulting in either enhanced performance (due to a more structured approach to work) or poorer performance (resulting from changes to workload patterns) (Russo et al. 1989).

In contrast, retrospective recall can decrease reactivity (van den Haak et al. 2003). This is because drivers are given the opportunity to complete a task in their own time and performance is likely to be consistent with normal driving. Even so, this style of reporting should only be used for short task durations as lengthy tasks carry an increased risk of omission and constructions (van Gog et al. 2009). This could lead to increased rationalisation or false reporting (Taylor & Dionne, 2000). According to Ericsson & Simon (1993), there are a number of measures that can be taken in an effort to encourage valid and complete accounts. These include collecting retrospective accounts immediately following task completion and emphasising the importance of accuracy in reporting,

Many studies have combined the use of concurrent and retrospective verbal protocols and found them to enhance the reliability and validity of the data collected (see Taylor & Dionne, 2000 for a review). A combined approach provides insight into both the strategies used in problem solving and also the types of knowledge used to underpin response execution. This makes a combined approach in automated driving research very appealing, especially given its potential to generate new insights into driver-vehicle interaction at increasing levels of autonomy.

Ericsson & Simon (1993) describe three levels of verbalisation; first, simple vocalisation sees a reproduction of information directly (e.g., Pennington et al. 1995); second, additional translation of the thought process through recoding reflecting information that is reported from a different modality (e.g., information from other modalities such as vision); and third, an explanation of thought which requires further processing effort. Think-aloud verbalisations at levels one and two should not change the structure of thought processing if detailed instructions are used (Ericsson & Simon, 1993). The study in this chapter attempts to make use of verbalisations at Levels two and three; concurrent verbalisations are likely to produce verbalisations equivalent to level two whereas retrospective verbalisations will probe for explanation of thought and are therefore likely to produce level three verbalisations (e.g., van der Veer, 1993). It was anticipated that this mixed methods approach would provide a useful insight into what the driver was doing whilst navigating through a journey in addition to the insights that were provided by quantitative performance data.

4.2.1 Aims and objectives

This study used direct observation methods to capture the underlying processes that mediate driver behaviour in emergency situations. Approaching systems design in this way enables a deeper form of analysis capable of delivering a more informed insight into how drivers use information from the environment to guide their behaviour and how drivers may experience a journey differently. This study formed part of a pilot for a much larger investigation into a pedestrian detection system following on from chapter three. Its primary aim was to explore and evaluate the use of VPA in the analysis of driver behaviour by highlighting its potential to enhance quantitative datasets in revealing the effects of automation on driver behaviour using the Southampton University Driving Simulator (SUDS).

SUDS is a fixed base Jaguar XJ saloon linked to the STISIM Drive M500W Wide-Field-of-View System with Active Steering (Figure 4.2). It has three driving displays allowing for a 135 degree driver field-of-view. Using in-vehicle driving controls and high-resolution digital sensors, SUDS automatically records driving performance including speed, lateral position and headway. The driving simulator environment permits the investigation of driver behaviour in a safe and controlled manner, unlike on-road assessment that has significant ethical implications (de Winter et al. 2012). Driving simulation has been used extensively in other behavioural adaptation studies (e.g. Kaber et al. 2012; Stanton & Pinto, 2000; Stanton et al. 2001; Vollrath et al. 2011).

4.1 Method

4.1.1 Participants

Three participants aged 23 (driver 1), 24 (driver 2) and 24 (driver 3) were recruited to take part in this study for in-depth analysis. Participants held a full UK driving licence for 6, 7 and 8 years respectively. Participant age and level of driving experience was not considered to be a critical variable of manipulation as the primary aim of the study was to evaluate the use of VPA. Treating responses as individual case studies enabled the analysis of specific momentary behaviour in a singular manner (Hancock, 2003). Miller et al. (2002) recognised that individuals, and therefore individual drivers, perform their own personal, complex computations of cognition. Combined with VPA, this individualistic approach attempted to identify how drivers were using information to guide their behaviour. In this way, disparities in information processing could be highlighted.

Ethical permission to conduct the study was granted by the Research Ethics Committee at the University of Southampton.

Figure 4.2. Southampton University Driving Simulator Laboratory

4.1.2 Experimental design and procedure

This study used one simulated driving condition designed using SUDS. The driving scenario used in this study simulated Euro NCAP's testing procedures for Pedestrian Protection Systems. In line with the known functional limitations of these systems, the experimental driving scenario was restricted to an urban environment with a mix of curved and straight sections of road, opposite-flow traffic and parked cars on either side of the roadway. At various points along the route, five critical braking events took place that were based upon typical circumstances surrounding pedestrian accidents (Lenard et al. 2011; 2014). For example, pedestrians of varied heights and gender (STISIM Drive (SDL) pedestrian model indices 1-10) crossed from the kerb side with or without obstruction but required the driver to take intervening action in order to avoid a collision with them. The simulated travel speed of the critical pedestrian events was set to 4 feet/second as per the examples provided in the STISIM manual (STISIM Drive (SDL) – PED – Pedestrian) when the driver was within 30 meters of the pedestrian on the side of the road. The travel speed of the pedestrian ensured that the driver needed to take evasive action. For every one critical event, there were three non-critical events (Parasuraman et al. 1997; Lees & Lee, 2007) that consisted of pedestrians crossing the road ahead at a much greater distance. These non-critical pedestrian events were defined as pedestrians who were set to enter the vehicle path at 4 feet/second when the driver was within 197 feet of them. This means that in each driving condition, drivers were presented with 5 critical braking events and 15 non-critical braking events. The non-critical events did not require driver intervention.

Upon providing informed consent, participants received a 30 minute training session to familiarise themselves with the simulator controls and received training in providing verbal commentaries. All participants watched a short video clip offering an example of concurrent verbal protocol and listened to another example using an audio recording. This was considered to be an appropriate approach to training as learning by observation is a recommended learning technique (Bandura, 1986). Cognitive load research has indicated that being shown a worked example can prove to be very effective for novices (van Gog et al. 2008) and other research has used similar video-based training that allows participants to observe an expert completing a task whilst concurrently verbalising their thoughts (e.g., Wouters et al. 2008). Verbalisation during the simulated driving task involved the driver talking aloud about their thoughts, representing level two of the Ericsson and Simon (1993) taxonomy, whilst a retrospective report was designed to elicit level three verbalisation (explanation of thought processes) following task completion.

Following this induction, drivers were instructed to drive along the pre-defined route as described above and verbalise their behaviour. Verbal commentaries were recorded using a digital recorder and microphone in both concurrent and retrospective reporting. If verbal commentaries stalled, prompts were given to encourage the driver to continue talking for the duration of the simulated driving condition (approximately 10 minutes). At the end of the simulated driving phase, drivers were then asked to complete a retrospective verbal commentary from memory enabling the analyst to probe for further information using modified exemplar questions from the Critical Decision Method (Klein et al. 1989; Table 4.1).

Although it is acknowledged that the act of producing a concurrent verbal commentary may interfere with response execution in the driving task (e.g., may increase reaction times and affect braking behaviours, Ericsson and Simon, 1993), the primary purpose of verbal commentary collection in this study was to extend our understanding of driver behaviour. At this stage, the research was specifically interested in 'what' information the driver was using to guide their behaviour. It was not therefore a study assessing driver ability. In addition to the collection of verbal reports, SUDS recorded data relating to braking and steering inputs so that the analyst would be able to compare the verbal reports to what actually happened during the simulation.

Table 4.1. Critical Decision Method (CDM) probes used by analyst to generate insight into driver decision making

Probes	Associated Questions
Situation Assessment	Can you summarise what happened in these emergency events?
Cues	How did you know that a critical situation was occurring? What did you see or hear?
Generalisation	Were you reminded of any previous experiences in which a similar decision had to be made?
Basis	Can you tell me what strategies you used to avoid the pedestrian? What information did you use in making this decision and how was it obtained?
Options	Were there any alternative strategies you could have used, or thought about using? Why were these rejected?
Time Pressure	How much time pressure was involved in your decision making?

4.1.3 Data reduction and analysis

Verbal reports were initially transcribed and then segmented into identifiable units of speech. An initial coding scheme based upon the information processing functions outlined by Endsley & Kaber (1999) and later adapted by Banks et al. (2014a) was used to analyse the content of verbal commentaries. These functions included Monitor, Anticipate, Detect, Recognise, Select, Decide and Respond. Refinement of the coding scheme followed using a hybrid of top down (theory-driven) and bottom up (data- driven) approaches. The iteration process was repeated until the protocols were judged to be adequately categorised into the coding scheme. Four of the initial codes were utilised (Monitor, Anticipate, Detect, Response). The authors judged that “detect” and “recognise” were too similar for further analysis as verbal reports suggested that these functions occurred simultaneously. For example, “there is a pedestrian walking out” indicated that the driver was both detecting and recognising the hazard to be a pedestrian. For this reason, “Hazard Detected” was included in the coding scheme. “Select” and “Decide” were also omitted because they failed to ‘fit’ any of the verbal reports. There was no evidence in the verbal reports that suggested that responses were in any way planned or options rejected. The authors felt that the code “Response” captured this more clearly. The final coding schemes for concurrent verbal commentaries contained 8 categories (see Table 4.2 for description and examples).

Although different categories were used for retrospective verbal commentaries due to the inherent differences in the information recorded between concurrent and retrospective recall, there was some overlap between the coding schemes (see Table 4.3). For instance, definitions for “Evaluation” and “Rule Governed Behaviour” remained the same whereas “Response” in concurrent reports and “Reactive Response” in retrospective reports were very similar. In contrast to concurrent verbalisations that generated information regarding action, retrospective reports offered a greater insight into how decisions had been reached. Specific to retrospective reports were “Consideration of Alternatives” and “Evaluation of Alternatives” because concurrent reports failed to provide insight into any pre-decisional behaviour regarding choice of action. In addition, “Strategies” was also included in the retrospective coding scheme because the verbal reports suggested that rather than driving being a completely reactive task, drivers were using strategies to guide their behaviour (see Table 4.3). Again, refinement of the coding scheme was guided by the information available in the protocols. The iteration process was repeated until the protocols were judged to be adequately categorised into the coding scheme. Where in concurrent recall (i.e. level two: information from modalities) participants were able to freely discuss whatever came to mind, retrospective recall (i.e. level three: explanation of thought) probed for information regarding specific events within the scenario. The authors felt that it would therefore be inappropriate to use the same coding schemes to analyse the verbal commentaries.

Table 4.2. Coding scheme, for concurrent verbal commentaries (level 2) including description and examples

Code	Description	Examples
Monitor	Description of the route and the information used	"In the distance there is a …light control crossing or junction which is red" "Just checking my mirrors"
Anticipate	Statements referring to being aware of what will happen and taking action to be prepared	"Lights ahead at a junction have just turned amber so anticipating having to stop" "Just coming into a town...so I'm going to begin to slow down"
Hazard Detected	References to potential hazards within the environment	"There's a pedestrian on the side of the road" "Pedestrians on my left hand side after the lights and parked cars either side"
Response	Statements describing what the participant is doing to cope with hazards only	"I have swerved" "I've just had to slam on the brakes"
Justification	Statements giving a reason for a certain choice or action	"(I have swerved) to narrowly avoid them" "…wasn't in any danger in terms of my speed"
Evaluation	Statement evaluating previous actions, choices or information	"…not paying attention" "Thankfully missed the pedestrian" "Managed to stop in time…"
Rule Governed Behaviour	Statements reflecting lawful driving	"…now waiting for the lights to change"
Interaction with vehicle	Statements relating to use of vehicle instruments (not related to intervening action) but inclusive of steering, braking and gear change	"Changed to second gear and accelerating" "First gear, changing into second"

Table 4.3. Coding scheme for retrospective verbal commentaries (level 3) including description and examples

Code	Description	Examples
Awareness	Observational statements giving insight into driver awareness	"Cues from the road and surrounding area so traffic lights and such" "Increased risk of something happening I guess"
Knowledge Based Behaviour	Statements referring to previous driving experience	"I was watching those pedestrians carefully because they were in full view and I was aware of the potential for them to walk out" "…I knew that I needed to brake as that's how you slow down"
Rule Governed Behaviour	Statements reflecting lawful driving	"To navigate through the town safely and obey the laws of the road"
Strategies	Statements describing what the participant did to cope with hazards	"I tried to anticipate them approaching"
Reactive Response	Statements referring to the pressure of action	"It's just one of those oh my God, I need to stop…."
Evaluation	Statement evaluating previous actions, choices or information	"There was only one issue and that was not reacting [quickly] enough"
Consideration of alternative strategies	Statements referring to possible alternative strategies	"Obviously you're trying to avoid a pedestrian and I think you have to decide whether braking or swerving will work…"
Evaluation of alternative strategies	Statement evaluating the success of alternative strategies	"I think most people would swerve because your hands are already on the steering wheel whereas your feet are concentrated on the accelerator and it may take more time to find the brake…"

4.2 Results

4.2.1 Frequency of observations

Figure 4.3 indicates that the total number of observations made during concurrent reporting was far greater than those made in retrospective reporting. This is a trend often reported in the literature because retrospective reports require the driver to retrieve information from their long-term memory (Camps, 2003; Ericsson & Simon 1993; van Gog et al. 2005). Concurrent verbal reports seem to provide a more complete representation of cognition in real-time (Ryan & Haslegrave 2007; Whyte et al. 2010).

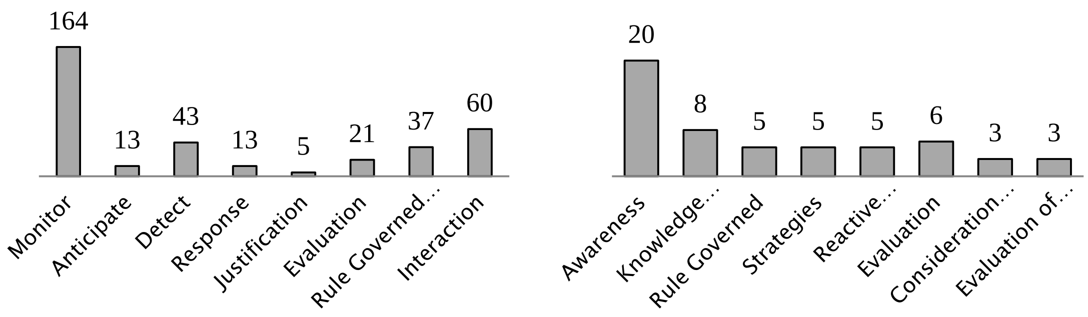


Figure 4.3. Total code occurrence for concurrent (including both critical and non-critical events) and retrospective (critical events only) reports

It is clear that the execution of the retrospective recall failed to deliver the richness of information that was expected despite using exemplar questions from the CDM. This may be due to limitations in accessing information from long-term memory following a ten minute task (e.g. drivers were unable to recall their thoughts of individual events post-trial). Ericsson & Simon (1993) suggested that this retrieval failure results from similar memory structures for multiple events being accessed rather than the cognitive processes for a single event being recalled. It is contended that the probability of retrieval failure increases if an individual completes a series of similar problems in a short space of time (Ericsson and Simon 1993). Even so, retrospective insights were included in this chapter because they were still very interesting.

Concurrent VPA suggests that driver monitoring is the overarching function that determines the pattern of subsequent processing (e.g. pedestrians who were obscured from view compromised the ability of the driver to both anticipate their movements and detect them). This supports the 'Information, Position, Speed, Gear and Acceleration' (IPSGA) system of car control approach outlined by Stanton et al. (2007b). The IPSGA system is loosely tied due to the dynamism of potential hazardous events. Each element of the IPSGA can be viewed as an underpinning behaviour of car control. Much like the researcher here, Stanton et al. (2007b) placed emphasis upon adaptive application of these system elements rather than a rigid sequence of behaviour (see Figure 4.4).

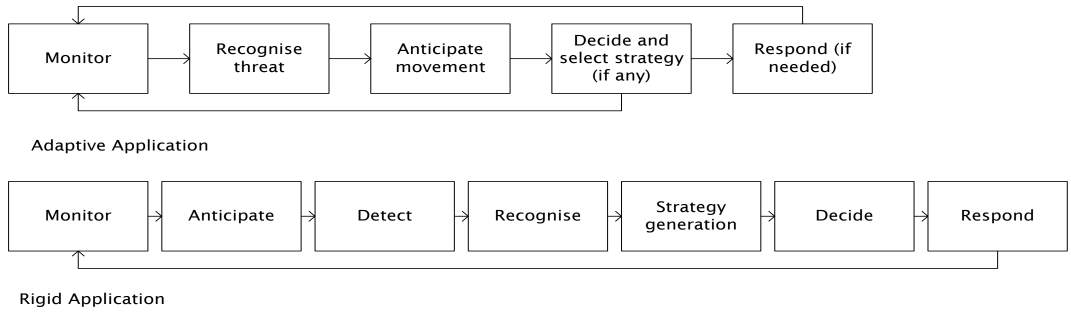


Figure 4.4. Adaptive versus rigid application of control elements

In this way, driving schemata (cf. Neisser 1967) guides monitoring behaviour that can assist in the interpretation of information presented in the wider environment and lead to subsequent action (see Table 4.4 for examples). These statements show that drivers were anticipating that a hazardous situation may arise based upon the demand of the task at specific moments in time. Pedestrian detection especially reflected a more adaptive approach to information processing, as drivers repeatedly recognised the threat and anticipated having to respond in some way. Additionally, it would also appear that driving behaviour was also being guided by top-down influences that were external to the driving task under simulation (pedestrian detection). For example, drivers slowed for all traffic signals and appeared to have an obvious desire to maintain speed limit boundaries. Reflective statements within retrospective reports offered unique insights into the cognitions:

> "I like to know how fast I'm going [because] I'm one of those people that will get caught speeding . . . ."

Reflective statements within retrospective reports also offered an important opportunity to make inferences about driver decision-making throughout the driving task. For instance, when participants were asked about strategies to avoid pedestrians during retrospection, one respondent reported (in reference to non-critical pedestrian events):

> "I knew I wasn't going fast enough to ever hit them . . . ."

This statement suggests that the driver was performing some form of risk assessment that was not obvious in the concurrent report.

Table 4.4. Examples of Adaptive Application

Concurrent	Retrospective
"…just coming into a town now…so I'm going to slow down a bit…" *"Can still see a lot of pedestrians on the pavement so I'm just going to be mindful"*	*"…I was more cautious when I was driving through the town because there was lots going on"* *"I tried to anticipate them approaching and then when I did see that someone was pulling out or crossing the road I tried to put on the brakes"*

4.2.2 Extending performance data with verbalisations

Despite not being able to prove or disprove what a driver is actually thinking, it is possible to relate the verbal reports collected as part of this study to a step-by-step breakdown of the built scenario and performance data generated by SUDS. Driving performance data recorded by SUDS is presented in Figures 4.5-4.7. These figures represent the speed and braking profiles of the three participants with annotations taken directly from their associated verbal reports. Responses to critical braking events are characterised by peaks in longitudinal acceleration due to braking. Other braking events throughout the journey can be attributed to red traffic signals that were included for realism. Logged pedestrian collisions indicate that all three drivers were involved in at least one collision throughout the experiment. Using hard data alone is however unable to provide any more insight into "how" or "why" collision occurred. The benefit of collecting verbal commentaries is that an insight into contributory factors can be attained.

The VPA relating to Figure 4.5 generated insights into possible contributory factors in the pedestrian collision both concurrently and in retrospection. Despite making five distinct braking attempts distinguished by the sharp peaks in longitudinal acceleration due to braking, one of these attempts resulted in collision with a pedestrian. Looking at the quantitative data alone does not give any insight into possible cause. After all, the peak at critical braking event 5 does not appear to differ from the others. However, the data available in the retrospective VPA suggests that driver reactions could have been slower for this particular event;

> "…I did spot the hazard. I just wasn't reacting quickly enough. There wasn't a lot of time between identifying the hazard and being able to stop in time"

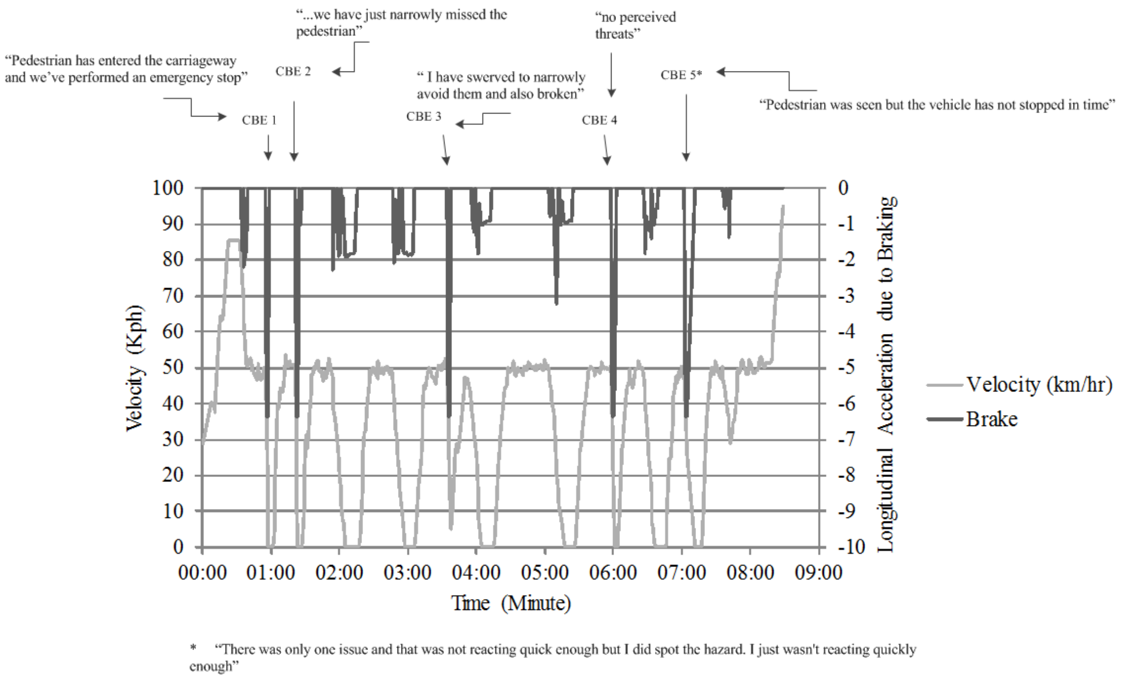


Figure 4.5. Driver 1 profile of speed and braking behaviour (* pedestrian collision)

According to the verbal commentary relating to Figure 4.6, it seems likely that resource conflict for visual attention between the instrument cluster (Eyes Down Display) and road scene (Eyes Up Display) was the causal factor in the collision that occurred at critical braking event 5. This conflict may have resulted in the driver not responding to the pedestrian event as evidenced in Figure 4.6 that shows no braking response was recorded. Although we want drivers to be aware of their speed, especially in highly populated urban environments, resource conflict occurred at a critical time. With less attention being paid to the Eyes Up Display (road environment), there was a failure to detect the pedestrian and hence resulted in a "no response". In this way, normal driving tasks (i.e. checking speed) appears to have been a cause of distraction for the driver. Without recording concurrent verbal reports, this information would have been lost. However, this information may be useful to inform the design of a warning system that can alert the driver to a potentially critical situation if the automation detects that the driver is not looking at the road ahead.

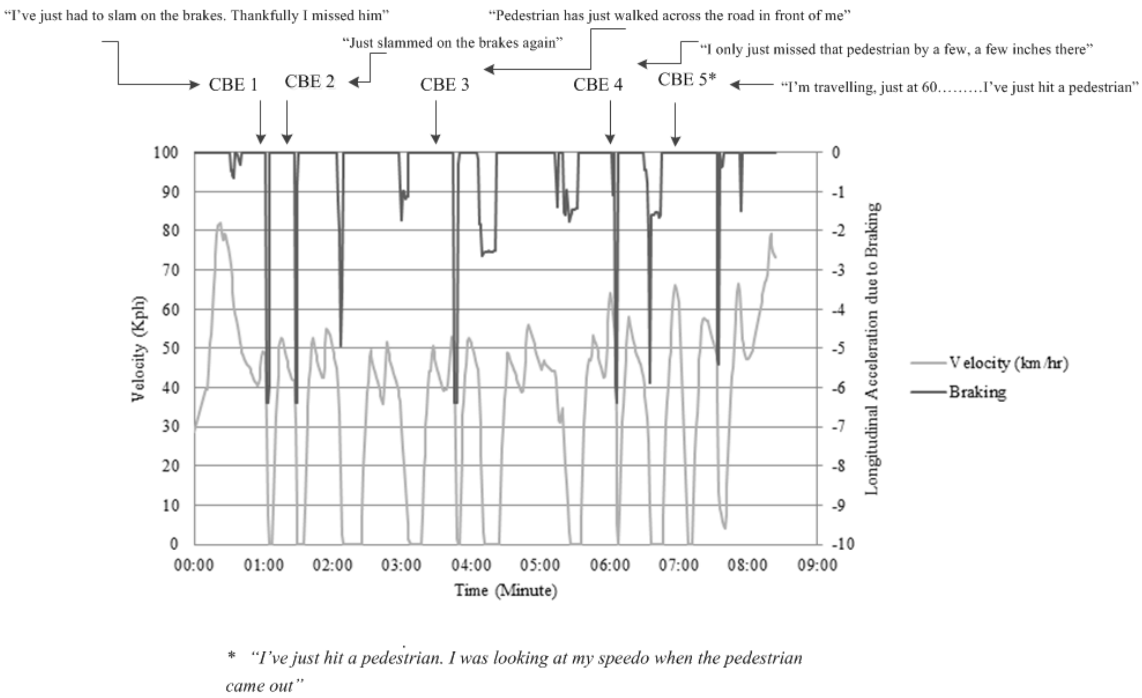


Figure 4.6. Driver 2 profile of speed and braking behaviour (* pedestrian collision)

In contrast, the verbal commentary relating to Figure 4.7 indicates that pedestrian collisions at critical braking events 1, 2 and 3 may have been a result of inadequately controlling the braking function. A comparison of Figures 4.5-4.7 indicates that longitudinal acceleration due to braking in critical braking events varied greatly. Where Figures 4.5 and 4.6 show that longitudinal acceleration due to braking in critical braking events ranged between -4.92m/s^2 and -6.37m/s^2 (average -6.20m/s^2) and -5.93m/s^2 and -6.37m/s^2 (average -6.27m/s^2), respectively, Figure 4.7 clearly demonstrates smaller peaks of longitudinal acceleration. Typically, the profile for driver 3 shows an average range of -4.71m/s^2 for longitudinal acceleration due to braking. This suggests that rather than insufficient driver monitoring or inattention, pedestrian collisions were a result of failure to manipulate vehicle controls appropriately with some evidence provided during retrospection. This failure to operate the vehicle controls effectively implicates the overall design of the experiment (see discussion).

