AN INVESTIGATION INTO A DRIVER-TO-DRIVER COMMUNICATION DEVICE TO MANAGE AND IMPROVE THE INTERACTION BETWEEN DRIVERS

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Abstract

Drivers must communicate with other road users to make their intentions clear, thereby enhancing the quality of the driving experience, improving safety on the roads and avoiding accidents. This interaction can be made either formally using legal signals approved by legislative bodies (e.g. use of indicators), or informally (e.g. hand gestures). However, this informal interaction may not be clearly understood by all drivers, and may lead to stress, strong emotional responses or aggressive driving behaviour. Moreover, a single informal interaction, e.g. flashing the headlights, can have several different meanings such as "Your headlights are on", "Thank you", or "I want to overtake you", depending on the situation. Driver interaction could be enhanced by an electronic driver-to-driver communication device (DDCD), which would allow motorists to exchange messages with each other. The technology associated with connected vehicles could be used for the design of this communication device. For example, wireless devices and sensors already allow vehicles to exchange information with other vehicles (V2V) and road infrastructure (V2I) at any time.

This PhD research initially introduces a driver-to-driver communication framework depicting a set of variables or factors that have a decisive effect on the communication process. The framework is also comprised of a task analysis for the DDCD. The framework is later expanded to include a specific set of design recommendations linked back to the variables that affect the communication process. These recommendations are specifically related to the DDCD and are based on a review of the literature and results from empirical studies conducted as part of the PhD.

A mixed-methods approach was adopted in this research to elicit opinions and attitudes of drivers, including interviews, observations, a workshop with academic experts and questionnaires. In total, five studies are described in the thesis, with STUDY A being an exploratory investigation on the feasibility of the DDCD. The second and third studies focused specifically on the task of receiving messages, with academic experts (STUDY B) and with regular drivers (STUDY C). A fourth study (STUDY D) involved on-road trials to investigate how drivers would identify a vehicle to send a message to. The final experiment (STUDY E) consisted of an evaluation in a driving simulator of a low-fidelity prototype of the communication device to send messages.

The studies were based on a set of driving communication scenarios, which facilitated the exploration of potential issues with the use of a proposed technology before implementation. The scenarios represented different examples of how, why and when drivers might communicate with one another, and were used as the focal point with study participants.

The findings from this research indicate that drivers would be willing to use an electronic communication device in situations directly related to the road context in which there is a decisive effect on their safety or that may alter their driving behaviour, such as a problem with their vehicle or a hazard on the road. There are many factors investigated in this research that have a significant effect on drivers' communication process. These factors include, but are not limited to, time criticality, trust issues in message content, the effect of passengers, sender anonymity and the general purpose of communication. These research findings will significantly contribute to the limited academic research currently available on social and connected vehicles and can also provide invaluable information for the automotive industry.

Publications

The following publications have emerged from the research conducted within this thesis:

Lamas, R., Burnett, G., Cobb, S., & Harvey, C. (2014, September). Driver link-up: exploring user requirements for a driver-to-driver communication device. In *Proceedings of the 6th International Conference on Automotive User Interfaces and Interactive Vehicular Applications* (pp. 1-5). ACM.

Lamas, R., Harvey, C., Burnett, G., & Cobb, S. (2014, September). A Driver-to-Driver Communication Device to Improve Drivers' Interaction. In *Adjunct Proceedings of the 6th International Conference on Automotive User Interfaces and Interactive Vehicular Applications* (pp. 1-3). ACM.

Lamas, R., Burnett, G., Cobb, S., & Harvey, C. (2015). Please let me in: a participatory workshop approach to the design of a driver-to-driver communication device. *Procedia Manufacturing*, *3*, 3309-3316.

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Acronyms

ADS – Automated Driving Systems

AOI – Areas of Interest

CB – Citizens-Band

CMC – Computer-Mediated Communication

CTAM – Car Technology Acceptance Model

DDC – Driver-to-Driver Communication

DDCD – Driver-to-Driver Communication Device

ECOM – Extended Control Model

FC – Free Content

HCI – Human-Computer Interaction

HF/E – Human Factors / Ergonomics

HMI – Human Machine Interface

HTA – Hierarchical Task Analysis

HUD – Heads-Up Display

IVIS – In-Vehicle Information System

IVNS – In-Vehicle Navigation System

JCS – Joint-Cognitive System

LMDI – Linguistic Model of Drivers Communicative Interactions

LTC – Less-Time Critical

PDL – Pre-Defined List

PDT – Pre-Defined Touch

POI – Point of Interest

SAM – Self-Assessment Manikin

SED – Subjective Estimation of Danger

TAM – Technology Acceptance Model

TC – Time Critical

TDT – Tactile-Detection Task

TLX – Task-Load index

UTAUT – Unified Theory of Acceptance and Use of Technology

VIS – Vehicle Identification System

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1 Introduction

1.1 Background

Humans are social beings and naturally communicate with each other in a vast variety of situations. In modern life, there is almost always some form of social influence in scenarios involving human beings. This statement also applies to the road environment. There are social factors involved from the moment humans choose which mode of transport to take to their actual participation in traffic (Wilde, 1976).

One particularly important social effect is when one driver interacts with another road user. While driving, road users must communicate with others to make their intentions clear and avoid accidents (Björklund & Åberg, 2005; Wilde, 1976). This interaction can be made either formally using legal signals approved by local legislation or official guidelines such as the UK Highway Code (e.g. indicators, brake lights) or informally, subject to cultural conventions (e.g. hand gestures, verbal utterances).

Compared to other means of communication, which are predominantly verbal and often face-to-face, the interaction between two drivers has specific characteristics (Björklund, 2005). Firstly, since the drivers are inside the vehicles, this creates a spatial separation and physical barrier between agents. Secondly, due to the fact that both vehicles are usually in movement, often at high speeds, this interaction needs to be completed in a much shorter time. Finally, visual information such as facial expressions and gestures may be unavailable (e.g. at night). All of these factors mean that it can often be difficult to verify the precise intent of other drivers. If a driver is not aware of another road user's real intentions, this can lead to misunderstandings (Renner & Johansson, 2006). For

example, there may be several reasons why a driver on the road flashes their headlights at oncoming cars.

The lack of clear communication or miscommunication between drivers can also result in aggressive driving behaviour, as mentioned by Rakotonirainy et al.:

"*The inclination to undertake unsafe driving behaviour is exacerbated by the inability to perceive or express social cues when feeling anonymous. Inoffensive acts or gestures tend to be interpreted by angry drivers as aggressive and can escalate into road rage in an anonymous environment."* (Rakotonirainy, Feller, & Haworth, 2008, p. 02)

As technology evolves, a hypothetical electronic device could be used to facilitate communication between drivers without adversely affecting the driving task (Pfleging, Schneegass & Schmidt, 2013). This device could use the technology and framework being developed as part of the extensive research on connected vehicles, which allows vehicles to be connected all the time, and for drivers to exchange information with each other using sensors and wireless devices (Evans-Pughe, 2005).

There are many predicted uses of this electronic device, which could make drivers' intentions and communication clearer leading to a more positive outcome. For example, by using an electronic communication device, drivers would be able to:

- Provide prior warnings of their intended behaviour to other vehicles in close proximity;
- Explain or apologise for a particular action involving another vehicle;
- Ask for permission to give right of way;
- Share traffic and other road information with other drivers;
- Share social information with other drivers (Riener & Ferscha, 2013);

The interaction with this electronic device can be divided into specific secondary or tertiary tasks that need to be accomplished while the motorist is focused on the primary

task of driving. Secondary tasks increase the demand on drivers' auditory, visual, physical and cognitive resources, which could cause a reduction in driver's attention to the primary driving task (Hedlund, 2006). In the last few decades, there has been an increase in the number of services or applications available for the vehicle such as Internet access and navigation systems. Due to this increased functionality available in a modern vehicle, there has been a change in the way that some of these functions were designed with numerous similar functions being combined via menu-based systems. The way that any electronic system available in the vehicle is designed will determine how complex it is for the driver to interact with it. Research shows that complex interactions with in-vehicle information systems (IVIS) are linked to poor driving performance, primarily due to longer glances away from the road (Horrey, 2011). The cognitive demand associated with these interactions can also impose an unsafe demand on the driver.