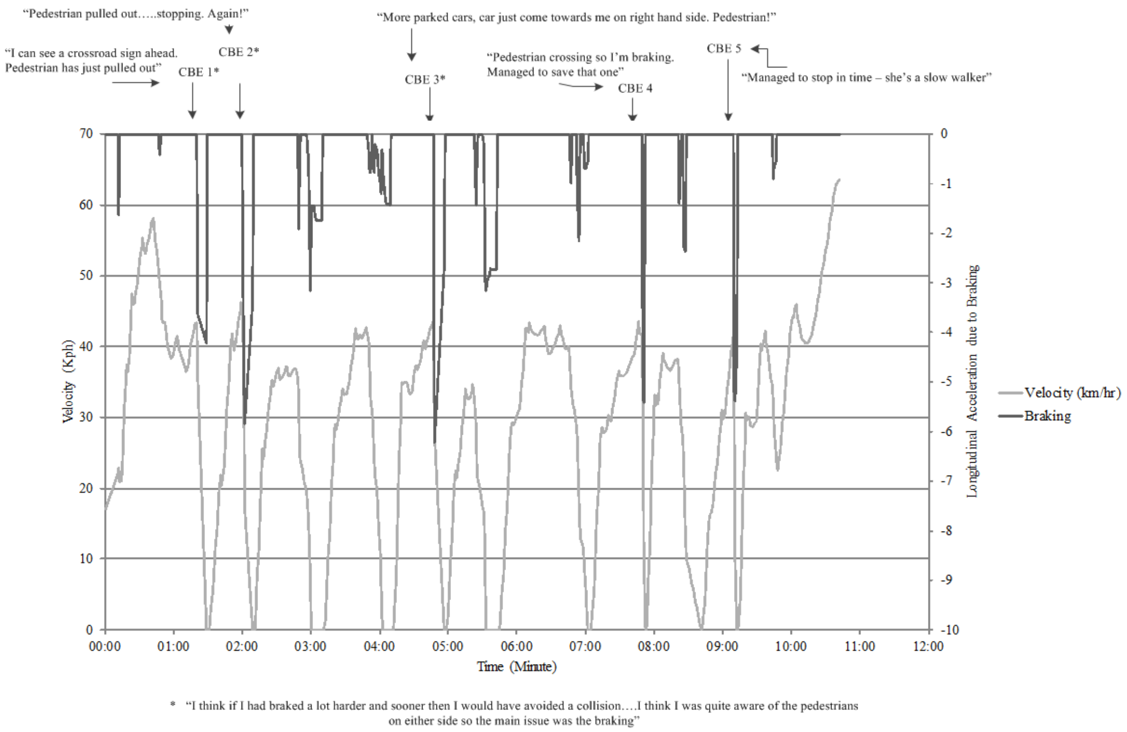


Figure 4.7. Driver 3 profile of speed and braking behaviour (* pedestrian collision)

4.3 Discussion

This study has shown the potential of VPA to act as a useful extension methodology in the validation and enhancement of quantitative data obtained using SUDS. The combination of VPA with driving simulation provides the opportunity to record complex behavioural responses in addition to information relating to driver-vehicle-world interactions in a much more overt manner than simulator data alone. As Underwood et al. (2011) argue, it is becoming more appropriate to include an assessment of higher level cognition in addition to perceptual-motor measures often reported in simulator studies.

Although the use of verbal reports measures are highly debated in cognitive psychology (e.g., Nisbett & Wilson, 1977; Baumeister et al. 2007; Boren & Ramey, 2000; Ericsson, 2002; Jack & Roepstorff, 2002), the method delivers a richness of information that would otherwise be inaccessible by any other form of data collection. For example, the use of eye tracking systems can only reveal visual scan patterns and foveal fixations, and although these can offer an accurate indication of where a subject is looking, they are not able to indicate if the participant is attending to an object with specific regard or thinking about something else (Lansdown, 2002). Quantitative data alone is also not enough to provide insight into the cognitive elements of the driving tasks and the researcher concludes that VPA can highlight issues surrounding driver error. In this study, pedestrian collisions were a result of reacting too slowly (driver 1), resource conflict (driver 2) and insufficient control manipulation (driver 3). Without VPA, this data would not have been available.

The benefit of collecting verbal reports pre-automation is that we can begin to understand the knowledge base of the target population (van Gog et al. 2008) and use this as a tool to guide development for more effective systems design. Designing a system that is capable of addressing these individual forms of error, for an identical task is certainly a long and enduring challenge for system designers.

4.3.1 Practical recommendations for future research

Whilst it can be concluded that the use of retrospective verbal commentaries went some way in validating the data provided by SUDS and information presented in concurrent verbal reports, it is acknowledged that a key weakness in the experimental design of this pilot study was the execution of retrospective probing. In order to address issues of retrieval failure, it is recommended that a "freeze probe" technique is adopted. This involves freezing the simulation immediately after a critical braking event so that drivers can be probed specifically about the event that just occurred. In contrast to the Situation Awareness Global Assessment Technique (SAGAT; Endsley, 1988) that has traditionally used a blank screen when simulation has been 'frozen', the author proposes a 'pause' within simulation allowing the driver to view the scene in front of them. It is hoped that using this approach and exemplar questions from the CDM outlined in Table 4.1, it will be possible to uncover specific events and actions that led to the behavioural outcome observed for each critical braking event. This momentary pause is likely to generate more information that can be used to analyse driver decision-making in the most crucial parts of the task as they can draw upon information from the environment. "Freeze probe" essentially allows for higher level analysis of individual critical braking events providing a means to explore the uniqueness of decision-making in emergency events. Thus, VPA holds some potential in uncovering thought processes underlying behavioural outcomes in emergency situations.

In addition, modification of the training that participants receive is required. It seems likely that drivers would benefit from an increased induction period to familiarise themselves with SUDS driving controls. This can be achieved by exposing participants to a longer 'practise drive' where they can navigate through a mix of curved and straight sections of road to address lateral and longitudinal control. The practise drive should also expose participants to some of the typical driving events that may occur during the experimental drive (e.g. pedestrians walking across the road and oncoming traffic). Participants should be instructed to perform an emergency brake manoeuvre three times once they reach the speed limit used in the experimental drive to familiarise themselves with the sensitivity of the braking system. This is in an effort to reduce or avoid any issue with control manipulation that driver 3 experienced. An increased induction period would also give drivers the opportunity to practise verbalising their driving behaviour more thoroughly.

To address concerns surrounding the use of concurrent verbal commentaries, it is recommended that a comparison of driving with verbal reports and driving without verbal reports is conducted. This means that drivers should be exposed to the same driving condition twice, easily achievable through looping the simulation. In the first half, participants should be instructed to verbalise their thoughts and analysts should freeze the simulation when a critical braking event occurs to conduct retrospective probing. In the second half of the driving condition, drivers should be instructed to 'stop talking' by the analyst. It is hypothesised that no significant differences in driving performance will prevail. However, this issue needs to be addressed in future work.

Finally, this study was a precursor for a much larger study into pedestrian detection and could therefore be criticised for its lack of data and insights. However, this study was an exploratory investigation to see whether or not VPA was an appropriate technique to analyse driver behaviour. In this way, the study has proved to be invaluable and a number of recommendations have been highlighted. Future work should make use of a larger sample size with greater age range.

4.4 Future directions

Chapter five builds on the work of chapter four by continuing to investigate driver decision-making in emergencies. A greater emphasis is placed upon how driver decision-making may alter depending upon the level and type of automation that is implemented into the driving system. It is hoped that the results of these investigations will reveal important Human Factors design considerations for future implementation.

Chapter 5: Contrasting Models of Driver Behaviour in Emergencies using Retrospective Verbal Protocols

5.1 Introduction

Although automated assistance in driving emergencies aims to improve the safety of our roads by avoiding or mitigating the effects of road traffic accidents, the behavioural implications of such systems remain unknown. This chapter introduces four models of Driver Decision Making in Emergencies (DDMiE) to investigate how the level and type of automation affects driver decision making and subsequent responses to critical braking events using evidence acquired from driver verbal commentaries and Network Analysis.

The purpose of this chapter therefore was to implement the second phase of the Systems Design Framework, highlighting issues within the potential design strategies used for a Pedestrian AEB system building upon chapters three and four (Figure 5.1).

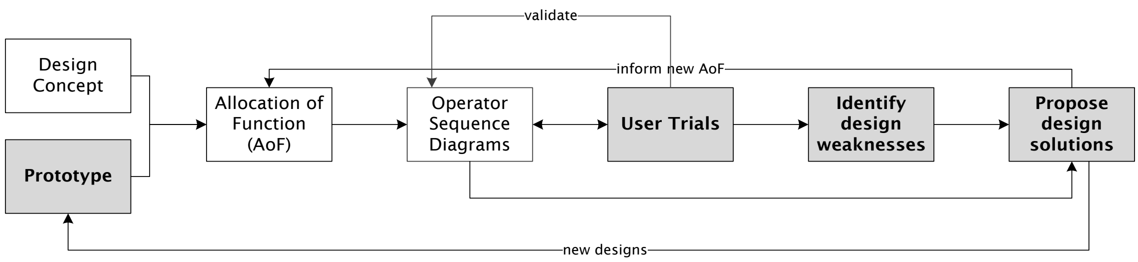


Figure 5.1. Aspects of the Systems Design Framework applied during chapter five as shown in grey.

5.2 Modelling decision pathways using VPA

It has long been suggested that driver decision making is a hierarchical paradigm that takes into consideration strategic decisions (e.g. route planning), tactical decisions (e.g. manoeuvring the vehicle) and operational decisions (e.g. executive acts) (Michon, 1985; Hollnagel et al. 2004). However, these high level descriptions fail to explicitly describe the processes underlying decision making. In order to understand how the introduction of automation into the driving task may affect the driver decision making process, more research is needed that looks specifically at the underlying processes that mediate behaviour. For example, Endsley & Kaber (1999) assigned the following information processing functions;

- System monitoring
- Strategy generation
- Decision making
- Response execution

to either the human operator with automated aid or as single entities. These were further adapted in chapter three to make them more applicable to driving by incorporating an anticipatory and recognition phase within information processing. The anticipatory phase takes into consideration the feed-forward mechanisms that occur within the driving task which are likely to be based upon previous experience whilst recognition provides a distinction between object detection and identification.

This study uses Network Analysis to interrogate retrospective verbalisations (Ericsson & Simon, 1993) to investigate how automation implementation using different design approaches may affect driver decision making and subsequent responses to critical braking events. Network Analysis and its associated analysis metrics are a potentially powerful technique to use in Systems Ergonomics due to their potential to explore network resilience in the design of anticipated networks in new systems (Stanton, 2014a). For example, if the links between information processing functions in driver decision-making are weakened or become severed as a result of automation implementation, it could signal that information processing may be less efficient. Whilst Network Analysis metrics have traditionally been used in the analysis of social networks (e.g. Driskell & Mullen, 2005), Houghton et al. (2006) suggest that the tool can be used to investigate decision making and the spread of information within a system.

5.2.1 Aims and objectives

The main purpose of the study was to compare and contrast different models of Driver Decision Making in Emergencies (DDMiE) using different levels of automation in the driving task. The basic model for the DDMiE is based upon the concepts derived from Endsley & Kaber (1999), Parasuraman et al. (2000) and Banks et al. (2014) into the allocation of system function between human operators and automation (Figure 5.2) with the addition of task relevant concepts relating specifically to automation (e.g. reliance on automation and recognition of automation engagement). The data generated from a large scale driving simulator study using SUDS and presented in this chapter, was used to validate and test the assumptions of this basic model. The solid lines within the DDMiE represent *expected* links between the information processing functions whereas the dashed lines represent expected *new* links within DDMiE as a result of introducing automated assistance into the driving task. Of course, there may also be a removal of links between information processing nodes as automation is introduced into the driving task. If this occurs, this may be represented by the removal of links resulting in a severed network. It is proposed that evidence within driver verbalisations will enable the analyst to validate and quantify the links between information processing functions within driver decision making.

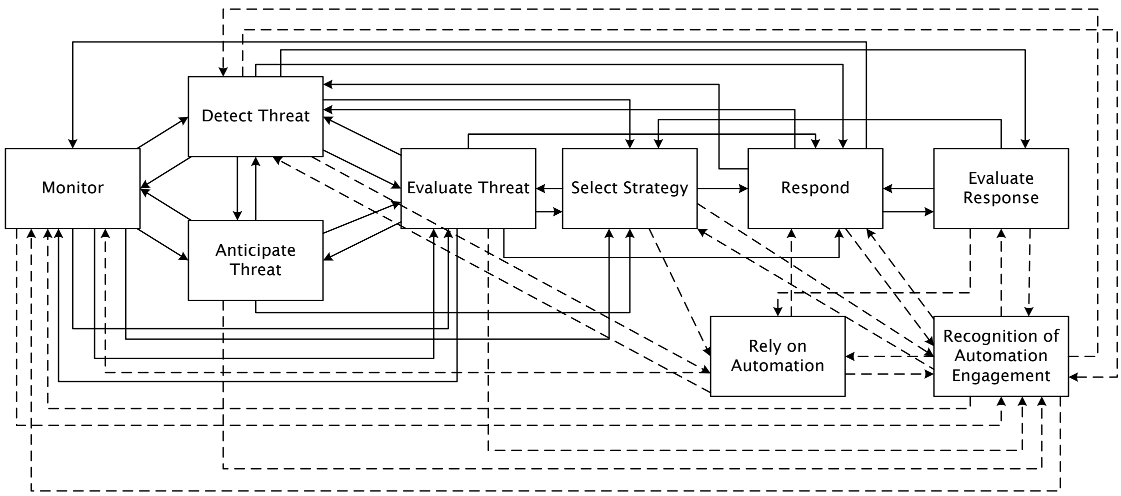


Figure 5.2. Proposed model of Driver Decision Making in Emergencies (DDMiE)

5.3 Method

5.3.1 Participants

A total of 48 participants were recruited from University of Southampton student and staff cohort. All participants held a full UK driving licence for a minimum of one year and were between the ages of 18 and 65. This was to ensure that the performance decrements associated with older drivers (i.e. over 65s) and novice drivers (i.e. drivers with less than 12 months driving experience) did not affect the results of the study.

Ethical permission to conduct the study was granted by the Research Ethics Committee at the University of Southampton.

5.3.2 Experimental design and procedure

This study along with the practical recommendations outlined in chapter four (section 4.5.1), made use of the same basic experimental design (section 4.3). Upon providing informed consent, participants received training in the provision of verbal commentary. Following this introduction to verbal commentary, participants were invited to take part in a 'practise drive' in SUDS where they were able to navigate through a mix of curved and straight road sections to familiarise themselves with lateral and longitudinal controls. During this time, participants were provided with examples of typical driving events that they may occur during the experiment (e.g. pedestrians walking across the road and oncoming traffic). They were also encouraged to manipulate the braking system to get used to the sensitivity of the braking system in an effort to limit any interference between control manipulation and verbalising their behaviour.

In total, drivers were required to complete four experimental runs that were designed to reflect three different levels of automation. These took into consideration the alternative methods of systems design implementation in the pedestrian detection task and were chosen for both their symmetry within Endsley & Kaber's (1999) taxonomy and relevance to the task;

- Manual (Level 1): A non-automated drive required the driver to complete all of the physical and cognitive tasks associated with driving without assistance.
- Decision Support (Level 4): A Warning made up of a visual (head-up) and auditory signal that could alert the driver to hazardous situations within their environment was developed to reflect Level 4 of Endsley & Kaber's (1999) taxonomy.
- Automated Decision Making (Level 8): An escalating warning approach that uses a warning to try and alert the driver to a critical hazard in the road ahead coupled with autonomous braking (AEB W).
- Automated Decision Making (Level 8): A non-warning based approach (AEB nW) that deliberately omits the use of a warning to alert the driver prior to autonomous braking.

Aside from the Manual driving condition that required drivers to complete all of the physical and cognitive tasks associated with driving, the remaining three automated driving conditions (Warning, AEB W and AEB nW) were designed so that drivers received assistance in the intervention of critical emergency events. These were defined as any event that without intervention would result in an accident. All three systems were designed using Visual Basic and were built to intervene in all critical emergency events regardless of driver intervention using a simple timing analysis (Table 5.1). This means that once active, AEB input would override any driver input. However, drivers were encouraged to respond as they normally would regardless of automation being present. Throughout the experiment, drivers were instructed to try and maintain a speed of 50 kilometres per hour (approximately 30 miles per hour) which is consistent with city driving in the UK.

Table 5.1. Automation Design Analysis

Speed (kph)	Speed (m/s)	Distance to Hazard on Warning Trigger (m)	Distance to Hazard on AEB Trigger (m)	TTC Warning Trigger (s)	TTC AEB Trigger (s)
10	2.78	4.55	2.84	1.64	1.02
15	4.17	7.12	4.54	1.71	1.09
20	5.56	9.88	6.48	1.78	1.17
25	6.94	12.83	8.65	1.85	1.25
30	8.33	15.97	11.05	1.92	1.33
35	9.72	19.31	13.69	1.99	1.41
40	11.11	22.84	16.57	2.06	1.49
45	12.50	26.56	19.68	2.13	1.57
50	13.89	30.48	23.02	2.19	1.66
55	15.28	34.59	26.60	2.26	1.74
60	16.67	38.89	30.42	2.33	1.83

In order for drivers to understand the functionality of each of these systems, participants were instructed to complete mandatory practise drives before each of the experimental runs. It was made clear that these systems would only intervene in critical emergency events and would be triggered autonomously. Trials were counterbalanced to remove order effects (see appendix A for all possible orders of presenting the four driving conditions to the driver).

The basic driving scenario for all driving conditions was identical to the one outlined in chapter four with practical recommendations considered (see section 4.1, page 50). Again, there were five 'critical braking events' and 15 non-critical braking events within each experimental drive. 'Critical' event locations were altered in an effort to reduce learning effects. Each experimental condition lasted for 10 minutes which although represents approximately half of the average journey time in England (e.g. Department for Transports

National Traffic Survey, 2013), reduces the risk of verbal omissions in retrospection (van Gog et al. 2008).

Throughout each experimental drive, participants were invited to verbalise their behaviour following critical braking events when asked by the researcher. To overcome issues of retrieval failure in retrospective probing, the simulation was paused directly following each critical braking event in an effort to generate greater insight into the most crucial parts of the decision-making task allowing for a much higher level analysis of individual emergency events. Using exemplar questions from the CDM (Klein et al. 1989), it was hoped that such a strategy would be better able to explore the uniqueness of decision-making in emergency events and how this may change as automation is introduced into the task. The researcher was primarily interested in capturing verbalisations at Levels two (translation of thought process) and three (explanation of thought) (Ericsson & Simon, 1993) with the freeze probe technique likely to capture both simultaneously.

5.3.3 Data reduction and analysis

Verbal transcripts were initially transcribed and then segmented into units of speech relating to critical braking events. An initial coding scheme was devised using a hybrid of top-down and bottom-up processes (Table 5.2). Inspiration was taken from the proposed DDMiE based upon Endsley & Kaber (1999), Parasuraman et al. (2000) and Banks et al. (2014).

Table 5.2. Coding scheme and examples used to analyse retrospective verbal reports

Code	Definition	Example
Monitor (M)	Acquire information from the environment relevant to perceiving system status	"Well the street scene widened out and I noticed that this pedestrian was standing back from the white line."
Detect Threat (DT)	Recognition of potential hazards within the environment	"But there was also another pedestrian a bit beyond him…."
Anticipate Threat (AT)	Being aware of what will or may happen in the future	"I thought he was going to cross…."
Evaluate Threat (ET)	Statement evaluating the risk that perceived threats may hold	"…I kind of evaluated them as a threat and then took action based on that…"
Select Strategy (SS)	Deciding on a particular option or strategy	"…I had a bit more time to brake"
Respond (R)	Implement chosen strategy *or* react to situation e.g. braking, steering	"I braked…"
Evaluate Response (ER)	Statement evaluating previous actions or choices	"…I felt I did enough, whether there was enough force on the brake I'm not 100% sure, but I felt I saw a lot quicker"
Recognition of Automation Engagement (RAE)	Statements reflecting an awareness of the presence of automation whilst driving	"…the first thing I saw was the warning, actually, rather than the pedestrian…"
Rely on Automation (RA)	Conscious decision to rely on automation during emergencies	"I decided not to brake. I wanted to test out the system…"

Units of speech were coded in a mutually exclusive and exhaustive way. This means that more than one theme could be applied to each data unit if appropriate (where one unit equalled one sentence). Only the first seven themes were relevant to the Manual control driving condition as the final two were only relevant to driving with automation. Five complete verbal transcripts (i.e. included verbalisations relating to all four driving conditions) were selected at random, and subject to further analysis by a secondary coder to calculate inter-rater reliability. This represented over 10% of the data. A score of 90% agreement was achieved between the coders meaning that the codes applied by the primary coder were accurately matched by the secondary coder 90% of the time.

5.4 Results

5.4.1 Frequency of links between information processing nodes

The decision-making pathways within driving emergencies (i.e. the connections between information processing functions) were defined as the sequential paths of coding within the verbal transcripts. For example, references to driver "monitoring" in the verbal commentaries may have been succeeded by references of driver "anticipation" and this would represent a link between the "monitor" and "anticipate" nodes within the DDMiE model. This may have then been superceeded by references to "detecting" a threat and this would represent a link between the "anticipate" and "detect" nodes within the DDMiE. A total of 960 emergency situations were analysed in this way; with 240 in each driving condition. Figures 5.3-5.6 represent the different DDMiE's for each experimental condition with associated links being annotated by the frequency data generated from interrogation of verbal commentaries. Thicker lines simply indicate an increased number of ties, known as edges, between nodes (Benta, 2005). The DDMiE models capture the idea of 'adaptive application' of information processing (Stanton et al. 2007b) indicating that decision making is not a rigid, one-way process. The DDMiE models also clearly indicate that the strength of linkages between information processing functions within driver decision making become significantly weakened as a result of automation implementation. For example, Figure 5.3 represents the model of DDMiE for driving under manual control. This means that the driver received no assistance within the driving task and was responsible for completing all of the information processing functions involved in driver decision making.

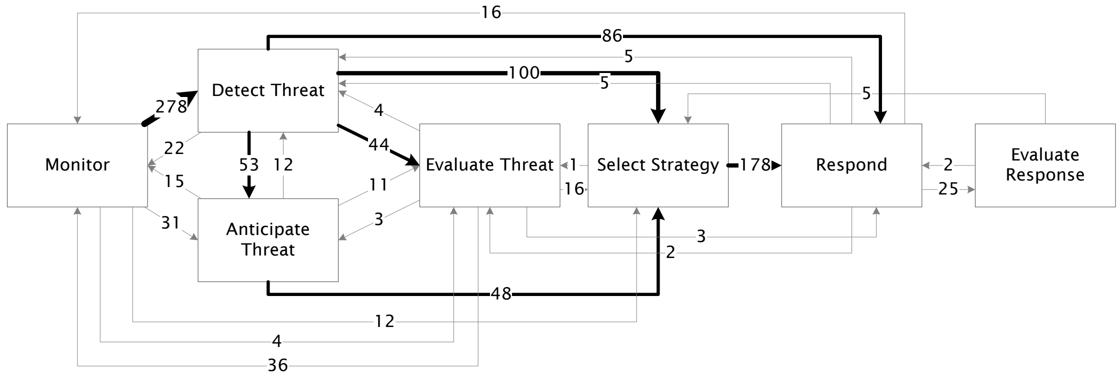


Figure 5.3. DDMiE for Manual driving showing the frequency of links between information processing nodes. Thicker lines represent the strongest links within the model.

In contrast, Figures 5.4-5.6 indicate that both the level and type of automation significantly affect the formation of the DDMiE models as evidenced by the introduction of new links within the decision making network (represented by the dashed lines).

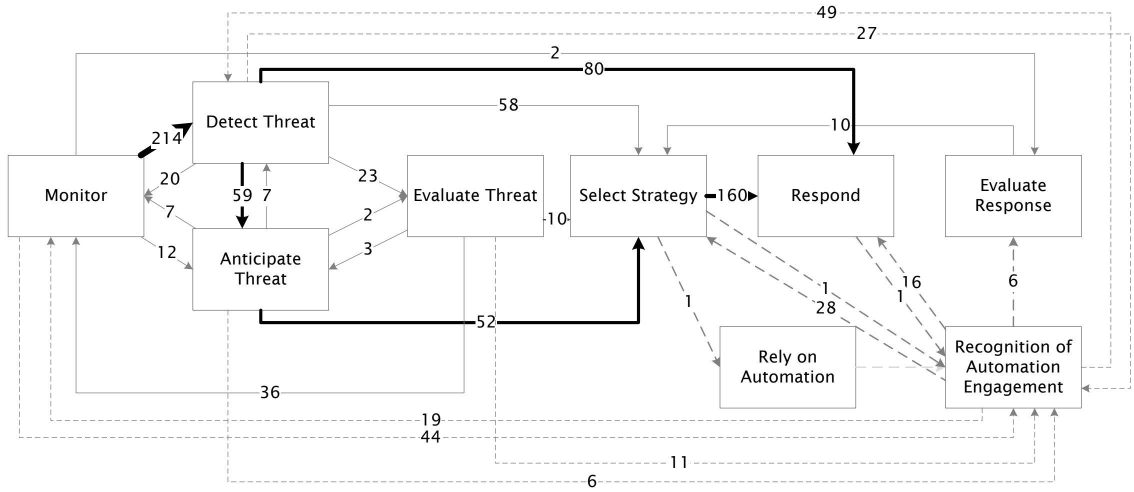


Figure 5.4. DDMiE for driving with assistance from a Warning (e.g. visual and auditory) showing the frequency of links between information processing nodes. Thicker lines represent the strongest links within the model.

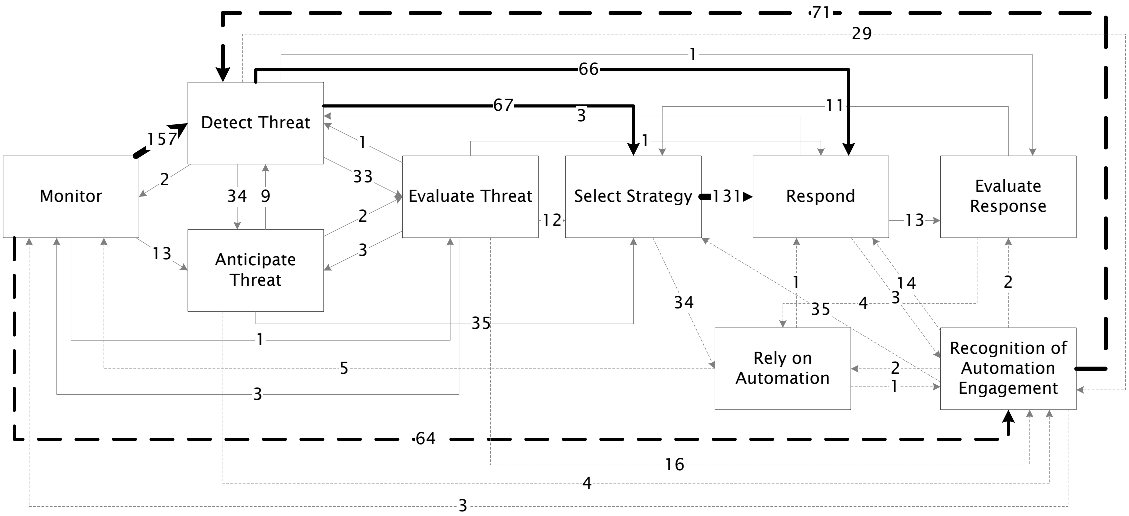


Figure 5.5. DDMiE for driving with assistance from AEB W showing the frequency of links between information processing nodes. Thicker lines represent the strongest links within the model.

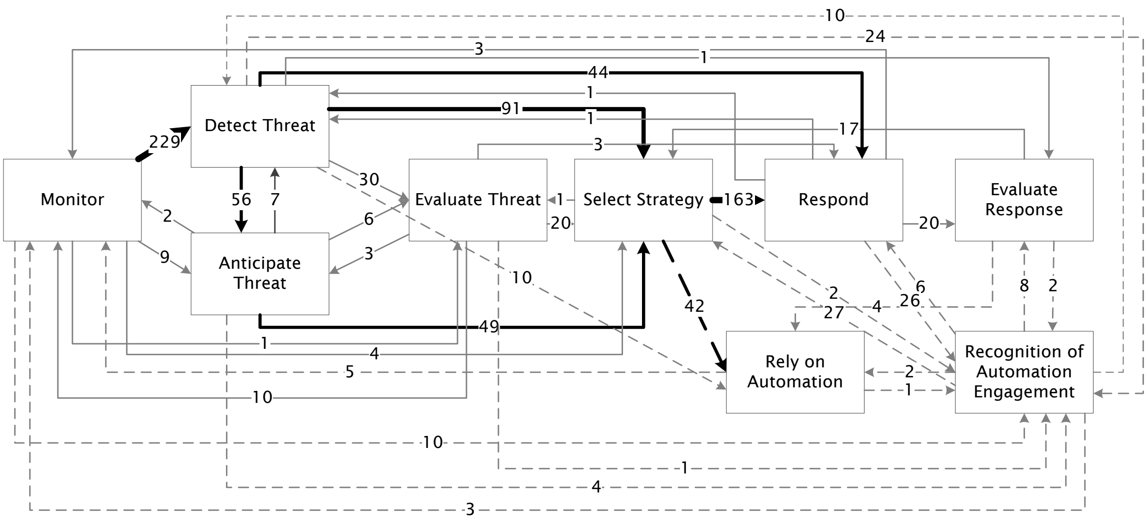


Figure 5.6. DDMiE for driving with assistance from AEB nW showing the frequency of links between information processing nodes. Thicker lines represent the strongest links within the model.

5.4.2 Network analysis

Whilst in its simplest form, a task network such as those represented in Figures 5.3-5.6, can be used to represent how nodes are connected to provide a qualitative overview of the network using directional arrows indicating communication frequencies, the network can also be represented as a matrix of association meaning that quantitative metrics can be applied directly to the data (Houghton et al. 2006). In order to understand the differences in network dynamics of individual DDMiE models, further analysis using the following network metrics that have been previously used in the driving domain were calculated using the Applied Graphic & Network Analyses package (Agna™, version 2.1; Benta, 2005; Salmon et al. 2009; Walker et al. 2011);

Network Density;

Represents the level of interconnectivity between nodes. It is expressed as a value between 0 and 1. A score of 0 represents a network that has no connections between nodes whereas a score of 1 represents a fully connected network (Kakimoto et al. 2006). Higher scores indicate an enhanced level of system awareness as there are a greater number of links between nodes (Walker et al. 2011). The formula for network density is presented below (adapted from Walker et al. 2009);

Network density = $\frac{2e}{n(n-1)}$

Network Diameter;

Network diameter is used to analyse the connections and paths between nodes within the networks (Walker et al. 2011). Greater diameter scores reflect an increased number of nodes within the network whilst denser networks have smaller values. Smaller values simply reflect that the route through the network (e.g. from driver monitoring to subsequent response) is shorter and more direct. It is calculated using the following formula (adapted from Walker et al. 2009);

Diameter = $max_{uy} d(n_i, n_j)$

Network Cohesion;

The cohesion of a network represents the number of reciprocal connections divided by the total number of possible connections (Stanton, 2014a).

Sociometric Status;

Sociometric status, rather than analysing the entirety of the system network, focusses upon the analysis of individual nodes and gives an indication of node prominence within the system network as a communicator with others in the network (Houghton et al. 2006). It is calculated using the following formula;

Sociometric Status = $\frac{1}{g-1} \sum_{j=1}^{g} (x_{ji}, x_{ij})$

where g is the total number of nodes in the network, i and j are individual nodes and are the edge values from node i to node j (Salmon et al. 2012).

Nodes with high sociometric values are highly connected with other nodes within the system network whereas nodes with low sociometric status values are likely to reside on the peripheral edges of the network (Salmon et al. 2012).

Table 5.3 presents the results of the Network Analysis conducted using AGNA™. All four of these networks can be described as weighted (i.e. non-uniform) and non-symmetric (i.e. directed). As to be expected, the size of the network increased as the level of automation increased as evidenced by the increased number of nodes and edges.

Table 5.3. Contrasting Network Metrics for different DDMiE models based upon AGNA™ analysis

	Manual	**Warning**	**AEB W**	**AEB nW**
Number of Nodes	7	9	9	9
Number of Edges	31	34	43	41
Network Density	0.74	0.47	0.60	0.57
Network Diameter	2	4	3	3
Network Cohesion	0.62	0.22	0.36	0.36
Number of Links	1017	964	886	958

It indicates that the Manual DDMiE model is the most densely connected network whereas the Warning DDMiE model represents the least densely connected. It seems likely that the effectiveness of the decision making process will be based upon strong inter-connectedness between information processing nodes meaning that these findings suggest that a Manual DDMiE model is the most desirable system network to adopt. However, with mandatory fitment of AEB (European Parliament and the Council for the European Union, 2009) over the next few years, it would appear that the most desirable system configuration to adopt is AEB W as this represents the strongest interconnected network after Manual driving.

Table 5.3 indicates that less 'hops' were required to get from one side of the network to the other within the Manual DDMiE model meaning that network diameter was smallest for Manual driving. However, the introduction of automation into the driving task leads to a slightly increased number of 'hops' meaning that additional complexity has been introduced into driver decision making and that the links between information processing nodes are weakened due to the size of the overall network.

Evidence from driver verbalisations suggest that the Manual DDMiE has more reciprocal links between information processing nodes in comparison to all other DDMiE models showing that it is the most cohesive (Table 5.3). The dynamism of the networks appears to change dramatically resulting in less reciprocal decision making models suggesting that the links between information processing nodes are significantly weakened as a direct result of automation implementation. This means that automation may lead to a noticeable change in the driver's monitoring and response strategies which can be seen clearly in Figures 5.4-5.6.

The sociometric status metric was used to identify key concepts within each DDMiE model with results shown in Table 5.4. For each network, any value above the mean sociometric status value (see Table 5.4) was identified as a key concept (Salmon et al. 2009). Based upon this rule, three DDMiE models (Manual, Warning, AEB nW) had identical key concepts underpinning driver decision making. These were "Monitor", "Detect Threat", "Select Strategy" and "Respond", yet importantly the strength of these nodes as evidenced by Table 5.4 significantly differ. Again, it is the Manual DDMiE model that consistently results in the highest scores on this metric. The same key concepts also apply to the AEB W DDMiE model in addition to Recognition of Automation Engagement which suggests that the way in which information was being processed by the driver had changed. Even so, the node that consistently achieved highest sociometric status was "Detect Threat" suggesting that this is the key node within all DDMiE models. Its prominence within all four models is unsurprising when considering that in order to respond to an emergency situation, the driver must detect that a threat is present. However, again, Table 5.4 indicates that its prominence does reduce as the level of automation introduced into the driving task increases. This may be attributed to the increased number of nodes within the system network or as a result of driver behavioural adaptation. For example, drivers may have been less likely to detect a hazard due to an increased reliance on automation functioning.

Table 5.4. Contrasting Sociometric Status for DDMiE models

Node	Sociometric Status of DDMiE			
	Manual	**Warning**	**AEB W**	**AEB nW**
Monitor	69.19*	41.00*	31.50*	33.75*
Detect Threat	102.00*	67.75*	60.50*	62.50*
Anticipate Threat	29.00	18.50	12.50	17.00
Evaluate Threat	20.66	7.00	9.00	9.50
Select Strategy	60.33	40.00*	40.88*	52.00*
Respond	53.17	35.89*	29.38*	33.25*
Evaluate Response	6.33	3.88	4.38	6.38
Recognition of Automation Engagement	-	26.00	30.63*	15.38
Rely on Automation	-	1.00	7.75	7.00
Mean Sociometric Status	**48.67**	**26.78**	**25.17**	**26.31**

* denotes key system agents based upon the rule that any value above the mean sociometric status value reflects dominance (Salmon et al. 2009)

Looking at the statistics for Recognition of Automation and Rely on Automation specifically, it is clear that systems design had a direct effect on the strength of sociometric status. For example, Warning and AEB W DDMiE models had higher scores on the Recognition of Automation Engagement mode which suggests that the warning aspect of the system caused more interference than the AEB nW system. Drivers may have been consciously waiting for the warning to activate, in this way using it as a tool to assist in the detection of a critical driving event. This would suggest issues of trust and complacency in system operation (de Waard et al. 1999; Larsson, 2012; Lee & See, 2004; Parasuraman & Riley, 1997). For example, if drivers perceived the warning system to be highly reliable, and indeed it was programmed to activate for all 5 critical events during the trial and thus deemed 100% effective, Young & Stanton (2002) suggested that drivers may not be able to monitor the system as closely as perhaps is warranted. In turn, this may delay driver response if they are waiting for confirmation of a collision risk. However, driver decision making may also have been influenced by the very presence of automation. For example, drivers could have simply perceived a reduced need to respond during these critical events if they could sense that the AEB W system, in particular, was responding for them (Stanton & Marsden, 1996). This does not necessarily mean that drivers will relinquish all control over the braking function; they may instead brake with less effort than would otherwise be needed to cope with the situation. However, due to the technical sophistication of the STISIM M500W software and the algorithms used to create the automated systems used in this study, it was not possible to investigate this further. This is because the presence of automation within the system configuration led to a static performance level once an emergency manoeuvre was initiated (ie. automatic braking overrode driver inputs).

5.5 Discussion

In summary, Network Analysis has shown to be a useful perspective in highlighting the inherent differences in driver decision making based upon the level of automation within the driving system. From a Human Factors perspective, it is essential to understand how decisions are reached when response execution has the potential to lead to undesirable outcomes (Jenkins et al. 2011). The analysis of driver decision making using DDMiE models and evidence from driver verbalisations suggests that whilst automation may not alter the decision making pathway between initial driver monitoring and response as indicated by identical key concepts, it does appear to significantly weaken or sever the links between information processing nodes. These weaknesses become more pronounced at higher levels of automation as both the physical and cognitive tasks associated with driving become shared between the driver and other system agents (Banks et al. 2014). Thus, not only do weaknesses appear in the cognitive functioning of the network (i.e. processing underlying response execution) as evidenced in this paper, but also appear to weaken the link between the driver and vehicle systems (i.e. “who” does “what” Banks et al. 2014; Banks & Stanton, 2014). For example, evidence from driver verbalisations suggested that “Recognition of Automation Engagement” was used as a trigger for drivers to seek out road hazards meaning that they were using automated assistance as a tool to guide their monitoring behaviour. If drivers did indeed choose to ‘wait’ for the automation to engage, we may not be improving safety in the way that we expect, despite the potential for significant reductions in accident statistics. This improper use of automation would be an unintended, emergent property of automation implementation within the system network yet highlights the need for a greater appreciation and acknowledgment of the changing role of the driver to ensure that the negative effects of automation are controlled for. It seems that for the collaboration between the driver and automation to be effective, drivers must have appropriately calibrated trust of an automated system (Lee & See, 2004; Madhaven & Wiegmann, 2007) and appropriate levels of awareness regarding its functionality.

5.6 Future directions

Chapter six builds on the work of chapter five by exploring the effects of systems design on measurable outcomes including frequency of accident involvement, reaction times and braking distances at increasing levels of automation within driving emergencies. With chapter five revealing that driver decision-making alters depending on the level at which automation is set, it is important to understand the implications of this changing behaviour on measurable outcomes. Furthermore, in order to determine whether or not drivers were "waiting" for AEB to activate or braking with less effort, analysis of the driving simulator data is needed.

Chapter 6: The Effect of Systems Design on Driver Behaviour: The case of AEB

6.1 Introduction

Although Retting et al. (2003) developed a number of engineering measures that sought to reduce the number of vehicle-pedestrian collisions, automated assistance in emergency situations can further improve road safety through the provision of visual and auditory warnings (e.g. Forward Collision Warnings) or through emergency brake assistance (e.g. Autonomous Emergency Brake: AEB) in an effort to avoid or mitigate the effects of road traffic accidents. Autonomous braking intervention can be achieved in one of two ways; following a system warning that a collision is imminent (AEB Warning: AEB W) or with no overt warning to the driver (AEB No Warning: AEB nW). Strategies for implementation have been interpreted by manufacturers of vehicles in different ways and depend heavily upon a number of important factors such as the number and type of sensors available on the vehicle, the decision to warn the driver, the automated logic itself that determines when braking will be initiated and so on (Lenard et al. 2014). The driving context does appear to influence the strategy for implementation, however, with city driving typically associated with an AEB nW system due to the certainty that autonomous assistance will be needed (i.e. greater proximity to hazards – Road Safety Analysis, 2013). This is in contrast to inter-urban driving that is often associated with increased fitment of AEB W systems. Although it could be argued, based upon these current design trends, that a Pedestrian AEB system is most likely to adopt a non-warning based approach due to the propensity for pedestrians to be located in cities, it is not yet clear how such systems will be implemented. Even so, it is generally agreed that the implementation of pedestrian detection and autonomous braking systems, regardless of design, will be advantageous in avoiding pedestrian collisions commonly caused by human error (Habibovic et al. 2013) and that automated assistance in such scenarios will have desirable benefits (Searson et al. 2014). It seems likely that it is for these reasons that Pedestrian AEB has been recognized by the European New Car Assessment Program (2013) as a critical safety system to be widely assessed and deployed from 2016 onwards (van Ratingen, 2012) with common accident scenarios providing a baseline for the construction of test protocols (e.g. Lenard et al. 2011).

6.1.1 Empirical testing of AEB

Although for some the benefits of automation may outweigh any costs (Khan et al. 2012; Stanton & Marsden, 1996; Young et al. 2011), a considerable amount of research into vehicle automation over the past thirty years has shown that drivers do not always respond in the way that engineers anticipate to automated assistance (e.g. Hoedemaeker & Brookhuis, 1998; Rudin-Brown & Parker, 2004; Stanton & Young, 2005; Young & Stanton, 2007a; 2007b; de Winter et al. 2014). Although in some instances driver behavioural change can be positive (e.g. if the driver is not looking at the road ahead or is distracted by other driving related tasks such as checking speed, an auditory warning could alert the driver to a problem and trigger their response), it can also be negative (e.g. drivers may become reliant on automation functionality and fail to respond as expected). For example, Stanton et al. (2011) found that increasing the level of automation can lead to complacency whilst Parasuraman (2000) suggested that it can cause decreases to driver situation awareness which are closely related to issues of mental underload and overload (Young & Stanton, 2002). The researcher argues that if we are to overcome these issues, more research is needed to ensure that undesirable behavioural adaptation does not occur (Stanton & Marsden, 1996; Stanton & Pinto, 2000) which can only be achieved if we acknowledge the *new* role of the driver in an automated driving system rather than purely focusing upon the efficacy of automation on frequency of accident involvement as a marker to determine if automated systems really do improve road safety.

Although Merat et al. (2014) suggested that both the level and type of automation implemented into the driving system can have a direct effect on the driver's level of engagement, AEB systems are unlikely to lead to an increase in driver's willingness to engage in secondary tasks as much of the control over vehicle handling remains in the hands of the driver. However, sudden increases to driver workload (e.g. Jamson et al. 2013) can be detrimental to driving safety (Rudin-Brown & Parker, 2004) and it is in these situations that automation of varying levels could be of greatest assistance. Even so, despite the allocation of system function being vital in understanding how automation may change the role of the driver (Banks et al. 2014), the automobile industry continues to be plagued by criticism for failing to acknowledge the changing role of the driver within automated systems once such systems have been deployed (Banks et al. 2013). This means that we do not fully understand the complexities of driver-automation cooperation (Weyer et al. 2015) and any associated performance outcomes.

Of course, the actual triggering of AEB is likely to be a rare event. However, Young & Carsten (2013) commented that AEB systems could be ripe for behavioural adaptation to occur, as drivers learn to push the limits of the system by driving more recklessly knowing that a safety net is present. However, Rudin-Brown (2010) and Hedlund (2000) propose that behavioural adaptation is less likely to occur if AEB offers no additional warning to the driver. From this perspective, a "silent" and "invisible" AEB system may be less prone to negative behavioural adaptation (Young & Carsten, 2013). However, it remains to be established whether or not this is the case.

6.2 Aims and objectives

The purpose of this chapter was to explore whether or not different AEB design strategies (i.e. warning versus a "silent" non-warning based system) could influence subsequent driver response to emergency situations. It focusses upon the analysis and interpretation of the data generated by SUDS in the previous chapter with regards to driver control inputs (or lack thereof) in coping with critical pedestrian events. Further thematic analysis of the retrospective reports generated in chapter five was also conducted using a data-driven approach to further explain these findings.

6.3 Method

Chapter six presents a continuation of the results reported in chapter five. However, to recap briefly, drivers were informed that the automated systems would only intervene in critical events meaning that no warnings or brake assistance would be provided for non-critical events. The AEB systems themselves were design to intervene regardless of driver control inputs, in this way acting as assistance if the driver initiated emergency braking first, or capable of acting autonomously if the driver failed to respond. Automatic intervention by AEB aimed to improve on the reaction time of the driver in an effort to mitigate injury rather than complete collision avoidance. Thus drivers were told that AEB was not deemed a replacement for them. Instead AEB should be viewed as a 'last resort' intervention strategy, in this way, maintaining the driver within the control-feedback loops for as long as possible. Any collision that occurred whilst AEB was active was indicative of reckless driving on behalf of the driver (e.g. elevated vehicle speeds).

6.4 Results

6.4.1 Accident involvement

One critical outcome measure relevant to the evaluation of automation in driving emergencies is the frequency of accident involvement. Unsurprisingly, Figure 6.1 reveals that the simulated AEB systems used in this study can reduce the overall number of accidents, regardless of design strategy. This observation suggests that a “silent” AEB system (Young & Carsten, 2013) has no additional benefit in comparison to a warning based AEB system within this study.

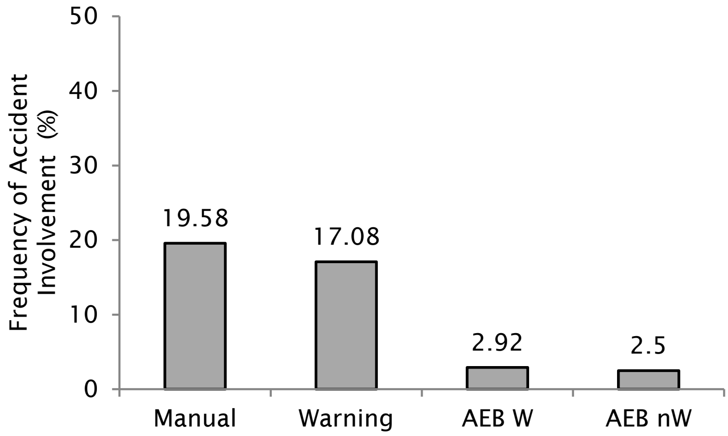


Figure 6.1. Percentage of drivers being involved in at least one collision across different levels of automation.

6.4.2 Driver-vehicle interaction

However, with Banks et al. (2013; 2014) and others (e.g. Rudin-Brown, 2010) proposing that the design of automation may affect the way in which drivers approach and deal with hazardous events, further analysis of SUDS data was completed to highlight any issues associated with automated design as evidence from driver verbalisations within chapter five made some suggestion that both the level of automation and type of AEB design directly affected the way in which drivers interacted with the vehicle.

6.4.2.1 SUDS data

At this point, the main focus of the analysis was based upon “who” was during critical braking events. Only data for AEB W and AEB nW were selected at this stage as it was in these conditions that the driver could relinquish their full control of braking to the automated AEB system. Within the data files, it was clear to see “who” (Driver or

Automation) was responsible for initiating the braking effort as the AEB feature had a clear identifier within the dataset. This raised the possibility to essentially log "who" interacted with the braking system first.

A Chi-Square test revealed that the design of the system (i.e. AEB W or AEB nW) significantly affected the frequency of "who" (Driver or Automation) initiated the braking response ($\chi^2(3) = 390.29$, $p < .001$, Cramer's V = 0.638). Figure 6.2 indicates that AEB nW was associated with a higher prevalence of 'Driver First' responses whilst AEB W was associated with an increased prevalence of 'AEB First' responses. 'Driver First' in this instance simply reflects that the driver responded to the critical braking event prior to AEB activation with 'AEB First' being the opposite. Out of a total 240 critical braking events (five per participant, per AEB condition), 34.2% (n=82) 'Driver First' responses were logged for AEB W in contrast to 57.1% (n=137) for AEB nW (Figure 6.2). This simply shows that different AEB design strategies do have some influence over driver-vehicle interaction patterns. This would suggest that if AEB is to remain active in the background of vehicle operation as intended, a "silent" and "invisible" AEB system (AEB nW) is most likely to preserve the traditional role of the driver (i.e. one that reacts prior to AEB activation). Perhaps AEB nW in this study encouraged drivers to monitor the road ahead much more diligently than AEB W because they knew no collision warning would assist them in detecting hazardous situations. Either way, driver responses must have been delayed in the AEB W condition given the higher frequency of 'Automation First' responses and the fact that both AEB systems were designed using the same algorithm and thus reacted at the time (Table 5.1, chapter five). With drivers being aware of the reliability of the system during simulation, it is possible that drivers were relying upon system activation in particular using the warning mechanism to trigger a response (similar to the purpose of a Forward Collision Warning) and thus not monitoring the environment as closely as was warranted (Young & Stanton, 2002).

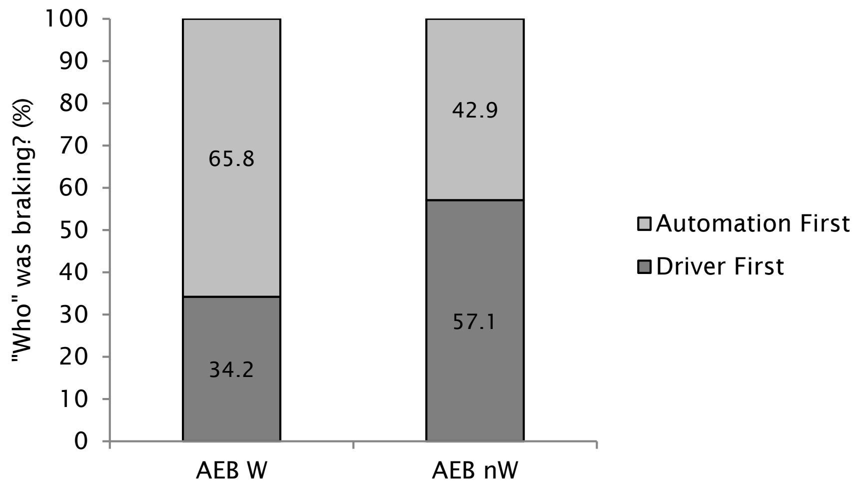


Figure 6.2. "Who" was braking?