Therefore, when designing any new in-vehicle system it is important to take into account drivers' individual capabilities such as response time, balance and visual focus as well as the complex interaction between the driver and the system, in order to avoid driver distraction and the threat to the safety of all road users.

1.2 Research aims and objectives

The overall aim of this research is to investigate Human Factors issues pertaining to an electronic means of driver communication in order to inform the design of a hypothetical DDCD. More specifically, this research aims to provide a set of specific recommendations for the design of this communication device, which currently do not exist. The following specific objectives address the overall aim – listed below and expanded upon in the subsequent text:

1. To investigate how drivers communicate with each other using traditional means of communication.
2. To provide a driver-to-driver communication framework.
3. To investigate drivers' emotions when receiving messages using a DDCD.
4. To investigate drivers' acceptance of the use of a DDCD in different driving communication scenarios.
5. To explore alternative Human-Machine Interface (HMI) designs for a DDCD.
6. To provide general design recommendations for a DDCD.

Investigate how drivers communicate with each other using traditional means of communication

Drivers communicate with other drivers in many different ways. The scope of this objective was to obtain background information regarding driver communication, without the use of any electronic device, to specifically support general driver communication. This objective was accomplished not only by a critical review of the literature on driver communication, but also by an initial, exploratory interview study, which is presented in Chapter 05. The outcomes of this objective defined the next step in the research.

Provide a driver-to-driver communication framework

Several factors may affect the communication between drivers. Therefore, it was deemed important to first of all thoroughly understand how communication between drivers could take place. One of the objectives of this research is to introduce a driver-to-driver communication framework, which depicts all the actors involved in the communication process and the variables that may affect this communication. This framework also

comprises of a task analysis and a set of communication scenarios and can be used as a reference tool for designers of a DDCD. The variables described in this framework provide the basis for the design guidelines presented in this thesis. This objective is addressed in detail in Chapter 04.

Investigate drivers' emotions when receiving messages using a DDCD

The use of a DDCD can significantly affect the outcome of the interaction between drivers. This outcome could be either positive or negative. A negative outcome can have a decisive effect on driving behaviour and in a worst-case scenario lead to road rage incidents and accidents (Walters, Pezoldt, Womack, Cooner, & Kuhn, 2000). Therefore, it is deemed important to understand how drivers' feelings are affected when they receive messages using such a device. This was investigated in both studies that focused on receiving messages using the DDCD, which are presented in Chapter 06. Details of the thesis structure and the studies carried out in this research are presented in Figure 1.1.

Investigate drivers' acceptance of the use of a DDCD in different driving communication scenarios

There are many situations in which drivers must communicate with other drivers to make their intentions clearer. Some of these situations, for example turning left, do not require the use of any other device, as the vehicle already provides indicators for the driver to clearly communicate their intention with the other driver. However, there are many other situations in which the driver needs to communicate with other drivers and has to rely on mechanisms available in the vehicle or gestures to try to transmit the message and their intentions, and this can often be unclear or confusing. Based on these specific situations, a set of different driving communication scenarios were designed and

the driver's acceptance of the DDCD in these scenarios was investigated. Drivers' acceptance of different scenarios was investigated in all three studies presented in Chapters 05 and 06.

Explore alternative HMI designs for a DDCD

This research aims to investigate alternative HMI designs for the DDCD. This objective is addressed in different ways in all the studies carried out in this research. The HMI designs explored in this research cover different modalities of information presentation (i.e. auditory and visual) and system interaction such as the use of speech and gestures. Message content and the best way to present messages were also investigated. Some of the general design recommendations provided at the end of each study chapter are closely related to the alternative HMIs explored.