6.4.2.2 Evidence from driver verbalisations

Further explanation for the trend presented in Figure 6.2 can be sought from additional analysis of the retrospective verbalisations collected during the study presented in chapter five. With the design of AEB seeming to influence "who" initiated the braking response in critical events, the author was curious as to "why" this happened. If for example, drivers actively chose to delegate their control of braking to the automated subsystems (i.e. there is an unintended shift in task loading which inhibits traditional behavioural response), a degree of skill degradation must occur (Jameson, 2003; Miller & Parasuraman, 2007; Parasuraman, 2000; Parasuraman et al. 2000; Stanton et al. 2001). Drivers may feel that the onus of responsibility for reacting to hazardous situations is now shared with an automated counterpart (Hoc et al. 2009) and thus, may delay their normal response as they attempt to cooperate with it (Hollnagel et al. 2004). Indeed, several studies have reported that performance under increased levels of automation can begin to decline as a result of lack of manual control inputs (e.g. Lavie & Meyer, 2010; Parasuraman et al. 2000; Miller & Parasuraman, 2007; Rudin-Brown & Parker, 2004; Stanton et al. 2001; Vollrath et al. 2011; Young & Stanton, 2007a; 2007b).

Additionally, if automation is perceived to be highly reliable (as it was programmed to be in this study), drivers may not be able to monitor the system as closely as is warranted (Young & Stanton, 2002). This could delay driver response if they wait for notification or confirmation of a collision risk such as that offered in AEB W.

A matrix coding query completed using NVIVO[10] for Windows software indicated that whilst direct references relating to a delay in driver response to critical braking events were small (AEB W = 22 references; AEB nW = 25 references), "waiting for automation to engage" (see code description in Table 5.2) was a conscious decision made by some participants. The following extracts are taken directly from transcribed driver verbalisations to demonstrate this idea;

"I tested the technology. Yeah, because I wasn't going quite as fast so I thought, see if it works"

"I think there's a tendency to go faster if you know something is going to catch you. So, I tend to go faster so it's like if you give someone enough rope, they'll hang themselves with it"

In contrast to chapter five which reports the thematic analysis of driver verbalisations to give specific insight into driver decision making processes, the purpose of the analysis at this stage was to support the observations of SUDS data by revealing driver perceptions of AEB. Table 6.1 defines additional codes that were used to analyse retrospective reports as well as providing examples and frequency counts.

The frequency of code occurrence for "failure to see threat" suggests that the monitoring behaviour of drivers was affected by AEB design strategy to some extent. These failures appeared to happen more frequently when drivers were supported by AEB W and this could be partly attributed to a change in the decision-making process (as discussed in chapter five) as they reported less anticipatory behaviours (see Table 6.1). For example;

"I think I'm not being as cautious because I know that there is a functionality there potentially I can take maybe a bit of a wider view of the world in terms of the traffic lights or where the roads going and things like that"

Table 6.1. Additional codes used to analyse retrospective verbal reports including frequency counts for different AEB design strategies

Code		Example	Frequency	
			AEB W	**AEB nW**
	Failure to see threat	"I didn't see her at all – I was looking the oncoming traffic"	69	21
	Anticipatory behaviours	"I've spotted her and slowed down just in case"	46	63
Thoughts on AEB	**Alerts driver**	"It helped me realise there was a problem. So I thought 'I need to do something'"	61	5
	Provides comfort and reassurance	"It's like if you have a mate looking out the window for you…."	60	69
	Validates driver thought process	…"it kind of confirmed that I should have braked, braked as I could, confirmation that that was the right choice to do"	24	1
	Ignores AEB system	"I didn't even think about the automation at all"	30	55

Of course, drivers are unlikely to exhibit such behaviours outside the security of driving simulation. Even so, such behaviour should be considered when analysing driver-vehicle interaction patterns remembering that humans are curious beings and will want to find and test automated system limits in some instances (Wilde, 1994; Young & Carsten, 2013).

6.5 Discussion

Assuming that automation is 100% failsafe, common causes of vehicular accidents such as driver distraction, inattention and a lack of timely response could be eliminated by its implementation (Amditis et al., 2010; Cantin et al., 2009; Donmez et al. 2007; Khan et al. 2012; Stanton et al. 1997). However, this study has demonstrated that whilst road safety can be improved with the implementation of AEB in emergencies, the strategy of implementation determines how far the traditional role of the driver remains and this is well worth recognising.

It can be argued that in order to maximize the safety of drivers and other vulnerable road users, designers should be aware of how different design approaches at differing levels of automation could affect subsequent responses to critical hazards. This study has shown that despite asking drivers to react to hazardous events as they normally would, the implementation of AEB did affect driver-vehicle interaction not only with regards to their decision-making (chapter five) but also with regards to the way in which they interacted with the vehicle and braking system. This means that we may not be improving the safety of our drivers as their changing role has not been fully recognised. AEB implementation, regardless of design strategy at this stage, appears to weaken the control-feedback loops (discussed in chapter two). This could lead to drivers not being equipped to cope with hazardous situations if automation failed (Sarter et al. 1997). It also implicates the concepts of trust and complacency in automation functioning (e.g. de Waard et al. 1999; Lee & See, 2004; Parasuraman et al. 1993; Young & Stanton, 2002).

It would appear that AEB implementation may lead to decoupling the link between the driver and vehicle systems within the control-feedback loops which may explain to some extent why 'Automation First' responses occurred. This decoupling was more pronounced when AEB W was used suggesting that a non-warning based AEB system is better able to preserve the traditional role of the driver.

Even so, in some instances a warning based system may be preferable – especially in instances whereby the driver has failed to recognise a hazard in the road ahead. Table 6.1 confirms that AEB W was most capable of alerting drivers to critical situations.

Finally, it is important to remember that it is difficult to say with certainty how different levels of automation in the driving task *really* affect driver responses in driving emergencies due to the limitations of driving simulation. Even so, the results of this study clearly indicate that the level of automation and the type of automation (i.e. systems design) does indeed have the potential to change the way in which the driver interacts with the vehicle (Merat et al. 2014; Stanton & Marsden, 1996; Stanton & Young, 2005).

6.6 Future directions

The research described so far in this thesis has focussed on applying Distributed Cognition to existing automated architectures that are readily available to buy in the current market. The remainder of this thesis explores a new automation concept, one that follows the progressive pattern of automation implementation outlined in chapter two. Entering the developmental sphere when a product is still in is conceptual stage is a very exciting opportunity as research findings may have a significant impact on the future of its design.

Chapter seven seeks to define the concept of "Driver-Initiated Automation" and identify the key system agents that exist in such a system. In order to reveal the true importance of their roles within the system network, Network Analysis metrics will be applied to system network representations created through the application of the Systems Design Framework introduced in chapter three. This can be achieved by subjecting frequency counts to Network Analysis using Agna™ (Benta, 2005). Although Agna™ is traditionally a Social Network Analysis tool, it can also be used for general Network Analysis.

Chapter 7: What's next for Vehicle Automation? From Design Concept through to Prototype Development

7.1 Introduction

Up until now, this thesis has been concerned with how far existing automated technologies protect the role of the driver from negative or maladaptive behavioural change. The thesis now moves on to looking at how future automated technologies may be deployed in the coming years. As vehicle manufacturers continue to improve the capability and sophistication of existing technologies apace, it is generally accepted by representatives within the automotive industry that vehicle automation will continue to evolve *progressively* (Figure 7.1) in line with NHTSA (2013), BASt (2012) and SAE (2015) automation taxonomies*.* This means that both the driver and automated subsystems remain key agents within the system network and must coordinate their behaviour with one another accordingly. Whilst an element of active control remains in the drivers grasp, it is critical that we understand what the driver is actually doing to ensure that they are capable of regaining control if required (e.g. Vienna Convention, 2014).

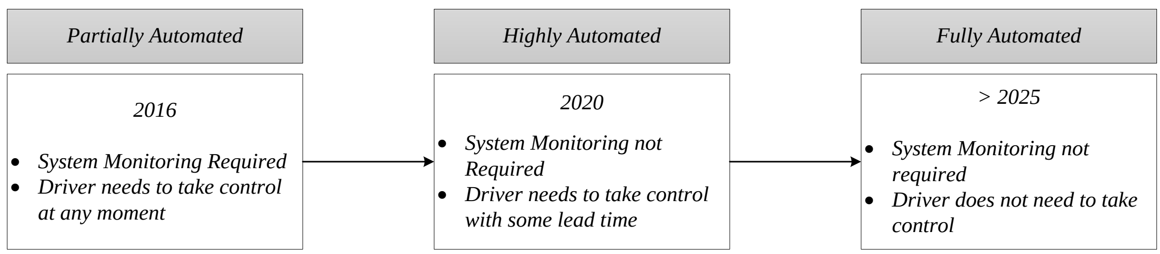


Figure 7.1. Proposed Automation Pathway (Adapted from Continental, 2014).

This chapter investigates how multi-system automation that enables the driver to become "hands and feet free" may affect the driving system and the role of the driver within it using the first three steps of the Systems Design Framework (Figure 7.2). The decision to focus upon these steps specifically is based upon the aims and objectives outlined below.

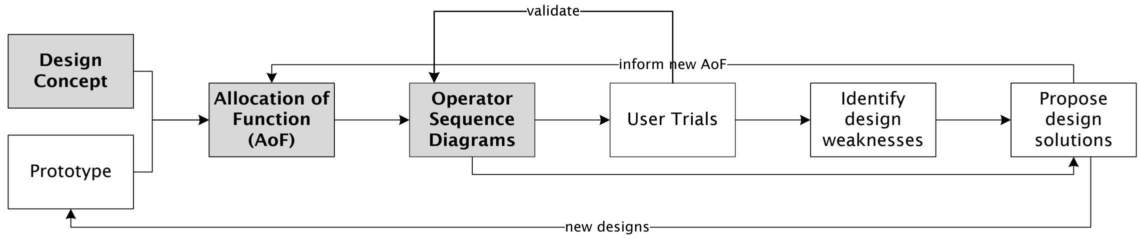


Figure 7.2. Aspects of the Systems Design Framework applied during chapter seven as shown in grey

7.2 Aims and objectives

Until the reliability level of automation is sufficiently high enough to introduce fully automated vehicles onto our roads, we will remain in a state of highly automated driving, requiring the driver and automation to work cooperatively in maintaining vehicular control (Soualmi et al. 2014). Thus, although fully automated cars are technologically feasible (Brookhuis & de Waard, 2006), during the intermediate phases of automation, the driver must remain active and in-the-loop (Hoeger et al. 2008). This poses many challenges for systems designers to ensure that the interaction between humans and automated systems are designed appropriately (Strand et al. 2014) to ensure that the negative effects typically associated with being out-of-the-loop are minimised (Endsley & Kiris, 1995; Stanton et al. 1997; Wickens & Hollands, 2000).

With both General Motors and Nissan predicting that 'almost' driverless cars will be ready to market from 2020, it is clear that highly automated vehicles that combine multiple automated systems are coming whether we are ready for them or not. Despite the allocation of function between the driver and automated subsystems being key in facilitating and developing driver-automation cooperation (Hoc, 2000), the industry has continued to be plagued by criticism for inadequately acknowledging the role of the driver and how it may change once these systems have been deployed (Stanton et al. 2007; Banks et al. 2013). This means that we do not fully understand or appreciate the complexities of driver-automation cooperation in modern day cars (Stanton & Young, 2005; Weyer et al. 2015). As increased control is delegated to the automation, there is growing concern within the Ergonomics and Human Factors community that the role of the driver is not being fully recognised. A greater appreciation of the driver's ability to undertake their *new* supervisory role is becoming increasingly important as the average motorist becomes less actively involved in traditional vehicle handling. With out-of-the-loop performance problems a serious concern within highly automated driving systems (Billings, 1988; Endsley & Kiris, 1995; Endsley & Kaber, 1997; Stanton & Marsden, 1996), this chapter aims to address some key research questions bearing in mind that one of the greatest challenges for systems designers is to reduce the high complexity of the automation into manageable complexity for the human driver (Kienle et al. 2009);

- What happens in an automated driving system?
- How does information flow between system agents
- What directional flow does the information have?
- Identification of key system agents via Network Analysis

The application of Network Analysis will show how the dynamism of the driving system and the role of the driver within it changes as more control is delegated to automated subsystems as part of the Event Analysis Systemic Teamwork framework (EAST; Stanton et al. 2013; Walker et al. 2006, 2010). The EAST framework proposes that system performance can be meaningfully described via three inter-linked network representations; task, social and information (Walker et al. 2006); to describe and analyse an activity. It was originally developed for the analysis of C4i activity (including command, control, communications, computers and intelligence) and aims to model the Distributed Cognition approach (Hutchins, 1995) with the methodological traditions inherent in Ergonomics research (Walker et al., 2006; 2010) by enabling analysts to examine the role of actors within complex socio-technical systems more succinctly. Whilst task networks can be used to provide a summary of the goals and processes involved in attaining these goals, a social network can analyse the organisations of system communications or interactions that can occur between human (i.e. driver) and non-human (i.e. automation) agents (e.g. Salmon et al. 2014). EAST has been successfully applied to aviation (Stewart et al. 2008; Walker et al. 2010), rail (Walker et al. 2006), naval (Stanton, 2014a) and military C4i scenarios (Walker et al. 2006) and would appear to be an appropriate method to apply in the driving automation domain. This chapter uses the representational mediums afforded by task and social networks to describe and analyse a Driver-Initiated Command and Control System that encourages the driver to remain actively involved in the driving task much like how Baber et al. (2013) analysed the role of system agents in maritime search and rescue scenarios.

7.3 Application of the systems design framework: Phase 1

Step 1: Identification of Design Concept

Driver-Initiated Automation essentially enables higher levels of automated functionality but maintains the driver in-the-loop through the adoption of a command and control relationship (e.g. Houghton et al. 2006). Essentially, a system of Driver-Initiated Command and Control is analogous to a management infrastructure (Harris & White, 1987) that sees the driver and automated subsystems communicating and behaving cooperatively to achieve a common goal (Hoc et al. 2009). Within the driving domain, Conduct-by-Wire (Winner & Hakuli, 2006) and H-Mode (e.g. Flemisch et al. 2003) are relevant concepts relating to the design of cooperative guidance and control systems (Flemisch et al. 2014). The allocation of function between the driver and automation should not be considered as static but instead a continual repartitioning process (Flemisch et al. 2012) where the driver and automation can influence the balance of control between system agents. For example, the driver can set higher or lower levels of automation whilst the automated systems can recommend or suggest tasks that can be automated (such as a lane change manoeuvre) or in emergency situations, transition control away from the driver to mitigate the effects of a collision (e.g. Autonomous Emergency Brake). In this way, 'initiation' can either be prompted by the automated system itself or by the driver. The key difference in a Driver-Initiated Automation system is that the driver must "*accept*" or "*ignore*" requests made by the automated system. Only when the driver accepts a request can the manoeuvre be performed automatically. Thus, although continual repartitioning occurs, it is the driver who influences the balance of control. In this way, the driver is able to exercise their control and authority over the automated system which keeps them informed of planning, directing and controlling when the resources available from the automation will be used (e.g. Builder et al. 1999). This would see the role of the driver becoming more analogous to the role of the co-pilot in aviation (Banks & Stanton, 2014; Stanton & Marsden, 1996; Young et al. 2007) meaning that although the status of the driver within the control-feedback loops of driving has changed (Banks et al. 2014), the link between the driver and vehicle is protected, to some extent, from disintegration which is thought to lead to out-of-the-loop performance issues (Billings, 1988; Endsley & Kiris, 1995; Kaber & Endsley, 2004; Stanton et al. 1997; Vollrath et al. 2011). Although command and control socio-technical systems are typically associated with Air Traffic Control (Walker et al. 2010) and military teams (Walker et al. 2009), there is no reason why such an approach cannot be applied to driving. After all, every 'agent' (both human and non-human) play a critical role in the successful completion of a task (Stanton et al. 2006; Salmon et al. 2008) even when the vehicle is capable of controlling all of the physical and cognitive tasks associated with driving (Stanton et al. 1997).

When considering that each facet of technology provides a stepping stone to reach higher levels of autonomy (e.g. Banks & Stanton, 2014), it seems likely that existing automated architectures such as cruise assist technologies (Stanton et al. 2011), could simply be extended to include lane centring and overtake capabilities in an effort to achieve higher levels of autonomy using a Driver-Initiated design approach (Figure 7.3).

Although the combination of automated longitudinal and lateral control systems is not an entirely new concept (Stanton et al. 1997; Young & Stanton, 2002), over recent years, there has been a significant increase in manufacturers introducing their own versions that fit such a specification (e.g. General Motor's Super Cruise, Fleming, 2012; Mercedes Distronic Plus with Steering Assist, Daimler, 2013a). However, the future of automated highway driving in particular appears to point to the following subtasks of driving being completed autonomously; longitudinal control, lateral control, all round lane monitoring, lane change, merging and collision avoidance. This suggests that at some point in the future, vehicles will be capable of performing complex lane change manoeuvres independently from the driver (e.g. Autobahn Pilots, Daimler, 2013b). These technologies are likely to be developed progressively meaning that the driver remains in ultimate control of the vehicle via a process of Driver-Initiated Automation design.

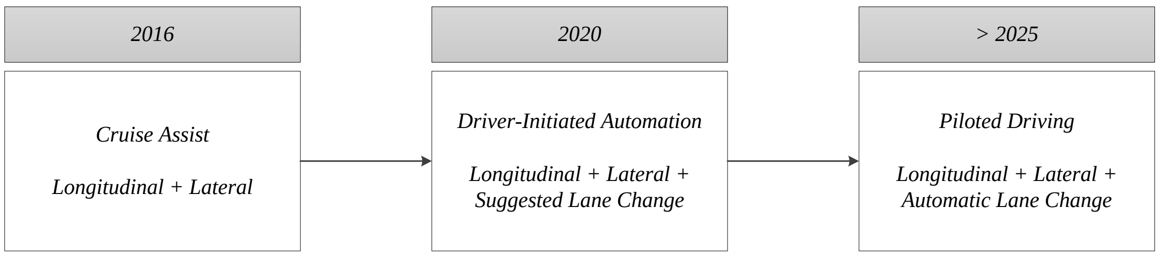


Figure 7.3. Hypothetical pathway for Driver-Initiated Automation implementation relating to future cruise assist technologies

A hypothetical system such as the 2020 vision portrayed in Figure 7.3 that combines longitudinal and lateral control with a suggested lane change is likely to be classified as a system that improves the driver experience in terms of comfort rather than be marketed as a traditional safety system. Such a system will require the driver to closely monitor system behaviour in order to establish whether its performance and lane change suggestions are indeed safe to complete. This keeps the responsibility of safe vehicle operation in the hands of the driver despite the vast majority of the driving task being completely automated (Parasuraman et al. 2000). The obvious concern is that the driver will quickly become disengaged and may willingly accept that automated subsystems are operationally sound meaning that if a lane change suggestion is offered at a time that would normally be considered unsafe by the driver (perhaps the sensing equipment fails to identify a vehicle in the adjacent lane), the driver may automatically accept the suggestion without adequately assessing the situation. Of course, the vehicle is unlikely to actually complete the manoeuvre due to the multitude of subsystem components analysing the road environment, but it could affect levels of driver trust in using such a system (e.g. Lee & See, 2004). Until such systems become available, it is difficult to say with certainty how drivers will interact with them. Even so, it is possible to model, even in the early stages of system development, how a system of Driver-Initiated Automation may be idealistically managed to ensure that the role of the driver is supported throughout active automated driving.

Step 2: Allocation of Function

Using traditional task analysis methods (Stanton et al. 2013), it is possible to outline the processes involved in achieving a common goal. For Driver-Initiated automation technologies that combine longitudinal and lateral control together with a suggested lane change, there appears to be three distinct driver commands; Activate Longitudinal Control, Activate Lateral Control and finally Driver Accept / Ignore Lane Change Suggestion. The reason for these three distinct driver commands is quite straightforward; whilst automated longitudinal control can be used on any road type, it seems most likely that automated lateral control systems will be confined to highway driving for the time being. This is because the opportunity for lateral control to be automated is based upon the provision of clear road markings and these are not always maintained on other road types. Thus, the activation of Driver-Initiated Automation in this form is likely to follow two stages;

1. Once the driver issues the command for longitudinal control to be automated, the Longitudinal Controller begins to hold, represent and modify information from the changing environment in order to reach the goal of the system network (in this case to maintain a desired speed and gap that is pre-set by the driver). This information is shared with the Driver-Initiated system of control and relayed back to the driver via the HMI. Of course, the driver is still free to override the Longitudinal Controller at any time by simply depressing the brake pedal. A task analysis by Stanton & Young (2005) highlighted the role of the driver within this process as one that monitors subsystem behaviour; checking that the Longitudinal Controller is maintaining the pre-set speed, correctly identifying vehicles ahead and responding accordingly.

2. If the driver chooses to automate Lateral Control, information is sent to the Lateral Controller relating to the drivers intention. In this instance, the shared goal of the system network is to safely stay within the confines of the lane and avoid deviation. The Lateral Controller will begin scanning the road environment for lane markings. If these are not found, the driver is notified that Lateral Control is not available via the HMI. In contrast, if lane markings are successfully identified, the vehicle can be controlled by the Lateral Controller. Again, this information is relayed back to the driver via the HMI. The system will continue to automate this task unless the system is disengaged by the driver through a steering override of approximately two Newton Metres, or the Lateral Controller fails to identify road markings ahead. Again, the role of the driver would be to monitor the behaviour of the Lateral Controller; checking that the system has correctly identified lane markings and that the vehicle remains within the confines of these boundaries.

When both Longitudinal and Lateral Controllers are actively automating these driving subtasks, the driver may become "hands and feet free". This is because they are no longer in direct control of active driving. However, they are still free to exercise their authority by overriding the system whenever they consider it necessary. Whilst driving control subtasks are automated, drivers are most vulnerable to disengagement from the primary task (driving) and more likely to engage in secondary tasks (i.e. in-vehicle entertainment: Carsten et al. 2012; Jamson et al. 2013). With the likelihood of "eyes-off-road" time increasing as the level of automation increases, any failure on the part of the automation may delay appropriate driver response (e.g. Stanton et al. 1997; Young & Stanton, 2007b). For example, failures of an automated longitudinal control system, such as Adaptive Cruise Control, have been associated with failure to reclaim control (Stanton et al. 1997), inappropriate braking responses in both driving simulator studies (e.g. Young & Stanton, 2007b) and also test-track studies (e.g. Rudin-Brown & Parker, 2004). In the case for automated lateral control systems, such as Lane Keep Assist, issues relating to complacency have been highlighted (e.g. Desmond et al. 1998). These performance decrements on behalf of the driver are thought to be related to decreased SA (Endsley, 1995) and changes to driver mental workload (Stanton et al. 1997; Stanton et al. 2001; Young & Stanton, 2002; 2007a). Reduced workload as a result of increasing levels of automation (Young & Stanton, 2002) in the driving system has been labelled as equally hazardous to road safety as the cognitive overload that drivers experience when automation fails (e.g. Hancock & Parasuraman, 1992). It would seem that the passive role of the driver to monitor a system of combined Longitudinal and Lateral Control (i.e. hands and feet free) will be less satisfactory than the active role that drivers assume in manual control (Bainbridge, 1983; Stanton & Marsden, 1996). An optimal level of automation, through means of a Driver-Initiated automatic overtake system extension may be more satisfactory to the driver because they are encouraged to interact with the vehicle more frequently in highway driving. For instance, it is very likely that at some point during highway driving, the vehicle, whether in manual or automated mode, will encounter traffic in the roadway ahead. The first response of the automated system would be to maintain the pre-set gap, determined by the driver, meaning that vehicle speed may decrease or increase. A 2020 version of the system of Driver-Initiated Automation (Figure 7.3) would begin to monitor the adjacent lanes for further traffic. If a gap is detected, making it possible to perform a lane change manoeuvre safely into an adjacent lane, information will be exchanged between the subcomponents of the automated system and a lane change suggestion will be presented to the Driver via the HMI. The driver can choose to ignore lane change offerings or complete the manoeuvre independently but if they choose to accept the automated suggestion, the Lateral Controller will deviate from its current lane into a new position in the adjacent lane. At this point the Longitudinal Controller will then seek to resume the pre-set speed. Similarly, when the host vehicle has passed the slower vehicle, the system will go through the same processes to offer a return back into the previous lane.

Step 3: Sequence Diagram & Quantitative Analysis

Using the above description, a sequence diagram has been developed to show the interaction that takes place between the driver and other non-human agents within the system network combining the two stage activation with an automated Lane Change Suggestion (Figure 7.4). This representation shows that much of the additional information that is added into the driving task as a result of automation implementation remains firmly embedded within the automated subsystem architecture, with only the most relevant information being shared with the driver via the HMI regarding system status. Based upon this interpretation, it would appear that automated subsystem components become central to the functionality of the driving system as the driver delegates increasing levels of control to them.

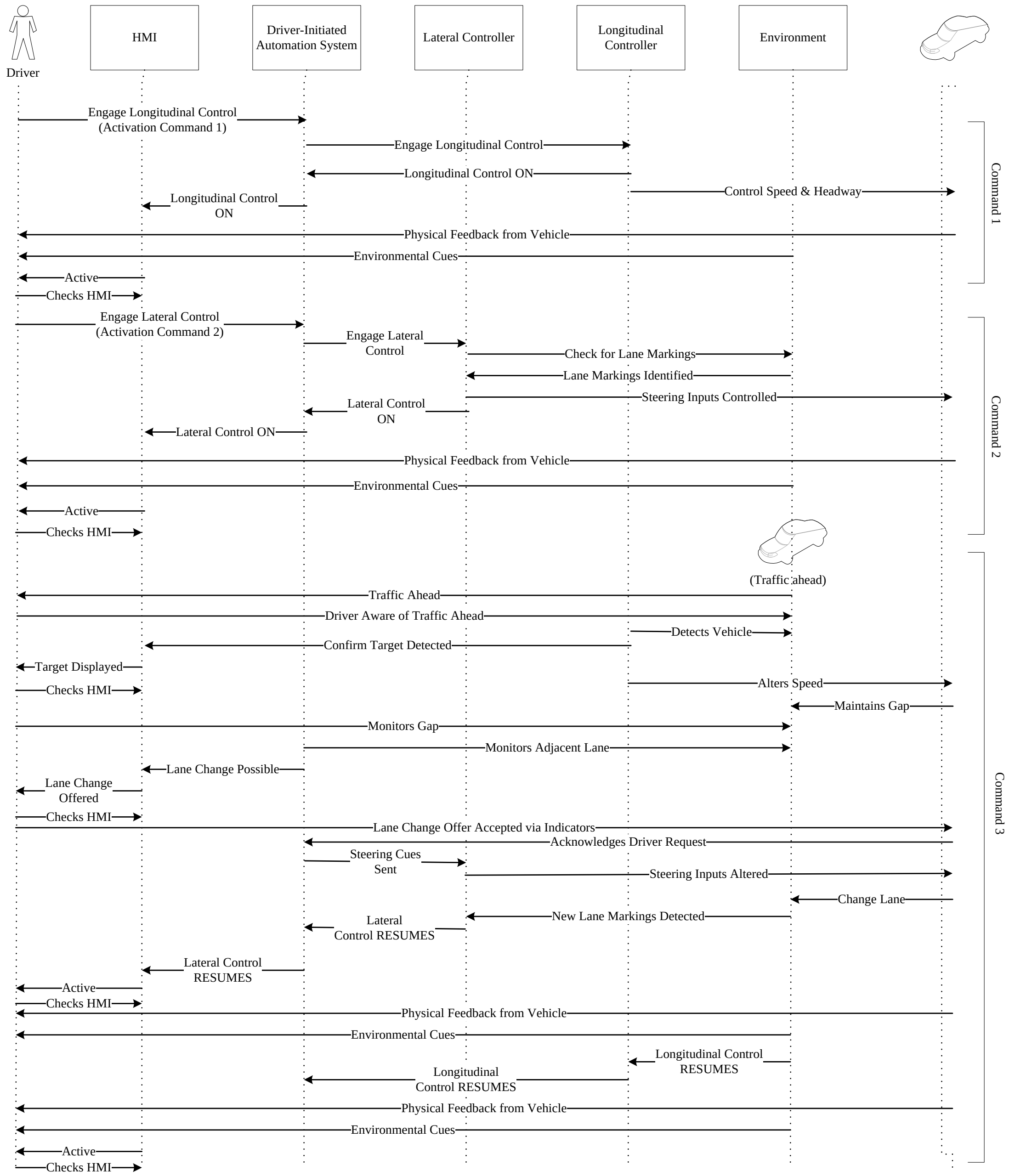


Figure 7.4. Interaction between key system agents involved in a driver-initiated automated driving system

However, with the emphasis of Driver-Initiated Automation aiming to keep the driver in-the-control-loop, we need to take a closer look at how network dynamism changes as the number of driver commands increases. The first step in addressing how network dynamism is affected by different driver commands is to construct social network diagrams (see Figure 7.5). Communication within social networks is represented by directional arrows and frequencies (Houghton et al. 2006) based upon the interaction patterns presented in Figure 7.4 for each driver command. These social network diagrams represent how key system agents are connected. In this way, it is possible to identify where the system network is most vulnerable, based upon the interaction that takes place between the different system agents (Griffin et al. 2010; Stanton et al. 2015). It is apparent that the most complex network results from the driver command relating to the Acceptance of a Lane Change Suggestion. This is a reflection of the increased communication that is needed between different system agents in fulfilling the command and can be confirmed by quantitative metrics (Houghton et al. 2006) that have been applied to driving (e.g. Salmon et al. 2009, Walker et al. 2011).

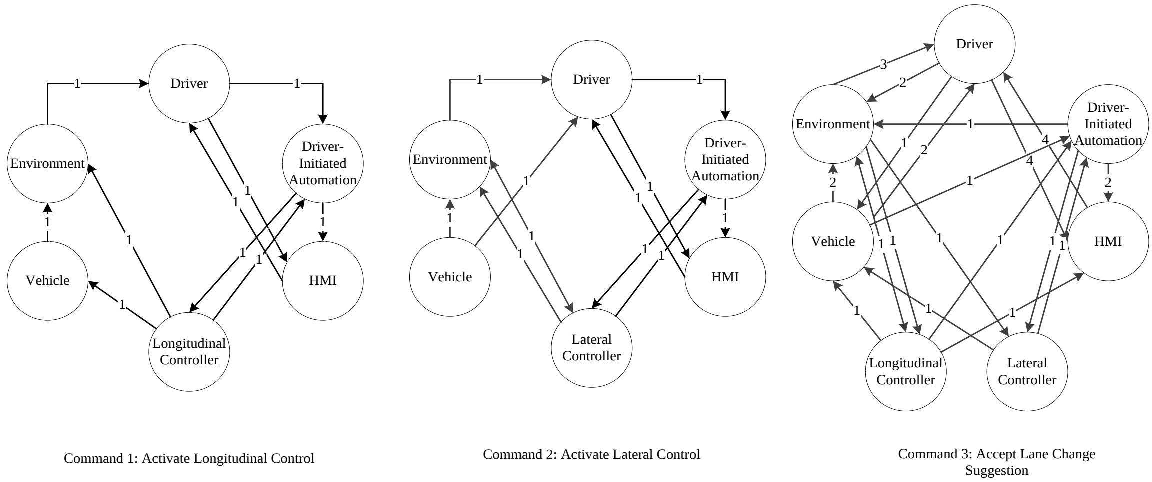


Figure 7.5. Social network diagrams relating to different driver commands within a driver-iniaited command and control system

Further analysis using Agna™ (version 2.1.1) was used to examine network density, diameter, cohesion and sociometric status for each of the different driver commands (see chapter five for full definitions and formulae). Table 7.1 provides an overview of the networks and indicates that both driver activation demands (e.g. Activate Longitudinal Control and Activate Lateral Control) can be described as binary (i.e. it can be represented by a zero-one matrix) and non-symmetric (i.e. directed) whilst the third driver command (Accept Lane Change Suggestion) can be described as a weighted (i.e. non-uniform) and non-symmetric (i.e. directed). The third driver command (Accept Lane Change Suggestion) can be described as a weighted (i.e. non-uniform) and non-symmetric (i.e. directed). The omission of the Lateral Controller agent in the "Activate Longitudinal Control" social network and the Longitudinal Controller agent in the "Activate Lateral Control" social network simply reflects the redundancy of each agent in these alternative driver commands.

Table 7.1. Basic description of networks

Driver Command	Number of Agents	Number of Edges
Activate Longitudinal Control	6	10
Activate Lateral Control	6	12
Accept Lane Change Suggestion	7	19

The level of interconnectedness between individual agents within the system network is represented as a value between 0 and 1 and is a reflection of network density (e.g. Salmon et al. 2014). A value of 1 reflects a fully connected network (Walker et al. 2011) whilst a value of 0 represents a disconnected network. Table 7.2 confirms that the most densely connected network is the "Accept Lane Change Suggestion" command which is also clearly visible in Figure 7.5 with a greater level of communication existing between all system components as task complexity increases. In its current state, the totality of the system network can be described as a medium distributed network that should have some resilience against a network failure.

Table 7.2. Contrasting network density for different driver commands

Driver Command	Density
Activate Longitudinal Control	0.33
Activate Lateral Control	0.40
Accept Lane Change Suggestion	0.45

The fluidity of the network (i.e. the number of 'hops' required to get from one side of the network to the other) is represented by values of network diameter (Stanton, 2014a; Stanton, 2014b). The results of the analysis are shown in Table 7.3 and indicate that the shortest network is also the most complex (Acceptance of Lane Change Suggestion). During the early stages of automation activation, the system agents work largely independently from one another as driving tasks are partitioned gradually. This means that there are less reciprocal links between system agents, as evidenced by Table 7.4 which presents the results for network cohesion. When the system is fully active (i.e. the system is capable of suggesting and executing an automatic lane change), the system agents work cooperatively with one another.

Table 7.3. Contrasting network diameter for different driver commands

Driver Command	Diameter
Activate Longitudinal Control	5
Activate Lateral Control	4
Accept Lane Change Suggestion	3

With network cohesion being a measure of reciprocal connections between system agents, Table 7.4 shows that as the driver relinquishes their control over the driving task, the level of network cohesion increases. This simply reflects that the communication between subsystem components increases as the driver is removed further from the control loop. However, just because the driver is removing themselves from active control, does not mean that they are removing themselves completely from the task. This is because a Driver-Initiated system of automation will only continue to function if the driver continues to issue commands for the automation to complete.

Table 7.4. Contrasting network cohesion for different driver commands

Driver Command	Cohesion
Activate Longitudinal Control	0.13
Activate Lateral Control	0.20
Accept Lane Change Suggestion	0.24

Sociometric status is a useful metric to determine agent prominence within a system network (Houghton et al. 2006). Table 7.5 shows that the intentions of a Driver-Initiated Automation design approach are met, with the driver remaining a key agent within the system network at all stages of the task (i.e. from the initial activation demands to the acceptance of a lane change suggestion). Table 7.5 also highlights other key system agents for different driver commands and indicates that agent prominence within social networks is directly affected by individual driver commands. For example, the driver and lateral controller are the most prominent agents within the social network relating to driver command 2 whilst the driver, HMI and environment are the most prominent agents within the social network relating to driver command 3. Importantly, as the driving task becomes more autonomous and the vehicle is controlled automatically by the automated subsystems (i.e. in the case of command 3), the HMI becomes increasingly important in maintaining and supporting the link between the driver and other system components. This is because it is the only tool that designers can use to ensure that the driver understands “what” the system is doing at any point in time other than the information that is available from the environment and vehicle.

Table 7.5. Contrasting sociometric status for different driver commands

	Command 1	Command 2	Command 3
	Engage Long. Control	Engage Lateral Control	Accept Lane Change
Driver	1.00*	1.00*	2.67*
HMI	0.60	0.60	1.83*
Driver-Initiated Automation	0.80*	0.80	1.17
Lateral Controller	Not Applicable	1.00*	0.67
Longitudinal Controller	0.60	Not Applicable	0.83
Environment	0.40	0.80	1.83*
Vehicle	0.60	0.60	1.33
Mean	*0.67*	*0.80*	*1.48*

*denotes key system agents based upon the rule that any value above the mean sociometric status value reflects dominance (Salmon et al. 2009)

7.4 Discussion

The task analysis of Driver-Initiated Automation may be criticised for being idealistic given its immature development, it offers a first attempt at describing how information may flow between key system agents during highly automated driving. Chapter seven shows how the application of EAST can be used to drive the way that automation can be designed to retain the role of the driver within the control-feedback loops. The application of Network Analysis metrics has revealed that system functionality and resilience to network failure is based upon the 'connectedness' of system agents in allowing the vehicle to perform complex subtasks of driving autonomously. In its current state, the processes that underpin highly automated driving, as presented in this chapter, do appear to maintain the driver in the control-loop despite the delegation of some driving functions being handed to the automation. This is important because the strategy assessed in this chapter was to leave the driver in charge of high-level decision making, giving permission to the automated subsystems to carry out manoeuvres. The use of network metrics to examine system performance and the role of human agents is becoming more popular (Stanton, 2014a; Stanton et al. 2015),

Even so, the consequence of this control transfer on driver behaviour remains unknown and more research is needed to ensure that the new driver role afforded by Driver-Initiated Automation is appropriate. The representations presented in this chapter offer a visualisation of how an "ideal" network may function. Realistically however, prolonged periods of driver inactivity (i.e. "hands and feet free" driving) could result in issues surrounding driver disengagement, boredom and fatigue (e.g. Stanton et al. 1997; Young & Stanton, 2002). In other words, highly automated driving (such as a system that automates longitudinal, lateral and overtake manoeuvres) is likely to divert the driver's attention away from the road to other tasks (de Winter et al. 2014). Merat et al. (2014) found that both the level and type of automation can have a direct effect on levels of driver engagement. However, whilst the likelihood of drivers engaging in non-driving tasks increased as the level of automation increased, this was not detrimental to driving in typical conditions. In addition, Jamson et al. (2013) found that when drivers experienced highly automated driving, they were less inclined to change lanes even in heavy traffic situations despite increased journey times. This suggests that a driver-initiated automatic overtake may not protect against driver disengagement in the way that is hoped but further research is needed to validate these findings. Of greatest concern is the need for drivers to resume control in atypical driving situations which could result in sudden changes to driver workload (e.g. Stanton et al. 1997; Jamson et al. 2013) that could be detrimental to driving safety (Rudin-Brown & Parker, 2004). This is because increased eyes-off-road time (e.g. Peng et al. 2013) is associated with reduced driver SA (Dozza, 2012; Young et al. 2012). One of the real concerns for highly automated driving systems of the future is how driver workload can be managed so that situations of mental underload and overload do not develop (Stanton et al. 1997; Young & Stanton, 2002; 2004).

In addition, driver familiarity with system operation is also likely to influence driver usage patterns. For example, there are a number of common events which automated longitudinal control systems (such as Adaptive Cruise Control) are unable to cope with, which means that the driver needs to resume control. These functional limitations are discovered and learned as a result of experience with the system (e.g. Larsson, 2012; Larsson et al. 2014; Strand et al. 2011). As drivers begin to learn the functional limitations of the automated system, they begin to build an understanding of what the system is capable of (Rasmussen et al. 1994). If the system is highly reliable, driver expectations are continually reinforced which may make them more susceptible to instances of 'automation surprise' or 'startle' in the case where the automated system behaves in an otherwise unfamiliar way (Sarter et al. 1997). Negative experiences such as this have been found to affect subjective ratings of trust (e.g. Wiegmann et al. 2001) which may lead to disuse (drivers reject the benefits of the system), misuse (drivers become complacent) or rejection (drivers will not use the system even when available) (e.g. Parasuraman et al. 1993; Sheridan, 1988). In addition, increased reaction times (e.g. Merat & Jamson, 2009; Young & Stanton, 2007b) are thought to be associated with issues of cognitive underload (Vollrath et al. 2011), overload (Stanton et al. 2011) and reduced responsibility (e.g. Farrell & Lewandowsky, 2000); all of which signal that driver desensitisation is a real concern in automated driving and should not be ignored.

More research is therefore needed to establish whether a command and control relationship between the driver and automation is sufficient to keep drivers actively engaged in the task (Stanton & Baber, 2006) and reduce the risk of driver disengagement. The driver should be required, or at the very least encouraged, to interact with the vehicle throughout the journey. Either way, it seems increasingly important for automated systems to be aware of the driver's state and have the ability to re-engage if desensitisation does occur (Merat et al. 2014) signalling further challenges in the quest to reach higher levels of driving autonomy. We may find that whilst a reliable system that will not breach driver expectations can be achieved, it may not reflect the highest capabilities of the technological components involved. Instead, we need to decide whether the most 'capable' system should be balanced with the most 'user-friendly system' (Zheng & McDonald, 2005). Future research should test the hypotheses developed in this chapter to empirically validate the findings. Using a highly instrumented vehicle capable of automating longitudinal, lateral and overtake manoeuvres will substantially increase our knowledge of driver behaviour and their interaction with both the vehicle and environment. Valero-Mora et al. (2013) claim that the use of such vehicles in a relatively naturalistic environment can significantly contribute to driver-automation interaction research that can overcome some of the issues associated with simulation.

7.5 Future directions

Chapters eight and nine continue to extend our understanding of the role of the driver within a highly automated driving system that adopts Driver-Initiated design through experimental investigation on multi-lane carriageways in live traffic. Going beyond driving simulation gives rise to unique insights into the changing nature of driver-vehicle interactions in a real-world setting.

Chapter 8: Discovering Driver-Vehicle Coordination Problems in Early Stage System Development

8.1 Introduction

This chapter explores the use of an early form of Driver-Initiated Automation in a naturalistic driving setting. A test vehicle equipped with a prototype system of Driver-Initiated Automation was used to explore driver-vehicle-world interactions to validate and extend our understanding of Distributed Cognition in highly automated driving systems (Figure 8.1). The use of a highly instrumented vehicle offers a step forward from traditional driving simulator studies (Valero-Mora et al. 2013) as research can be carried out in a more naturalistic driving environment. The test vehicle used in this study was capable of recording a large amount of data from the driver, vehicle and the wider environment continuously throughout the experimental drive.

Figure 8.1. Test vehicle equipped with a prototype system of driver-initiated automation

Whilst the purpose of chapter seven was to provide an exploratory basis for future systems design, chapter eight presents a pilot study that was designed to explore and develop a methodological procedure for future research into the use of Driver-Initiated Automation. The underpinnings of which were based upon the application of the Systems Design Framework (Figure 8.2).

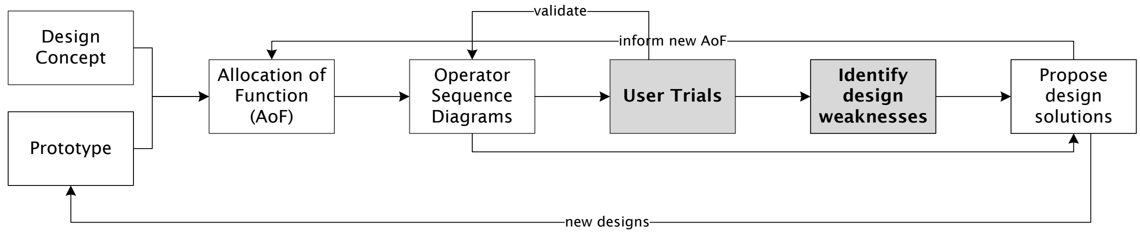


Figure 8.2. Aspects of the Systems Design Framework applied during chapter eight as shown in grey

8.2 Pilot study of driver-initiated automation

8.2.1 Aims and objectives

A critical question being asked by many vehicle manufacturers is what *actually* happens when the driver finds themselves being "hands and feet free" within their vehicles. This case study was used as an investigation into the functionality of Driver-Initiated Automation (both system capabilities and architectural issues) at a very early phase of system development. Using a selection of popular Human Factors tools, a multi-disciplinary team of Researchers, Engineers and Systems Designers wanted to explore how the use of a highly instrumented vehicle could be used in extending our understanding of driver-vehicle interaction patterns under high levels of driving automation. The aim of the study was to observe the behaviour of drivers in an unobtrusive manner (Backer-Grøndahl et al. 2009) whilst they interacted with the new system.

8.3 Method

8.3.1 Participants

Two participants with Advanced Driver Training were recruited to take part in this study due to the exploratory nature of a highly automated prototype technology. One participant was an experienced user of Driver-Initiated Automation having built up a number of hours using the system the preceding week whilst one participant was an inexperienced, first time, user of the system.

Ethical permission to conduct the study was sought and granted by the sponsoring company.

8.3.2 Experimental design and procedure

After gaining informed consent, both drivers were instructed to complete a much condensed version of the Dundee Stress State Questionnaire (DSSQ: Matthews et al. 2002) that included the Energetic Arousal and Tense Arousal sub-scales. According to Matthews et al. (2013), Energetic Arousal can be seen as similar to the level of task engagement whilst Tense Arousal can infer levels of distress. The two sub-scales consisted of 39 items that were coded as required by the developers (Matthews, 2002). In addition, the inexperienced user was also given a brief introduction to the functionality of the Driver-Initiated system by means of images of the HMI. This was so that the inexperienced user could familiarise themselves with the functioning of messages and controls. As new vehicle consumers do not receive any training in the use of vehicle subsystems, a description like this was considered to be consistent with current custom and practice. Upon completion of the pre- drive DSSQ, drivers were able to familiarise themselves with the host vehicle as they made their way from the University of Warwick (UK) campus to the A46 dual carriageway; a distance of approximately 2 miles (Figure 8/3). The host vehicle was a BMW equipped with both radar and Light Detection and Ranging (LIDAR) sensors that analysed the surrounding environment and monitored for other road obstacles and lane markings (Figure 8.1).

The test route consisted of a 16 mile stretch of the A46 between Coventry and Warwick that took approximately 20 minutes to drive (Figure 8.3). Throughout this time, drivers were invited to complete a verbal commentary recorded using Smart Voice Recorder version 1.7. Upon joining the A46, drivers were invited to use the Driver-Initiated automated system given the understanding that drivers would manually override the subsystem when necessary (e.g. in the case of malfunction which caused automation to drop out). A Safety Driver sat beside the driver in the passenger seat who could answer any questions that the driver posed whilst the experimenter sat in the rear of the vehicle. Upon return to the University of Warwick campus, drivers were instructed to complete the post drive DSSQ and NASA-TLX (Hart & Staveland, 1988) to assess workload during the task.

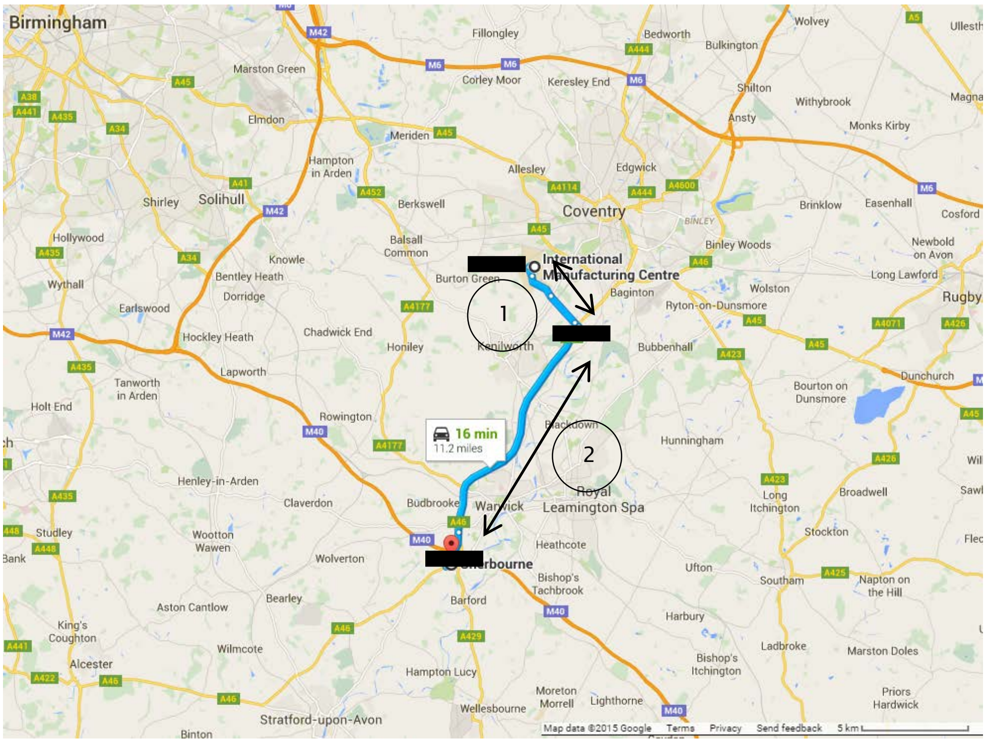


Figure 8.3. Test route via A46; 1 = Familiarisation drive, 2 = Test route

8.3.3 Data reduction and analysis

Once verbal commentaries had been transcribed, an initial coding scheme based upon systemic SA research (e.g. Walker et al. 2011) was used to analyse the content of verbal reports. Refinement of this coding scheme ensued using a hybrid of theory-driven and data-driven approaches. The iteration process continued until the verbal reports were judged to be adequately categorised into the coding scheme. The final coding scheme consisted of seven categories (see Table 8.1 for descriptions and examples).

Table 8.1. Coding scheme for verbal commentaries including descriptions and examples

Code	Description	Example
Behavioural Disparity	Disparity in system performance and what the driver would normally do	"See really I would have pulled over by now"
Driver Knowledge	Reference to driver knowledge of system behaviour / operation	"This wouldn't let me do that"
Other Traffic	Any reference to the behaviour of other traffic	"You can never really second guess what other people are going to do"
Driver Behaviour	Statements referring to own behaviour	"Quite happy to take my hands off the wheel"
Manual Override	Evidence of the driver regaining control of the vehicle	"I'll just do it manually"
System Behaviour	Overt references to system operation	"It's keeping me in the lane"
Functionality Issues	A lack of understanding surrounding system function	"So it's still working now?"

8.4 Results

8.4.1 Thematic analysis

Figure 8.4 shows the total number of observations made for both the experienced and inexperienced system users. Unsurprisingly the inexperienced user generated evidence of a greater number of functionality concerns characterised by an increase in questions posed to the Safety Driver to seek validation on system behaviour. These questions typically focussed on clarification of system behaviour, the meaning of HMI content and system limitations.

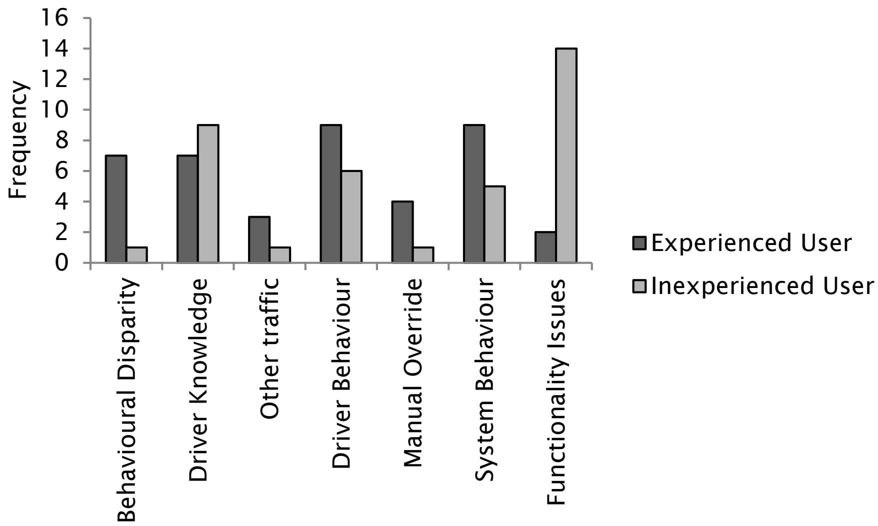


Figure 8.4. Frequency of code occurrence following thematic analysis of driver verbalisations

Table 8.2 shows the code frequency as a percentage of total coding and indicates that the inexperienced user of the system was heavily focussed upon functionality issues and building their knowledge database of system functionality whilst the experienced user was more evenly spread.

Table 8.2. Code frequency as a percentage (%) by user

Code	User	
	Experienced	Inexperienced
Behavioural Disparity	17	3
Driver Knowledge	17	24
Other Traffic	7	3
Driver Behaviour	22	16
Manual Override	10	3
System Behaviour	22	13
Functionality Issues	5	38

8.4.1.1 Evidence of Driver-Vehicle Coordination Problems

Interestingly, the verbal commentary provided some evidence of mode confusion on behalf of the inexperienced user;

> "Thanks for telling me because I didn't spot the lines [on the HMI display]. So because I'm unsure of what state it's in, what I'm going to do is press the brake and I'm going to start all over again…"

Mode confusion occurs when the human operator of a system fails to understand the current and future state or behaviour of automated subsystems (see Sarter & Woods, 1995; Stanton & Salmon, 2009). In this case, the driver believed that the system was on when actually it was not (e.g. Sarter, 2008). This statement implicates the importance of HMI design and suggests that the current prototype lacked transparency (Stanton & Marsden, 1996) although these types of error might reduce over time as experience in using the system increases;

> "I think it's quite clear and precise really. You know exactly what you're being offered and when" [experienced user]

The experienced user of the system provided evidence of a good working knowledge of the vehicle subsystem and appeared at ease throughout the drive apart from when the automation behaved in a way that was unexpected (e.g. automation surprise; Sarter et al. 1997). This behaviour deviated from their established mental model of system operation signalling a breakdown of driver-automation coordination. At this point, the driver sought clarification from the Safety Driver and appeared anxious;

> "What happened there? .....I'm just a bit more aware, there's a few things that happened back there that makes me definitely keep in control of it"

This unanticipated system behaviour challenged internal mental models surrounding system functionality and disrupted normal data-driven and knowledge-driven monitoring of the system (Sarter et al. 2007). It is errors like these that have the potential to result in future accidents especially if the automation behaves consistently for prolonged periods enabling drivers to become complacent. Complacency may have happened to the experienced user of the system;

> "I was thinking it's going to be a breeze on the way down, not a problem and then it went and did something like.... But like you say, on the way back I felt a lot more comfortable. It's knowing exactly what it's going do and what it's capable of"

8.4.2 Subjective stress and workload

The results of the DSSQ are presented in Figure 8.5 and show a shift in Energetic Arousal and Tense Arousal by both users. The post drive scores indicate that the experienced user of Driver-Initiated Automation became less energetically aroused (engaged in the task) and more tensely aroused (stressed by driving) whilst the inexperienced user became more energetically aroused and less tensely aroused. Desmond & Matthews (2009) reported that prolonged driving can produce a loss of task engagement and this appears to be true for the inexperienced user of Driver-Initiated automation. The control transition that took place between the inexperienced user and the automated system appeared to lower task demand and subsequent stress levels.

As Hockey (1997) proposed that the degree of effort required to sustain system performance is directly related to the level of task demand, it comes as no surprise that the inexperienced user reported lower scores on all but one dimension of the NASA-TLX (Figure 8.6). These findings are very similar to those found by Young & Stanton (2002). The experienced user experienced increased workload, perhaps attributable to having greater knowledge of system functionality and its subsequent limitations. This may have led to an increase in the experienced user monitoring subsystem behaviour, which may have followed the behavioural disparity that was experienced between the experienced user and the automated system (as evidenced by the VPA). In addition, the experienced user was potentially more capable of knowing when the automated system was behaving unusually.

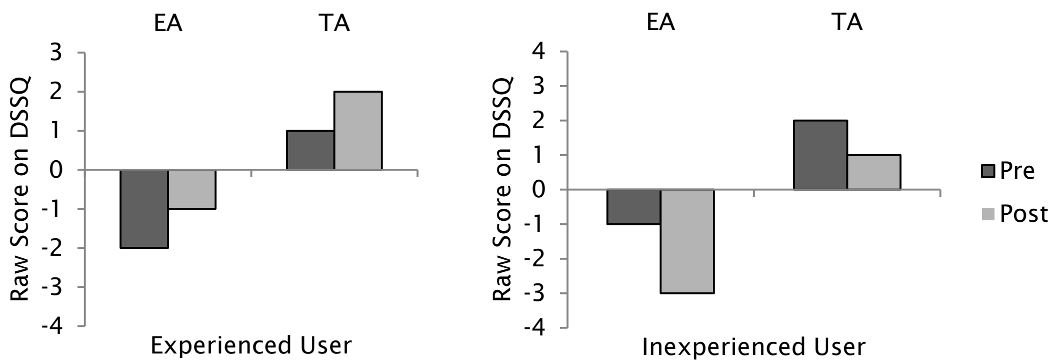


Figure 8.5. Scores on DSSQ for Energetic Arousal (EA) and Tense Arousal (TA)

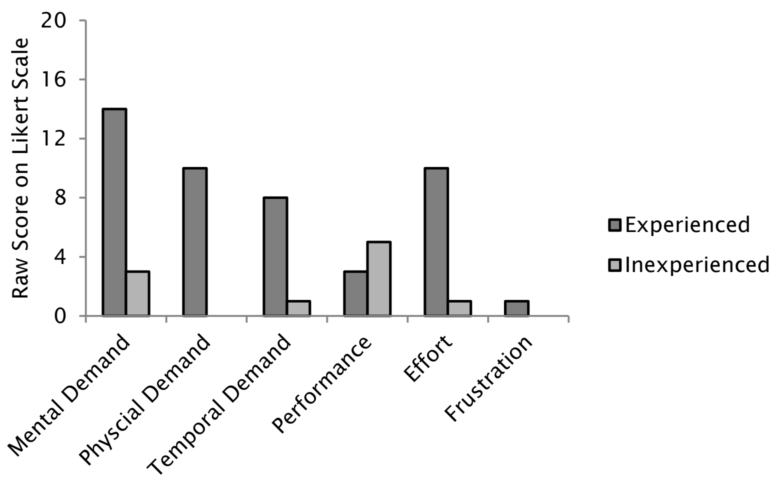


Figure 8.6. Subjective workload scores across the six dimensions of the NASA-TLX for both the experienced and inexperience system user

An automation surprise is likely to be more stressful than a mode confusion because it challenges pre-existing mental models (e.g. Hoc et al. 2009; Revell & Stanton, 2014) whereas the mode confusion is most likely to occur when mental models are still being constructed. It has been previously suggested that the workload imposed by a task can have a direct effect on objective performance and subjective stress response (Matthews et al. 2002). These results support this claim.

8.5 Discussion

Although the use of verbal reports is highly debated (e.g. Baumeister et al. 2007; Boren & Ramey 2000; Ericsson, 2002; Jack and Roepstorff, 2002; McIlroy et al. 2012), they offer a means to explore the momentary thoughts related to driver-vehicle coordination problems. This includes effects of sudden demand transition which can be supported through use of subjective measures (e.g. Helton et al. 2004). Without verbal commentary, it seems unlikely that the problems experienced by the drivers would have been captured. Observation alone did not reveal any problems with driver-vehicle coordination. It was only with the analysis of the verbal commentary that these coordination problems became apparent.

Much like in aviation, automation surprises within driving are likely to be experienced by all drivers, regardless of their experience in using the system. However, it is more likely to cause greater stress to those with greater usage (Sarter et al. 1997). This is because experienced users may have created more robust mental models about how the system functions and have developed more trust in the system (due to its perceived reliability). In contrast, new users of a system remain flexible to change as new experiences that would otherwise be perceived as 'unexpected' help create these robust models in the first place.

Stanton & Marsden (1996) proposed that one of the issues to the introduction of automated aids is when the system itself fails to deliver the expected benefits outlined during its design. These performance shortfalls on the part of the system may actually lead to an increase in accidents due to confusion over system state or not behaving in the way expected by the driver. As integrated ADAS becomes more common on the road to full vehicle automation, it seems likely that the prevalence of automation surprise in a driving environment will become more common. This is because automation remains incapable of coping with all driving eventualities (Norman, 1990). Whilst the prevalence of mode confusion may reduce as drivers quickly learn the different system states (Larsson, 2012), it would seem that a brief introduction to Driver-Initiated Automation was not sufficient enough to avoid mode confusion in this study. Further investigation is required to see whether the mode confusion reported in this study was in fact a designer error (e.g. Chapanis, 1995).

The results of this study highlight also the importance of maintaining the driver in-the-loop to ensure they remain sensitive to changes within their environment (Endsley, 2006; Flemisch et al. 2012). If control is transferred back to the driver when they are least expecting it, their ability to take back control may be restricted and system performance will be significantly affected. Encouragingly, the results of this study demonstrate that far from being removed from the control-feedback loop (Stanton et al. 1997; 2007b), the setup of Driver-Initiated Automation maintained pre-automation driver status meaning that driver-vehicle coordination problems were quickly and effectively overcome. The irony of automation as discussed by Bainbridge (1983) is that highly automated systems still require human operators as automated subsystems have restricted functional envelopes (Zheng & McDonald, 2005). However, as long as automation remains 'adaptable', the division of labour between the driver and automated subsystems can remain dynamic and flexible (Parasuraman, 2000). This means that any deviation from normal system behaviour could be quickly addressed through a swift control transfer back to the driver as was the case of the driver-vehicle coordination problems found in this study.

8.5.1 Practical recommendations for future research

This study offered a very unique opportunity to observe driver-vehicle coordination problems in a more naturalistic setting than that of driving simulator studies. However, there were a number of practical constraints that limited the feasibility of data collection that were beyond the control of the researcher. These included;

- *Commercial Sensitivities*

The Driver-Initiated feature used in this study was an early prototype model. At this stage of development, it was not possible to share detailed information relating to any of the vehicle technology on-board. Due to these sensitivities, this study was constrained to using individuals who held an up-to-date Non-Disclosure Agreement with the sponsoring company and external supplier. Although this issue is not easily overcome in the short term, future research should attempt to widen the demographic of the participant pool to include individuals with a non-engineering background.

- *Test Vehicle Availability*

The test vehicle was only made available for a limited testing period. Although the experimental design had been planned in advance, the testing schedule was significantly shortened due to other commercial needs. This meant that only two drivers could be selected to take part in the study. It is highly recommended that future research should guarantee access to the vehicle to ensure a greater number of participants can take part. An official testing period or "User Trial" would ensure that experimental design and procedures can be followed as planned.

- *Legal Constraints*

For insurance purposes, only drivers with Advanced Driver Training *and* who were employees of the sponsoring company could take part. This was a mandatory requirement for any research being conducted with the use of a prototype technology. However, this was also likely to bias the data to some extent as the sample used in this study was unlikely to be representative of a typical driver population. As employees they also held a vested interest in the success of future market deployment. Although these legal constraints are difficult to overcome in the short term, the use of a Safety Driver in future research may mean that individuals without Advanced Driver Training will be able to participate. Given appropriate permissions, participants representing a typical driver population may be recruited.

- *Sample Size and Demographics*

As an exploratory investigation into driver-vehicle-world coordination problems, this study proved to be an invaluable source of information for system designers at the sponsoring company. However, future research should make use of a larger sample size of mixed age, gender and experience in the use of reliable Driver-Initiated automation. Even so, the opportunity to observe driver behaviour in a naturalistic "hands and feet free" driving system was worthwhile especially when considering that there has been growing concern about what drivers may do if they are not in active control. In addition, with concerns growing over how well drivers will cope in the event of system failure (e.g. Hoc et al. 2009; Shorrock & Straeter, 2006), this research provided some encouraging results. Although it seems unlikely that the final Driver-Initiated Automation product would elicit the same sort of automation surprise observed in this study, both drivers were quickly and efficiently able to regain control of the vehicle despite a sudden increase in subjective stress levels.

It seems likely that the greatest obstacle to overcome in terms of driver-vehicle coordination problems is issues surrounding driver complacency. It is evident that keeping the driver in-the-loop does not safeguard against this phenomenon. Continued research is needed to ensure that overall system safety can be maintained after prolonged periods of reliable automation.

8.6 Future directions

Chapter nine continues to build upon chapter eight by further exploring the relationship between the driver and automated prototype in a real-world setting. Chapter nine specifically seeks to address issues relating to HMI design given the coordination problems revealed in this chapter. It is hoped that data generated from further investigation will lead to strategies for continued design development.

Chapter 9: Driver-Initiated Design: An Approach to Keeping the Driver in Control?

9.1 Introduction

The unanticipated problems that have often been associated with automation implementation has led more recently to a significant call for sociotechnical systems design over *either* human-centred design *or* technology-centred design (Sarter et al. 1997). This means that '*a priori'* acceptability of a technology is likely to become an increasingly important concept to adopt in the continued development of automated driving systems. Although *a priori* infers that the evaluation of a technology can be conducted before having had any interaction with it and thus more likely to generate information relating to driver expectations of system functionality, technology acceptability looks specifically at perceived usefulness and ease of use (Davis, 1989). We learnt from chapter eight that driver expectations of system operation can heavily influence the way in which drivers perceive a 'new' driving feature. The Technology Acceptance Model (Davis et al. 1989) postulates that whilst intentions to use a technology affect subsequent usage behaviour, the perceived ease of use (i.e. systems usability) is also likely to determine the intention to use. If for example a driver perceives an automated system to be confusing, they are less likely to use it. Previous literature has found that driver attitudes are more positive when automated assistance is available during otherwise monotonous driving situations (e.g. Fancher et al. 1998). For example, automated assistance on highways brings the added benefit of improving driver comfort and convenience (e.g. Saad & Villame, 1996). It is important therefore to explore the appropriateness and acceptability of a Driver-Initiated system of automation on subjective reports of driver stress and workload.

9.2 Usability of driver-initiated automation

9.2.1 Aims and objectives

The primary purpose of this study was to conduct an initial assessment of a prototype system of Driver-Initiated automation combining lateral and longitudinal control in addition to an auto-overtake system that could either be accepted or ignored such as the system described in chapter seven. The main purpose of which was to assess the systems design effects on subjective reports of driver mental workload and trust as well as gaining some insight into the design of the HMI. The purpose of the latter assessment was so that any potential design weaknesses within the prototype HMI architecture could be highlighted given the coordination problems highlighted in chapter eight. In addition, results of any subsequent analysis would provide recommendations for suitable revision that would improve system transparency. This is because it was recognised that the "weakest link" within a Driver-Initiated system could lie between the HMI and the driver. This process followed Phase 2 of the Systems Design Framework (Figure 9.1).

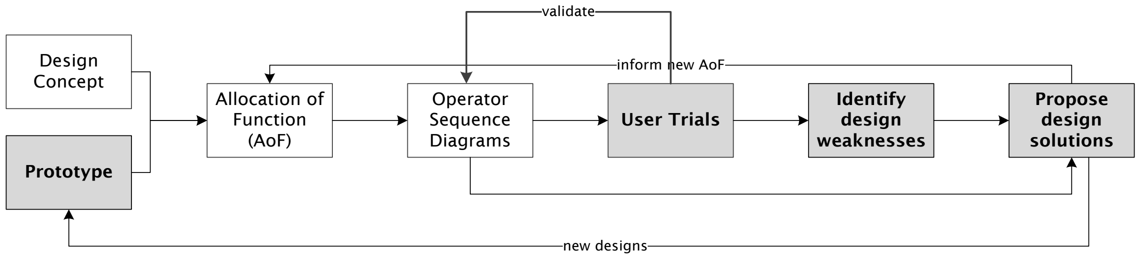


Figure 9.1. Aspects of the Systems Design Framework applied during chapter nine as shown in grey

9.3 Method

9.3.1 Participants

A total of 32 participants (mean age = 38, SD = 10.8) were recruited from the staff cohort of the sponsoring company. The study was made available to all employees via an internal Google Calendar where they were asked to select a time and date most suitable to them. All participants held a full UK driving licence and were between the ages of 25 and 60. This was to ensure that the performance decrements often demonstrated by older drivers (i.e. over 65s) did not affect the results of the study.

Ethical permission to conduct the study was sought and granted by the sponsoring company. A comprehensive risk assessment included a number of mitigation measures. For example, the role of the Safety Driver was not only to monitor the roadway environment to ensure that manoeuvres could be performed safely but also ensured that if for any reason the driver failed to regain control of the vehicle following an audible and visual system warning, they could provide verbal instruction. Importantly, all participants were told that whilst system warnings may occur in the Automated driving condition, a total loss or failure of automation would be unlikely to occur. Even so, the Safety Driver could override the automation completely (i.e. switch back to Manual) by pressing a button if needed. In addition, a Safety Vehicle was used to monitor the traffic ahead of the test vehicle and communicate any hazardous situations, such as harsh braking, to the Safety Driver via radio link.

9.3.2 Experimental design and procedure

The test vehicle was a left hand drive, medium sized family saloon car equipped with a prototype system of longitudinal and lateral control that allowed for the automation of driver-initiated overtake manoeuvres (i.e. pull out and pass). Although participants were UK licence holders, they were all familiar with driving left hand vehicles on UK roads which was an essential demographic criterion to ensure that task complexity was not inadvertently increased by a lack of experience in driving left hand vehicles.

Upon providing informed consent, participants were given an introduction to the functionality of the system within the vehicle. Within this introduction, drivers were presented with a series of icons that they may see on the HMI that was represented on a Head-Up display situated on the windscreen (see Figure 9.2). Following this introduction, drivers were invited to familiarise themselves with the controls and ask any questions.

Drivers were requested to complete two driving conditions within a 20.4 mile circular test route along the M40 motorway; Manual and Automated (Figure 9.3). The presentation of these conditions to drivers was counterbalanced to eliminate order effects. Upon joining the carriageway, drivers were instructed to maintain a speed of 110 kilometres per hour (70 miles per hour) and abide by UK driving law at all times. Drivers were not directly invited to drive “hands free” at any time but were invited to drive in a manner they felt comfortable with. Throughout each experimental condition, drivers were invited to perform three basic driving manoeuvres; maintain speed and distance to Target Vehicle, perform an overtake (pull in and out) and finally perform a lane change without use of directional indicators when safe to do so. In the Manual driving condition, the autonomous features were not active. In the Automated driving condition, drivers were invited to activate the automated system as soon as they had safely joined the highway. Drivers were prompted to perform these manoeuvres by a Safety Driver who sat in the front passenger seat and upon completion were asked a series of questions by the researcher who was sat in the back of the vehicle. These questions were specifically designed to assess driver knowledge and understanding of the HMI prototype in an effort to highlight design weaknesses within the current system architecture. Responses were recorded through use of video and audio equipment as well as written observational notes. The content of the interview was subjected to Thematic Analysis as has been previously demonstrated by Banks et al. (2014). In addition, drivers were invited to complete the NASA-TLX (Hart & Staveland, 1988) and Checklist for Trust between People and Automation (Jian et al. 2000) following each driving condition to measure subjective ratings of workload and trust.

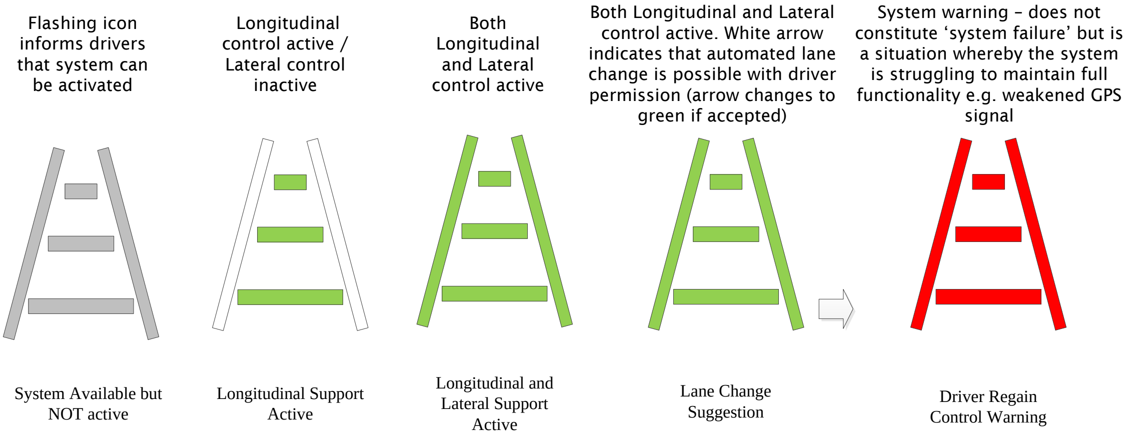


Figure 9.2. Schematic representation of display icons located on head-up HMI

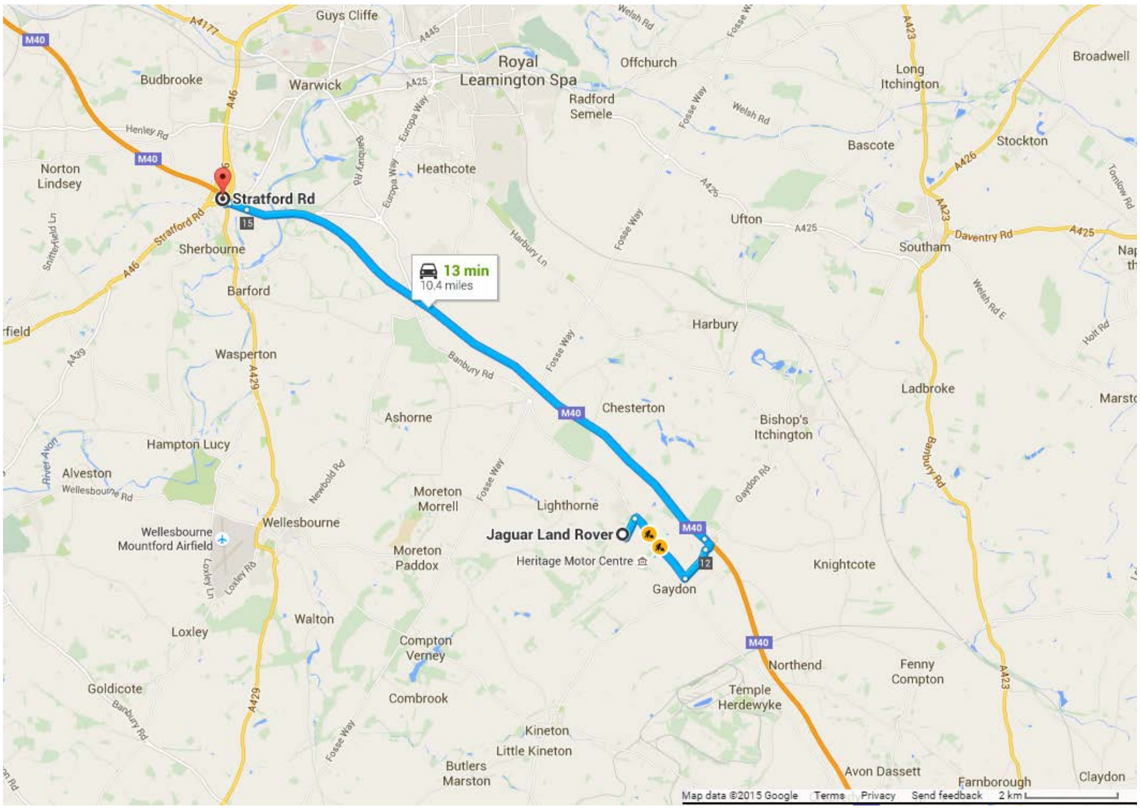


Figure 9.3. Test route section of the M40 used within the study

9.3.3 Data reduction and analysis of observational data

An initial coding scheme was developed using a data-driven approach. The aim of the coding scheme was to reveal information relating to system usability and driver behaviour. A small focus group consisting of two design engineers and two human factors researchers read through all of the driver responses to the structured questionnaire and began to highlight key themes. Following repeated iterations, the focus group agreed on a final coding scheme consisting of five key themes (see Table 9.1). Four verbal transcripts (representing approximately 10% of the sample) were selected at random to be subjected to further analysis by a secondary coder to calculate inter-rater reliability. This analysis resulted in 97.88% agreement, which is over the 80% threshold (Marques & McCall, 2005).

9.4 Results

9.4.1 Thematic analysis

Results were analysed based upon the frequency of code occurrence in each driving condition (Table 9.1). They provide a useful, albeit, exploratory insight into driver perception of system usability and possible design deficiencies within the current prototype architecture.

Results of individual Key Themes are discussed in turn.

- Knowledge of system engagement

Figure 9.4 shows the frequency of occurrence for the Knowledge of System Engagement key theme. It indicates that the primary information used by drivers to ascertain if the system was engaged or not was the Head-Up HMI display for both Manual and Automated driving. This suggests that the interaction or link that exists between the driver and HMI agent is extremely important. Figure 9.4 also indicates that the emphasis that drivers placed upon each category was affected by the level of assistance that they received. For example, drivers were more likely to reference being in control and using information from their environment to aid their understanding of system engagement in Manual driving, whilst more emphasis was placed upon physical feedback from the vehicle in Automated driving.

- Expectation management

The management of driver expectations regarding their subjective perception of "how" the system would behave was on the whole very good (Figure 9.5). However, driver expectations of system behaviour were more likely to be unmet in Manual driving. Reasons for the mismanagement of driver expectation may be found in an analysis of codes relating to System Usability.

- System usability

Figure 9.6 shows that whilst it is encouraging to note a high number of positive references to understanding the HMI were observed for both Manual and Automated driving, drivers were more likely to misunderstand the meaning of the HMI in Manual driving. A common mistake was for drivers to think the system was actively assisting the driver when it was not, representing a form of mode confusion (Norman, 1990; Sarter & Woods, 1995; Stanton & Salmon, 2009). In many instances, this represented that driver expectation of system functionality went beyond the original design parameters hence the increased frequency of driver expectations being unmet signalling an issue within the feedback presented to the driver via the HMI. Even so, drivers were able to correctly identify the system state most of the time; 89% correct in Manual driving and 85% correct in Automated driving.

In addition, code frequencies for the remaining subthemes of System Usability highlight a number of other important considerations that may affect the way in which drivers choose to use the automated system in the future (Figure 9.7). For example, unexpected lane changes (caused directly by the driver inaccurately using the controls) and the perception of unsafe lane offerings, although experienced by only a small number of participants, indicate that the driver-initiated system in its current state requires some modification. The implications of these 'negative' experiences are likely to be reflected in subjective trust and workload ratings.

Table 9.1. Coding scheme, descriptions and frequency of occurrence for manual driving and automated driving whilst the system of driver-initiated command and control was active

Key Theme	Subthemes	Description	Frequency	
			Manual	Automated
Knowledge of System Engagement	Driver in Control	References to the Driver being in control / not having engaged system	43	17
	Information from the Environment	References to look at other traffic, lane markings	29	15
	HMI Display	References to the colour of lines / icons	67	65
	Physical Feedback	References to physical feedback from the steering wheel	14	39
	Automation in Control	References to the Automation being in complete control of vehicle operation	N/A	8
Expectation Management	Expectation Met	Realistic expectation of system operation	80	76
	Expectations Unmet	Unrealistic expectation of system capabilities	15	7
	Unknown Expectation	Driver did not know what to expect	2	3
Behavioural Observations	Driving "Hands off"	Observation of "hands free" driving	N/A	41
	Failure to Regain Control following System Warning	Observation that Drivers required prompts to regain control of the steering wheel	N/A	7
System Usability	Required Assistance from Safety Driver	Verbal instruction given to Driver regarding system functionality / meaning	2	11
	Unexpected Lane Change Occurred	Vehicle moved across two lanes instead of one.	N/A	3
	System Initiation Problems	Struggling to turn the system on or off	N/A	9
	Perception of Unsafe Lane Offerings	Mismatch between driver perception of safety and what the system suggests is safe	N/A	2
	Misunderstanding of HMI Display	Misinterpretation of HMI display	22	6
	Correct Understanding of HMI Display	Correct interpretation of HMI display	40	57
System Mode	System On	Driver reports system is on	7	76
	System Off	Driver reports that system is off	85	11
	Unsure	Driver reports that system status is unknown	4	3

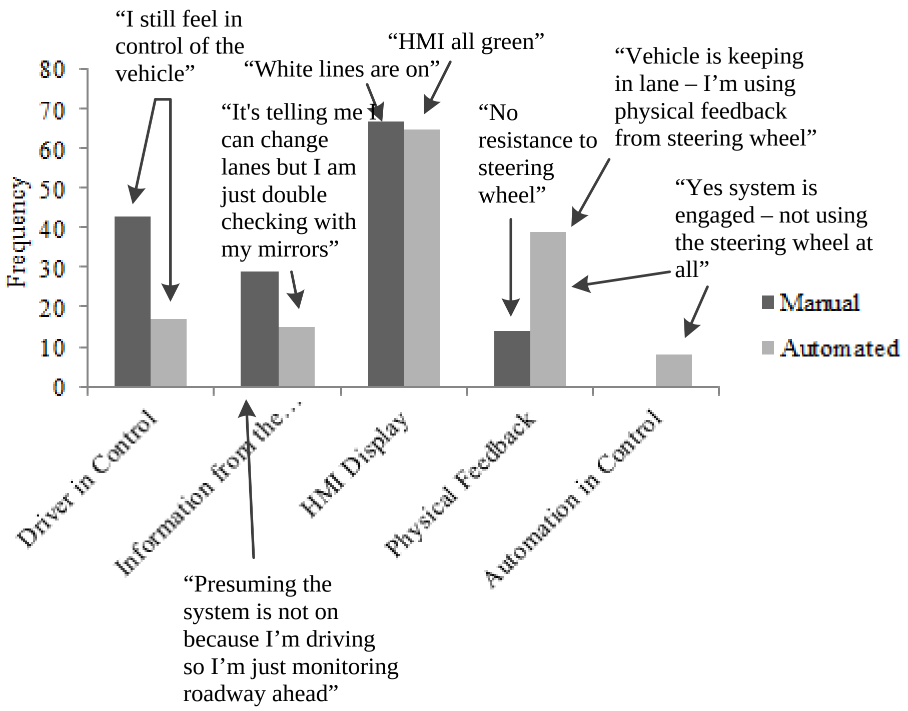


Figure 9.4. Frequency of subthemes regarding Knowledge of System Engagement

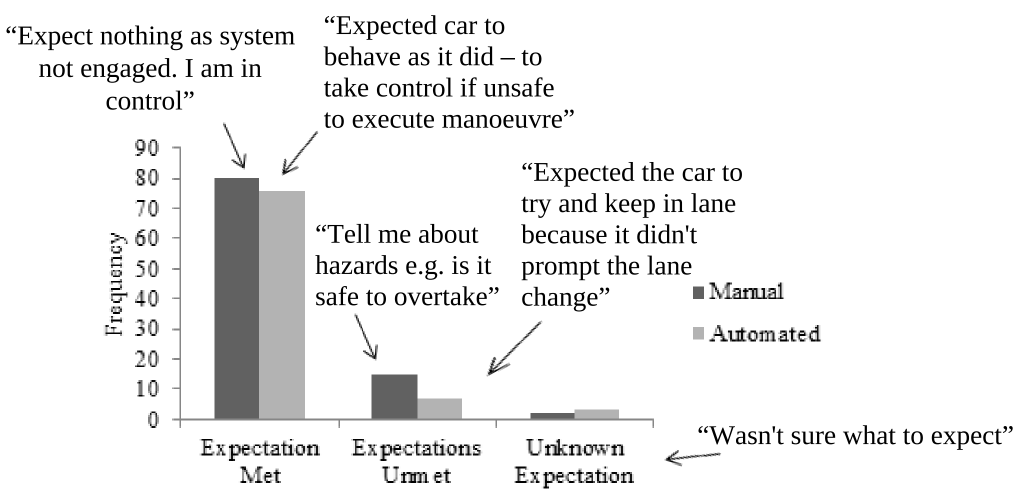


Figure 9.5. Graphical representation of subthemes relating to Expectation Management

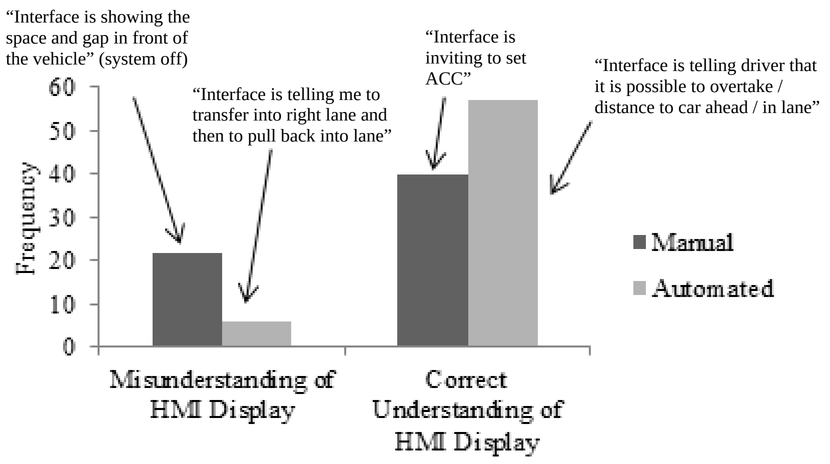


Figure 9.6. Driver Understanding of HMI content based upon level of automated assistance

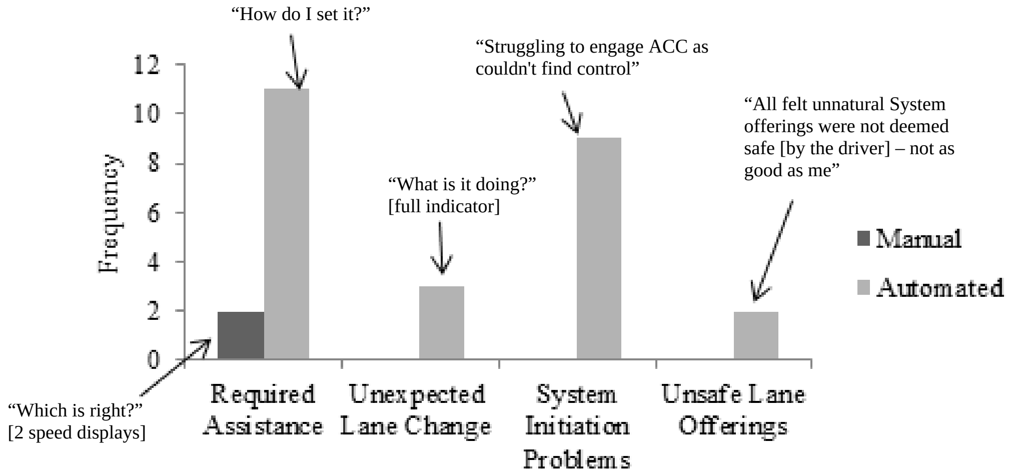


Figure 9.7. Frequency of automated system design issues experienced by drivers

- Behavioural observations

Out of a possible 96 instances where the driver could become 'hands and feet free' whilst driving in automated mode, 41 observational references, made by the experimenter who was sat in the back of the test vehicle, were made to being 'hands free'. This means that almost half of the manoeuvres in the Automated driving condition saw the driver adopt a more 'supervisory' role, allowing the vehicle to perform the manoeuvre or task autonomously. This is an important observation for designers to consider, especially given that in the current study, drivers were told to remain in control of the vehicle at all times.

Their willingness to allow the vehicle to take full control could signal a form of complacency.

In addition, and what is more concerning, is that seven drivers had to be prompted to regain active control of the vehicle following a system warning. Although this represents a small proportion of the sample, it highlights a severe deficiency in the current design of the warning system.

9.4.2 Driver trust

Results of the 7-point Checklist for Trust between People and Automation (ranging from 1 ‘Not at all’ to 7 ‘extremely’) show that driver responses to negatively framed questions are consistently rated less favourably for automated driving in comparison to manual driving (Figure 9.8). Wilcoxon signed rank tests revealed the following; deceptive ($z = 2.532$, $p < 0.05$, $r = 0.45$), underhanded ($z = 2.076$, $p < 0.05$, $r = 0.37$), suspicious ($z = 3.749$, $p < 0.01$, $r = 0.66$), wary ($z = 3.306$, $p < 0.01$, $r = 0.58$) and harmful ($z = 2.864$, $p < 0.01$, $r = 0.51$). This may be attributed to drivers not having yet learnt the competence limits of the technology (Fitzhugh et al. 2011) or having experienced some of the issues highlighted above (e.g. unsafe lane offering). It may also signal underlying issues, such as a refusal to transfer control to an automated system despite Driver-Initiated design that is used to maintain a command-control relationship between the driver and automation.

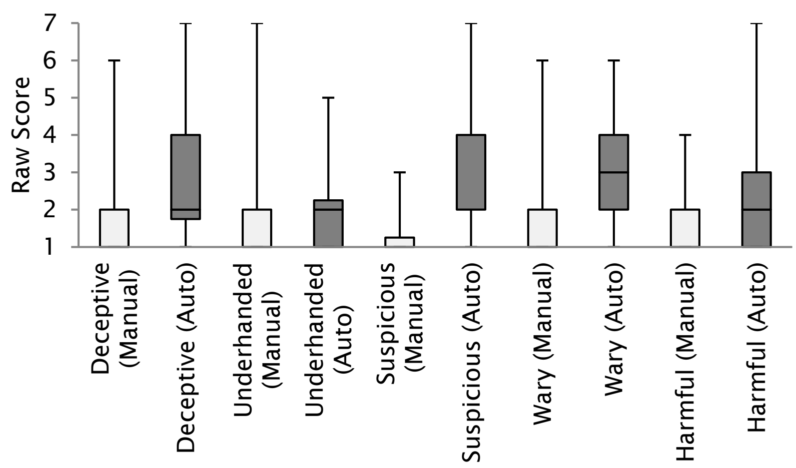


Figure 9.8. Responses to Negatively Framed Questions

Again, manual driving was rated more favourably than automated driving when drivers were asked positively framed questions (Figure 9.9). Wilcoxon signed rank tests revealed the following; confident ($z = -3.546$, $p < 0.05$, $r = -0.63$), security ($z = -2.170$, $p < 0.05$, $r= -0.38$), dependable ($z = -2.999$, $p < 0.05$, $r = -0.53$), reliable ($z = -2.974$, $p < 0.05$, $r = -0.53$) and trust ($z = -3.469$, $p < 0.05$, $r = -0.61$). The greater range in driver responses to automated driving is likely to be a reflection of the consequence of first time system use in addition to the discussion of negatively framed questions. In order to encourage driver trust in automation (Ashleigh & Stanton, 2001; Lee & See, 2004; Stanton, 2011), drivers need a clear understanding of what the system is capable of and its purpose (Rasmussen et al. 1994). Any violation of a driver's expectation of system functionality is likely to have an effect on subjective ratings of trust. For example, Dzindolet et al. (2002) propose that naive operators are more likely to expect automated assistance to be capable of outperforming them. If the automation fails to perform in the way expected, ratings of trust begin to decline (Wiegmann et al. 2001). Future research should seek to expose drivers to longer periods of highly automated driving to see if subjective ratings of trust change over time.

A 'negative' first time experience of using a new automated system is also likely to affect subjective ratings of driver workload as internal mental models are continually challenged as the driver attempts to build a picture of how the automated system works. Any sudden or unexpected system behaviour is likely to induce stress and increase workload. For example, an unexpected lane change could lead to an automation surprise (Sarter et al. 1997) that could result in a sudden increase in driver workload as they attempt to understand 'why' the system is behaving in this way as well as inducing driver stress.

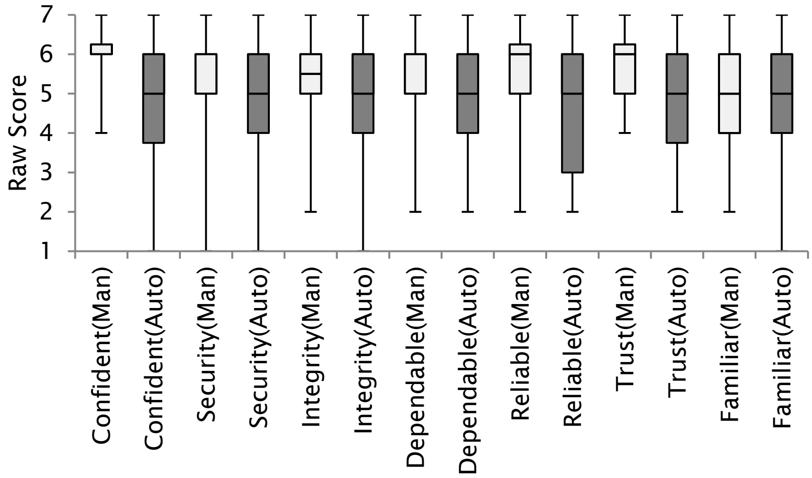


Figure 9.9. Responses to Positively Framed Questions

9.4.3 Driver workload

Analysis of the NASA-TLX revealed that median Overall Workload scores were significantly higher in automated driving (*Mdn* = 42) in comparison to the Manual drive (*Mdn* = 26.5), $z = 3.107$, $p < 0.005$, $r = -.55$ (Figure 9.10).

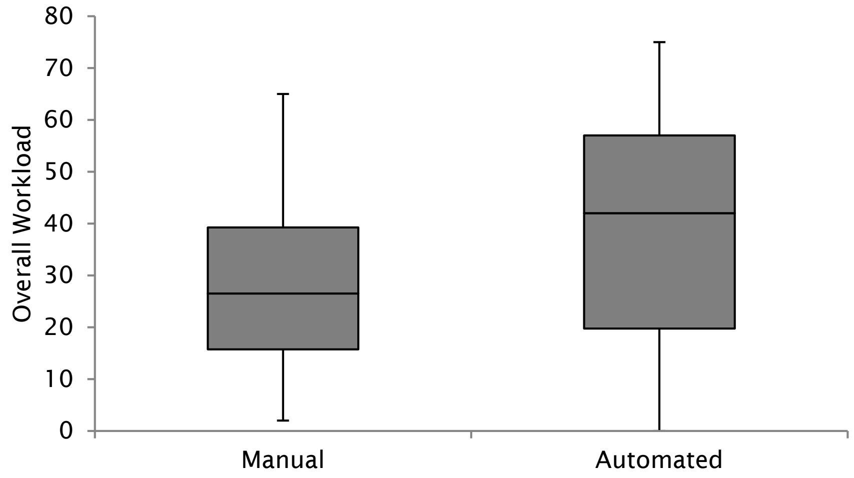


Figure 9.10. Overall workload scores of the NASA-TLX between manual and automated driving conditions.

Further analysis of the individual subscales of the NASA-TLX revealed significant differences between mental demand ($z = 3.327$, $p < 0.005$, $r = -.59$), temporal demand ($z = 3.134$, $p < 0.005$, $r = -.55$), effort ($z = 2.409$, $p = 0.05$, $r = -.43$) and frustration ($z = 2.843$, $p < 0.005$, $r = -.50$) with automated assistance consistently resulting in increased ratings (Figure 9.11). This on the one hand may be a simple reflection of the fact that these ratings were collected during first time use of the automated system. However, it may also signal more important issues that require consideration. For example, increased workload could be a reflection of the additional requirement for drivers to monitor system behaviour and ensure the vehicle was responding effectively, in addition to traditional driver monitoring of other traffic on the road (de Winter, 2014; Stanton et al. 1997, 2001, 2005; Merat et al. 2012; Young & Stanton, 2002) as they develop their internal working models. This means that although the driver was not in direct control of vehicle outputs, they had to remain aware of changes in their environment (Parasuraman & Wickens, 2008) suggesting that far from reducing workload, automation may simply shift driver attention to other tasks such as system monitoring (Reinartz & Gruppe, 1993). This additional responsibility could be enough to increase subjective workload ratings (Stanton et al. 1997, 2001, 2005).

However, over time, subjective workload ratings of driving may begin to decrease as additional attentional resources are released to complete other tasks (Liu & Wickens, 1994; Rudin-Brown & Parker, 2004; Stanton et al. 2001). de Winter et al. (2014) argued that automation of longitudinal and lateral control is distinctly different from traditional Adaptive Cruise Control because it has the potential to divert driver attention to secondary tasks. In addition, Carsten et al. (2012) report that drivers are more likely to engage in other tasks when they receive lateral support. Future research should expose drivers to increased duration of automated driving to see how comfort levels and ratings of workload change over time. This would be especially useful to see how levels of driver engagement are affected by increased durations of automated control.

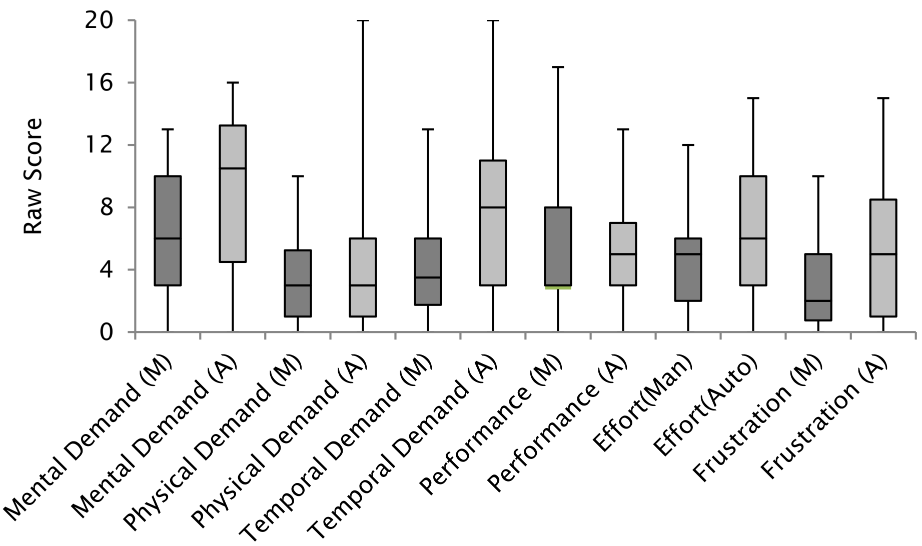


Figure 9.11. Subjective workload scores across the six dimensions of the NASA-TLX (M = Manual; A = Automated)

9.5 Design recommendations for future user needs

The benefit of adopting a driver-initiated systems design is that an element of command and control remains within the driver's grasp (Banks & Stanton, 2014). This means that rather than becoming a passive monitor of the system (e.g. Byrne & Parasuraman, 1996) the driver remains an active supervisor. This means that although the status of the driver within the control-feedback loop has changed, a *Driver Initiated design* could prevent against the disintegration of driver-vehicle links within the control-feedback loops (Banks et al. 2013; Banks & Stanton, 2014). Based upon the results presented in this chapter, it is clear that the prototype system of Driver-Initiated automation used in this study requires further development in order to improve ratings of driver trust and workload. Although it was hypothesised that a Driver-Initiated automated control system could protect against the occurrence of out-of-the-loop performance problems often cited within the wider literature (e.g. Billings, 1988; Endsley & Kaber, 1997), it is not clear whether or not a command-control relationship between the driver and automation will be successful. However, it is proposed that such a system may be successful if appropriate design modifications are made. These are based upon both improving the transparency of systems design through HMI feedback and setting more appropriate system limits that eliminate the likelihood of the automation behaving in an inconsistent manner (e.g. remove the potential for unsafe lane offerings and unexpected lane changes). The researcher proposes the following systems design modifications;

1. Remove the capability of the automated system to offer an automatic overtake. Although the occurrence of unsafe lane offerings was low (Table 9.1), it highlights an important facet in the development and maintenance of driver-automation cooperation (Hoc et al. 2009). Removing the overtake offering will mean that drivers will need to continue to rely upon their own judgement in initiating complex driving manoeuvres with the knowledge that a background system of automation is capable of overriding the driver (i.e. it will not change lanes if a fast moving vehicle occupies the intended lane) if the manoeuvre cannot be completed safely. In its current state, the prototype used in this study does not reach an acceptable standard of combining human decision-making with automated decision-making (Madhaven & Wiegmann, 2007). According to Moiser & Skitka (1996), human-machine decision-making should result in a high-performing control system that enhances the quality of joint performance. However, the conflict that existed between the driver and automation highlighted that a thorough appraisal of driver decision-making processes relating to the execution of an overtake manoeuvre had not been completed. Madhaven & Wiegmann (2007) argue that it is essential that such an analysis be completed if automated support systems like this are to be a success. Systems developers may be underestimating the power of 'trust' in determining the success of human-automation performance (Sheridan & Ferrell, 1974; Lee & See, 2004; Walker et al. 2015). Instead, the authors recommend removing the offering as performing an automatic overtake manoeuvre is driver-initiated regardless of the presence of a system offering. In other words, the offering is meaningless given that as soon as

the driver expresses their intent to change lane, as signalled by manipulation of the directional indicators, the automated system takes over. The removal of the lane change suggestion would therefore not reduce the overall level of automation.

2. Remove the capability of the automated system to change more than one lane at a time. This would mean that in order to travel from Lane 1 to Lane 3 of a highway, *two* driver initiated lane changes would be needed. Although only 9% of all overtake manoeuvres resulted in an unexpected lane change, it highlights the potential for such system behaviour to occur in the first place. System behaviour that is unwanted is not only likely to affect ratings of driver trust and workload, but also have the potential to affect the safety of other road users. For instance, an automated manoeuvre could indirectly lead to a road traffic accident if any other vehicles on the network take evasive action to avoid the host vehicle.

3. Improve the HMI feedback provided to the driver during manual driving. Presently, the symbology relating to system availability leads to driver confusion over system state. Although the occurrence of this form of mode confusion may reduce as drivers become more familiar with the system (Larsson, 2012), more transparent HMI content could reduce the frequency of occurrence further (Stanton et al. 2011).
   In addition, the current prototype may be inaccessible to individuals who are colour blind and thus further testing is required to ensure that inclusive design principles are followed. According to the Colour Blind Awareness organisation, approximately 1 in 12 men and 1 in 200 women have some form of colour vision deficiency. This equates to 4.5% of the UK population.

4. Improve the warning system used to encourage drivers to regain control of the vehicle. With nearly one quarter of the sample used in this study failing to place their hands back on the wheel in safety critical driving situations, the current system may fail to maintain the safety of both the driver and other road users. Whilst Noujoks et al. (2014) support the use of visual-auditory takeover requests as featured on the prototype used in the current study, more explicit warning was needed in this instance. It has been suggested that screen-mounted LED's may capture attention more quickly (Noujoks et al. 2014). Even so, visual-auditory warnings are more favourable than purely visual warnings as people tend to react more quickly to auditory signals despite preferring visual warnings (e.g. Shelton &

Kumar, 2010). Noujoks et al. (2014) found that reaction times to system failure (i.e. time between the warning and the driver regaining control of the vehicle) was between 0-5 seconds for visual-auditory in comparison to 0-20 seconds for purely visual warnings. Of course, drivers failing to regain control of the vehicle may have been attributable to a natural curiosity of discovering system capabilities and limits (e.g. risk compensation; Wilde, 1994).

5. Improve the design of system initiation. Analysis of the interview data revealed that many of the issues encountered by drivers were due to inappropriate control location. For example;

"How do I? How does it switch on? Do I push it up? Oh no, that's the indicator…"
"I can't set the cruise control because I don't know where you turn it on…"

For the current prototype, the control stork is located out of the driver's main field of view meaning that in some instances, drivers were actively trying to look for the control which is located on a steering wheel stork underneath the traditional indicator mechanism. These initiation problems could be resolved by moving the location of the automated controls, within easy reach and sight of the driver. Many vehicle manufacturers use steering-mounted controls to engage Adaptive Cruise Control (e.g. BMW, 2014; Jaguar Land Rover, 2014) which would be a more appropriate location for Driver-Initiated automation control systems.

Notably, these recommendations are only applicable to the automated feature that was tested.

9.6 Summary and conclusions

It was found that despite putting the driver in control of the automated systems by enabling them to accept or ignore behavioural suggestions (e.g. overtake), there were still issues associated with increased workload and decreased trust. Trust and workload are important concepts to consider in the future implementation of higher level autonomy because inappropriate levels of trust may lead to disuse (i.e. drivers reject the potential benefits of the system) or misuse (i.e. drivers become complacent: Parasuraman et al. 1993). In addition, a 'negative' first time experience in using the system could lead drivers to reject the system completely (i.e. not use it even when it becomes available: Sheridan, 1988). This means that in order for drivers to experience the full benefit afforded by the automation of longitudinal and lateral control, they must have appropriate levels of trust in system operation (Lee & See, 2004).

In order for the implementation of the automation of longitudinal and lateral control to be a success, the driver must be comfortable with the degree of control transfer given to the system. Interestingly an investigation by Larsson (2012) surrounding the usage and perceived issues of vehicles equipped with traditional Adaptive Cruise Control technology found that despite previous concerns, the very fact that Adaptive Cruise Control is not a perfect system means that intermittent changes in control between manual and automated driving is actually beneficial to performance because the driver remains actively in the control loop (Stanton & Marsden, 1996; Bryne & Parasuraman, 1996; Stanton & Young, 2005; Walker et al. 2015).

There are still concerns that after prolonged exposure to highly automated driving, driver desensitisation may occur resulting in a lack of task engagement. If this happens, manual override in unanticipated and unexpected events will be difficult to manage, increase workload and stress as well as create surprise or startle effects (Sarter et al. 1997). For example, Merat & Jamson (2009) and Young & Stanton (2007b) have shown that driver response times to unexpected hazards increase by 1.0-1.5 seconds when driving with Adaptive Cruise Control in comparison to manual driving. Notably, this increased response time was for well motivated and alert drivers. This has previously been attributed to cognitive underload (Vollrath et al. 2011; Young & Stanton, 2002), reduced responsibility (Farrell & Lewandowsky, 2000) and the cost of control transfer between automated and manual control (Funke et al. 2007). These are issues that may become more prevalent as drivers become more familiar with the mode of system operation and experience months or years of high reliability. These remain important areas of future research.

Chapter nine builds upon chapters seven and eight by providing a thorough appraisal of the role of the driver within a Driver-Initiated system of automation. Where chapter eight revealed evidence of driver-vehicle coordination problems, chapter nine advances our understanding of system usability further by highlighting a number of design weaknesses that may contribute to the occurrence of driver-vehicle coordination issues. For example, unexpected system behaviour leading to automation surprise may result from system initiation issues in some cases.

Chapter ten concludes the thesis by summarising the research objectives in light of the findings presented in previous chapters. It evaluates the research approach and briefly discusses areas of further academic enquiry that have arisen from this research.

Chapter 10: Conclusions and Future Work

10.1 Introduction

The aim of the research presented in this thesis was to investigate how automation implementation into the driving task affects traditional driver-vehicle interaction patterns that have been inherent in our society for decades. This aim also encompassed advancing our understanding and investigation of driver-vehicle interaction using a mix of qualitative and quantitative research methodologies. The main findings are discussed below along with a discussion on the contributions and implications of the research. The limitations of the research approach are addressed along with a discussion of avenues for future academic enquiry.

10.2 Summary of findings

The work presented in the thesis was structured around three key objectives. The findings are summarised in relation to the aims and objectives of this research.

10.2.1 Objective 1: Increase the awareness of Human Factors in the design of automated aids by focussing on the interaction that occurs between the driver and other system agents

Chapter three introduced the concept of Distributed Cognition in driving and described how it may be applied using a two phase Systems Design Framework that was developed as part of this thesis. This multi-method framework seeks to better define and recognise the role of the driver and how it may change as a result of automation implementation. As long as the system to be modelled is well defined (e.g. the components required to complete the function are known), analytical methods can be used to model individual system agent behaviour using traditional task analysis techniques (Stanton et al. 2013). Whilst in the automotive industry, the use of sequence diagrams has typically been based upon modelling the interaction that occurs between technological components, the framework presented in this thesis takes into account *all* of the agents involved in the driving task (both human and non-human).

Empirical methods applied during Phase 2 of system development helped identify other design weaknesses, beyond technological components, that required modification (e.g. chapters five, six, eight and nine).

Overall, this thesis demonstrated the possible use of the Systems Design Framework within the automobile industry (chapters seven, eight and nine). It successfully provided Systems Engineers and Designers with a foundation to design and conduct research into the human factors implications of increasing levels of automation within the driving task using methodologies that have substantial pedigree.

10.2.2 Objective 2: Assess the appropriateness of automation deployment and context of use

The novel application of Network Analysis to driver decision making in emergencies in chapter five has been useful in highlighting the inherent differences in driver processing at different levels of automation within the driving system implicating both the contextual use of automation and also the appropriateness of systems design. For example, remembering that the intention of an AEB system is not to remove the driver from the control-feedback loop but instead serve as a 'backup' in case of the driver failing to intervene effectively, findings presented in chapter six suggest that in some instances, the presence of AEB alone can affect the way in which drivers process the information from their environment and their subsequent response. This means that despite significant improvements to road safety (i.e. reduced frequency of accident involvement with the addition of AEB), there are still important aspects of its design that should not be ignored (i.e. the appropriateness of system warnings).

Chapter eight also provides a useful, yet worrying insight, into how the level of driver experience in using highly automated driving features may lead to 'automation surprises' in the case of unexpected system behaviour. It also highlighted the possibility of driver coordination problems to arise in the first place.

10.2.3 Objective 3: Provide design guidance on automated features based upon experimental evidence

Recommendations for design development were proposed in chapter nine for a new prototype system of automation based upon thematic analysis of driver protocols. These protocols gave light to issues relating to the transparency of the HMI. Based upon these results, recommendations were put forward in an effort to improve system transparency and set further functional limits to avoid 'unexpected system behaviour' that would otherwise be caused by human error (e.g. such as in the case of unexpected lane changes which were caused directly by the driver inaccurately using the controls).

These recommendations were accepted by the industrial partner associated with this research. New HMI designs have sought to improve system transparency and make the role of the driver even more prominent. One of the main alterations is that the lane change suggestion has been removed. This means that an automated lane change is now fully driver-initiated and the system can no longer 'suggest' a lane change. Instead, the vehicle will only change lanes automatically if the system is engaged and the driver expresses their intent to change lane using the indicator stork. In this way, the driver is maintained in-the-loop and must continue to monitor their surroundings, check their blind spots and so on. If the vehicle deems the manoeuvre to be 'unsafe', it will override the driver and stay in lane.

10.3 Evaluation of the research approach

This research used a combination of traditional task analysis techniques to model system behaviour. These were subject to validation from data generated from experimental user trials that incorporated specifically chosen extension methodologies to reveal the underlying cognitive processes of driver-vehicle interaction at differing levels of autonomy.

Qualitative thematic analysis was the primary data analysis technique used in this thesis and formed an integral part of all four studies. Such an approach is highly flexible and can be adapted to meet the needs of the research question. It can provide useful insights that would otherwise be difficult to obtain from purely quantitative data collection. In general, the results are very accessible to many people. On the downside, it is often heavily criticised for not being subject to the same scientific rigour of quantitative analysis due to its subjectivity. However, the novel application of Network Analysis metrics to otherwise qualitative system models and driver protocols provides an exciting area of future research. This is one way of quantitatively analysing qualitative data.

Flyvbjerg (2011) argues that qualitative research practice presents no greater bias than those inherent in other research methodologies as researchers take great care to ensure transparency and reliability. With so many questions remaining to be answered relating to what the driver is actually doing within an automated driving system, verbal protocol analysis can provide researchers with a means to gain insight into 'how' and 'why' drivers use automation in the way that they do. Thematic analysis of driver verbalisations in chapter five revealed that whilst automation in emergencies did not alter traditional driver decision-making pathways (i.e. the processes between hazard detection and response remain similar regardless of the level of automation within the driving task), it did appear to significantly weaken and in some cases remove the links between information processing nodes. This disruption to the decision-making process is an important consideration for the design of future automated technologies as it represents an unexpected outcome of automation implementation.

Similarly, analysis of driver verbalisations in chapter eight revealed evidence of driver-vehicle coordination problems during high levels of automated driving depending upon the level of experience that drivers had in using the system. This was an unexpected finding for system developers who had overlooked the potential for miscommunication to occur between the driver and automated system. Again, driver verbalisations provided insight into the perception of system usability, trust and workload in chapter nine enabling the formation of design recommendations to improve HMI design and system transparency.

Whilst the analysis of driver verbalisations can be labour intensive (Vitalari, 1985), it has been proven to provide rich insights into how individual drivers behave at varying levels of automation. Thus, whilst traditional task analysis and modelling can reveal an insight into how system agents may interact or communicate with one another, verbalisations can act as a tool to validate or dispute the accuracy of these descriptions using qualitative analysis techniques. Relying upon quantitative data alone to meet the aims and objectives of this research would have resulted in an incomplete representation of the issues relevant to driving automation.

10.4 Implications of research

10.4.1 Theoretical

This thesis offers a novel application of the theory of Distributed Cognition to the driving automation domain. It adds to the growing body of literature that stipulates that knowledge does not lie solely within the individual but rather, knowledge lies within all agents involved within a system network (Hutchins, 1995a; Stanton et al. 2006). Throughout the thesis we have seen how Distributed Cognition can be used as a framework to identify allocation of system function and how knowledge can be distributed across system agents. This has been modelled through use of Operator Sequence Diagrams

(Brooks, 1960). Empirical investigations using driving simulator studies and on-road user trials have been used to validate and extend our understanding of these representations.

10.4.2 Methodological

Within this research project, the main stimulus used to elicit driver verbalisations was exemplar questions from the CDM (Klein et al. 1989). This is traditionally a retrospective interview. The associated disadvantages of using the CDM, such as increased vulnerability to memory decay, was highlighted in chapter four. To address this issue, recommendations were made to use CDM in conjunction with a 'freeze probe' technique to address issues of retrieval failure. This alteration to delivery was extremely successful in generating richer insights into driver decision-making in chapter five.

Additionally, the application of Network Analysis to driver verbalisations in chapter five has shown that it is possible to quantitatively analyse decision-making processes. This has made it possible to see 'how' decision-making changes as a result of automation implementation. This new methodological application may be used in future research.

10.4.3 Practical

It is important to consider the practical applications that might derive from this research. One of the key areas for consideration is the application of the Systems Design Framework presented in chapter three, to be applied to other automated architectures within driving. Further to this, there is no reason why this framework cannot be applied to any other system that involves a human operator of an automated counterpart throughout the design process. It is therefore not constrained to driving automation.

10.5 Future work

The potential implications of the findings presented in this thesis have raised several lines for further academic enquiry. These are summarised below.

10.5.1 Automation and the role of driver monitoring

Although subjective measures of driver workload, situation awareness and trust can offer useful and insightful information relating to driver performance, they are not appropriate techniques to monitor behaviour over time in a naturalistic environment. For this reason, future research should concentrate on developing and enhancing more objective measures of driver monitoring that enable non-invasive, real-time monitoring of the driver and what they are doing. Being able to recognise different driver states at higher levels of driving autonomy will enable researchers to explore the most efficient strategies of transferring control.

Of course, as with all methods of driver monitoring, its capability is dependent upon a number of confounding variables including the complexity and sensitivity of calibration and light quality. However, with the continuing trend to develop systems capable of higher levels of autonomy, there is an increased need for communication and coordination between drivers and automation (Sarter et al. 1997). It is therefore imperative that further research into the area of driver monitoring is conducted in order to ensure that the driver remains aware, and is able to access all of the information required at any given time.

10.5.2 Suitability of automation for target demographics

Previous research has already indicated that performance differences do exist between experienced and inexperienced drivers as well as older and younger drivers (Cantin et al. 2009; Patten et al. 2006). Perhaps automation may be most beneficial to specific populations rather than the average user. For example, Clarke et al. (2010) highlighted the safety concerns surrounding older drivers (aged 60+) documenting that out of 2007 accidents, an estimated 60% involved an older driver who was described as being partially to blame for its occurrence, suggesting that there does appear to be a relationship between increased age and prevalence of accident involvement. As mentioned earlier in chapter one, automated technologies may improve the accessibility of personal transportation to a wider population (Khan et al. 2012). One example is sophisticated technologies that can monitor the road ahead may benefit drivers who experience degraded eye sight.

10.5.3 The “ethics” of automation

Both the manufacturing and research community are currently constrained by the limitations of law and convention meaning that whilst a fully automated vehicle is technically achievable, they remain largely illegal across the world. There have been of course recent developments in this area with the first driving licence being issued to the Google Self-Drive Car in 2012 and more recently, Audi in 2014. These permissions have meant that self-drive cars are becoming an increasingly familiar sight on public roads in California. It also means that similar licences are likely to be granted in coming years. Despite this, there are a number of questions that remain to be addressed. These include issues relating to attribution of blame in the case of accidents, whether or not automated vehicles are capable of making moral decisions and whether is it acceptable to enable vehicles to learn and copy undesirable driving habits from the vehicle owner.

At some point, an autonomous vehicle may need to choose between two bad outcomes based upon an inevitable accident (Goodall, 2014a; 2014b). Goodall (2014a) terms this as the “pram or bus stop dilemma”. More research is needed in the growing area of designing moral automated systems, especially in relation to unavoidable accidents involving an automated vehicle (Goodall, 2014a; 2014b; Gerdes & Thornton, 2015).

10.6 Closing remarks

It is hoped that the work presented in this thesis will promote and encourage systems designers and engineers to consider the role of the driver within an automated system network so that some of the human factors issues identified in this thesis are addressed at the earliest design phase.

Appendices

Appendix A: Counterbalance Procedure

1	Manual	Warning	AEB W	AEB nW
2	Manual	Warning	AEB nW	AEB W
3	Manual	AEB W	Warning	AEB nW
4	Manual	AEB W	AEB nW	Warning
5	Manual	AEB nW	Warning	AEB W
6	Manual	AEB nW	AEB W	Warning
7	Warning	Manual	AEB W	AEB nW
8	Warning	Manual	AEB nW	AEB W
9	Warning	AEB W	Manual	AEB nW
10	Warning	AEB W	AEB nW	Manual
11	Warning	AEB nW	Manual	AEB W
12	Warning	AEB nW	AEB W	Manual
13	AEB W	Manual	Warning	AEB nW
14	AEB W	Manual	AEB nW	Warning
15	AEB W	Warning	Manual	AEB nW
16	AEB W	Warning	AEB nW	Manual
17	AEB W	AEB nW	Manual	Warning
18	AEB W	AEB nW	Warning	Manual
19	AEB nW	Manual	Warning	AEB W
20	AEB nW	Manual	AEB W	Warning
21	AEB nW	Warning	Manual	AEB W
22	AEB nW	Warning	AEB W	Manual
23	AEB nW	AEB W	Manual	Warning
24	AEB nW	AEB W	Warning	Manual

Appendix B: Participant Information Sheet I

UNIVERSITY OF Southampton

Study Title: Does the level of automation in Pedestrian Warning and Detection Systems affect driver performance?

Researcher: Victoria Banks **Ethics number**: 7740

Please read this information carefully before deciding to take part in this research. If you are happy to participate you will be asked to sign a consent form.

What is the research about?
This research forms part of an EngD project that aims to assess the degree of driver behavioural adaptation as a result of increased vehicle automation. Systems design is plagued by criticism for failing to adequately define the role of the human within the system as a whole. We argue that rather than focussing only upon technical limitations of automation, a holistic approach is needed to ensure that the risks associated with behavioural adaptation are not ignored. Questions still remain over whether or not automated technologies that are capable of performing the same information processing functions as the driver fundamentally change the driving task by affected the ways in which the driver interacts with vehicle systems.

Why have I been chosen?
You have been chosen because you are aged 18 or over and hold a full UK driving licence with at least 12 months driving experience.

What will happen to me if I take part?

The experiment will last approximately 2 hours 30mins in total. After completing and signing the consent form, you will be trained in the method of Verbal Protocol. This means that you will be able to verbalise your behaviour during the simulated driving task. The experimenter will then show you the simulator controls and you will be given the opportunity to practice using it. Once you are happy with operating the simulator you will drive the first test scenario. You will be asked to complete four test sessions, each lasting 20 minutes (10 minutes driving with concurrent protocol; 10 minutes retrospective protocol). These sessions will **not** be identical;

1. A manual session will enable you as the driver to complete the circuit independently.
2. A warning session will mean that an auditory warning will sound when the Pedestrian Detection system identifies a pedestrian in the vehicle path. At the sound of the warning, you will be expected to take intervening action.
3. An automatic braking session will mean that the Pedestrian Detection system is able to perform an emergency stop in order to avoid collision.
4. A warning with automatic braking session will mean that the Pedestrian Detection system provides an auditory and visual warning before an emergency stop is performed by the system.

During each session, you will be expected to use verbal protocol which will be recorded using a voice recorder.

Note that these sessions will occur in any order. You will be asked to talk throughout the test scenario. These protocols will be recorded. I am interested in what you are thinking about as you drive. I am not assessing your ability to drive. After each test scenario, you will be asked to provide a retrospective account of the task. I am interested in what you remember from the task and the information that you used to complete the task.

All phases will be driven using manual transmission. Once all four sessions have been completed, you will then be free to leave.

Are there any benefits in my taking part?
You will be providing valuable data regarding the performance impacts of different levels of driving automation.

Are there any risks involved?
Although risks are minimal, some participants may experience motion sickness. If you begin to feel unwell, please tell the experimenter immediately and the experiment will be stopped.

Will my participation be confidential?
Personal information will not be released or viewed by anyone other than researchers involved in this project. Results of this study will not include your name or any other identifying characteristics.

What happens if I change my mind?
Your participation is voluntary and you may withdraw your participation at any time without your legal rights being affected.

What happens if something goes wrong?
In the unlikely case of concern or complaint, you should contact Dr Martina Prude, Head of Research Governance (02380 595058, mad4@soton.ac.uk).

Where can I get more information?
Vicky Banks (IDTC Research Engineer: vab106@soton.ac.uk)
Professor Neville Stanton (n.stanton@soton.ac.uk)
Dr Catherine Harvey (c.harvey@soton.ac.uk)

Appendix C: Consent Form I

UNIVERSITY OF Southampton

CONSENT FORM

Study title: Does the level of automation in Pedestrian Warning and Detection Systems affect driver performance?

Researcher name: Vicky Banks
Study reference: 7740
Ethics reference: 7740

Please initial the box(es) if you agree with the statement(s):

I have read and understood the information sheet (insert date /version no. of participant information sheet) and have had the opportunity to ask questions about the study. ☐

I agree to take part in this research project and agree for my data to be used and recorded for the purpose of this study ☐

I understand my participation is voluntary and I may withdraw at any time without my legal rights being affected ☐

I am happy to be contacted regarding other unspecified research projects. I therefore consent to the University retaining my personal details on a database, kept separately from the research data detailed above. The 'validity' of my consent is conditional upon the University complying with the Data Protection Act and I understand that I can request my details be removed from this database at any time. ☐

Data Protection
I understand that information collected about me during my participation in this study will be stored on a password protected computer and that this information will only be used for the purpose of this study. All files containing any personal data will be made anonymous.

Name of participant (print name)…………………………………………………

Signature of participant……………………………………………………………

Date…………………………………………………………………………………

Appendix D: Participant Information Sheet II

Study Title: What can we learn from Driver Protocols in highly automated vehicles?

Researcher: Vicky Banks

Please read this information carefully before deciding to take part in this research. If you are happy to participate you will be asked to sign a consent form.

What is the research about?
This research forms part of an EngD project that aims to assess the degree of driver behavioural adaptation as a result of increased vehicle automation.

Why have I been chosen?
You have been chosen because you are aged 18 or over, hold a full UK driving licence with at least 12 months driving experience and have received Advanced Driver Training in the last 12 months.

What will happen to me if I take part?

The experiment will last approximately 30mins in total. After completing and signing the consent form, you will be trained in the method of Verbal Protocol. This means that you will be able to verbalise your behaviour during the driving task. The experimenter will then show you the feature controls and you will be given the opportunity to practice using it. Once you are happy with operating the system you will begin the experiment. You will complete a 15 mile circular section of the A46 from Warwick University to the M40 during which time, you will be expected to drive with the automated feature “on’ at all times unless otherwise stated by the experimenter.

During the session, you will be expected to use verbal protocol which will be recorded using a voice recorder. You will be asked to talk throughout the test scenario. These protocols will be recorded. I am interested in what you are thinking about as you drive. I am not assessing your ability to drive. After each test scenario, you will be asked to provide a short retrospective account of the task. I am interested in what you remember from the task and the information that you used to complete the task.

The test vehicle is a left hand drive, automatic saloon vehicle.

Are there any benefits in my taking part?
You will be providing valuable data regarding how drivers may interact with an automated feature that uses Longitudinal, Lateral and a Suggested Overtake.

Are there any risks involved?
Although risks are minimal, please bear in mind that this is a prototype technology. A Safety Driver will be able to assist you if the system fails so it is important that you as the driver remain in full control throughout the test.

Will my participation be confidential?
Personal information will not be released or viewed by anyone other than researchers involved in this project. Results of this study will not include your name or any other identifying characteristics.

What happens if I change my mind?
Your participation is voluntary and you may withdraw your participation at any time without your legal rights being affected.

Where can I get more information?
Vicky Banks (Research Engineer: vab106@soton.ac.uk)
Jim O’Donoghue (Project Engineer: jodonog1@jaguarlandrover.com)

Appendix E: Consent Form II

Study title: What can we learn from Driver Protocols in highly automated vehicles?

Research Team: Vicky Banks, Jim O'Donoghue, Mark Dawson, Vasilis Serghi and Dan Martin

Highway Assist Team
Advanced Engineering Research
JLR, IARC, Warwick University, CV4 7AL

CONSENT FORM

	Please tick to indicate agreement
I,____________________(please print your name in block capitals) confirm that I have volunteered to participate in the Highway Assist Research Event (7 – 18th Jul 14).	☐
I understand that my data will be treated in confidence and it is not the intention of the researchers to allow any of my data to identify me. I understand that the data I provide will be stored within the JLR organisation in accordance with the Data Protection Act, 1998, and for the purposes of reports and publications will be anonymised and aggregated with the data of other participants.	☐
I understand that I am free to withdraw from the Study at any stage. I also understand that up until the point where my data is aggregated with the other participant's data, I may ask for my data to be withdrawn from the Study by a request to the researcher, using the contact details I have been given.	☐
I understand that due to commercial and intellectual property rights that any publication using data from this study will not be provided to me except through the normal commercial channels, however, draft work and summaries may be sent to me by the researcher prior to publication for the reflection of my views, proof-reading and to prevent the disclosure of any potentially harmful information.	☐
I would like to receive a 'one-off' summary of the results of this study.	☐
Signature: Date:	

Appendix F: Participant Information Sheet III

Study Title: Highway Assist User Trial

Research Team: Vicky Banks, Jim O'Donoghue, Mark Dawson, Vasilis Serghi and Dan Martin

Please read this information carefully before deciding to take part in this research. If you are happy to participate you will be asked to sign a consent form.

What is the research about?
This research forms part of an EngD project that aims to assess the degree of driver behavioural adaptation as a result of increased vehicle automation.

What will happen to me if I take part?

The experiment will last approximately 1 hour in total. After completing and signing the consent form, you will be shown the vehicle controls and asked to leave Gaydon and navigate to the M40 Northbound. You will proceed 2 junctions along the M40 carriageway and then have a short break at the Hilton Hotel in Warwickshire where you will complete a short questionnaire pack. You will then return to Gaydon along the Southbound carriageway. You will be expected to adhere to UK driving laws at all times and demonstrate good driving practice to continue. Please follow the safety driver's instructions when told to do so (but also make sure it is safe to do so). Ask any questions if you are unsure and do not do anything that you are uncomfortable with.

You will complete two driving conditions;
1. Manual driving (please do not activate any automated controls)
2. Automated driving (use Highway Assist throughout).

Within each condition, you will be prompted to perform three set manoeuvres. Please listen to the Safety Driver for instruction. These include;
1. Maintain speed and position
2. Overtake
3. Lane Change

Following each manoeuvre, you will be asked a structured set of questions. Your responses will be recorded via audio equipment and noted down by an Experimenter sat in the back of the vehicle.

Are there any benefits in my taking part?
You will be providing valuable data regarding the design and acceptability of Highway Assist.

Are there any risks involved?
Although risks are minimal, please bear in mind that this is a prototype technology. A Safety Driver will be able to assist you if the system fails so it is important that you as the driver remain in full control throughout the test.

Will my participation be confidential?
Personal information will not be released or viewed by anyone other than researchers involved in this project. Results of this study will not include your name or any other identifying characteristics.

What happens if I change my mind?
Your participation is voluntary and you may withdraw your participation at any time without your legal rights being affected. Please continue to drive in a safe and controlled manner. Return back to Gaydon as directed by the Safety Driver.

Where can I get more information?
Vicky Banks (Research Engineer: vab106@soton.ac.uk)
Jim O'Donoghue (Project Engineer: jodonog1@jaguarlandrover.com)

Appendix G: Consent Form III

Study title: Highway Assist User Trial

Research Team: Vicky Banks, Jim O'Donoghue, Mark Dawson, Vasilis Serghi and Dan Martin

	Highway Assist Team Advanced Engineering Research JLR, IARC, Warwick University, CV4 7AL

CONSENT FORM

	Please tick to indicate agreement
I,______________________________(please print your name in block capitals) confirm that I have volunteered to participate in the Highway Assist Research Event (7 – 18th Jul 14).	☐
I understand that my data will be treated in confidence and it is not the intention of the researchers to allow any of my data to identify me. I understand that the data I provide will be stored within the JLR organisation in accordance with the Data Protection Act, 1998, and for the purposes of reports and publications will be anonymised and aggregated with the data of other participants.	☐
I understand that I am free to withdraw from the Study at any stage. I also understand that up until the point where my data is aggregated with the other participant's data, I may ask for my data to be withdrawn from the Study by a request to the researcher, using the contact details I have been given.	☐
I understand that due to commercial and intellectual property rights that any publication using data from this study will not be provided to me except through the normal commercial channels, however, draft work and summaries may be sent to me by the researcher prior to publication for the reflection of my views, proof-reading and to prevent the disclosure of any potentially harmful information.	☐
I would like to receive a 'one-off' summary of the results of this study.	☐
Signature: Date:	

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