Provide general design recommendations for a DDCD

The final objective of the research is to provide general design recommendations for a DDCD. These general recommendations, some of which can also be applied to other in-vehicle devices, are based on the results of each study and therefore are presented at the end of each study chapter. A subset of all these recommendations is described in Chapter 09. The guidelines presented in Chapter 09 are specific to the DDCD and they were written to provide designers and developers of automotive interfaces with guidance on how to design an electronic communication device. Design recommendations have considerable power to improve the usability of a product by assisting designers to achieve the best outcome. These guidelines were incorporated into the driver-to-driver communication framework.

1.3 Thesis overview

The thesis is organised into ten chapters, starting with an introduction, which describes the background of the research, the aims and objectives and an overview of the thesis together with the overall structure (Chapter 01). The following sections describe each of the remaining chapters in turn.

Chapter 02 – Literature review

This chapter presents a critical review of the diverse fields and disciplines, which have informed the research presented in this thesis. The chapter begins with a structured progression of different forms of human communication, from the theory of common ground to non-verbal and technology-mediated communication. The chapter then describes the social interaction between motorists with relevant models of driver interaction. A review of different models of user acceptance is also presented in this chapter.

Chapter 03 – Methodology

The methodology chapter provides a description of the different methods and approaches used to investigate the feasibility of the DDCD, such as observations, task analysis, scenarios etc. This mixed-methods approach is useful for eliciting a large quantity of rich information, which can then be studied in more depth or validated as necessary. The methodology described includes both the approaches to data collection and data analysis. This chapter also presents any assumptions that have been made during the analysis of the data obtained during the studies.

Chapter 04 – Introduction to the driver-to-driver communication framework

One of the objectives of this research is to provide a driver-to-driver communication framework. This chapter addresses this specific objective. The framework is initially represented as a diagram, which presents the main elements involved in driver-to-driver communication and several variables that can affect this communication. The second part of the framework is a task analysis, which was designed based on the two main general tasks necessary to interact with the DDCD – to receive and to send messages. Based on the diagram and the task analysis, a list of seven examples of common use case scenarios was created. The framework presented in this chapter provides a sound basis for designers to generate new use case scenarios. Moreover, the set of specific guidelines presented in Chapter 09 are linked to the variables in the diagram.

Chapter 05 – Exploratory investigation into the feasibility of a DDCD

This chapter presents an exploratory study, which was designed to investigate driving behaviour. This study aimed to explore various communication issues raised while driving a vehicle, and how an electronic device could address these issues. Twenty-four participants were asked to give their opinions on how they would react to a subset of six of the driver-to-driver communication scenarios most relevant to this particular study, firstly using only the traditional means of communication (e.g. gestures, honking their horns) and secondly using a hypothetical electronic device. The scenarios were presented in textual form.

The findings point to the importance of the message content and type on the outcome of the communication. The identification of the driver who sent the message also plays an important role on the outcome of the communication. Results also highlight the potential influences of passengers on the communication when using an electronic device.

Chapter 06 – Receiving messages with the DDCD

This chapter presents two studies, which aimed to investigate the specific task of receiving messages with the DDCD. The first study was a workshop which aimed to capture opinions from a group of Human-Computer Interaction (HCI) and Human Factors / Ergonomics (HF/E) experts. Fifteen participants actively worked in small groups to answer the same four questions regarding a subset of five of the driver-to-driver communication scenarios most appropriate for this workshop, presented to them in graphical form. The questions were designed to capture opinions regarding the content of the message, the best modality to receive the message and participants' feelings about receiving the message. Results highlighted various design recommendations, such as the advantage of having the DDCD integrated with other in-vehicle devices (e.g. satnav), and that the content of the message should be carefully considered.

The second study aimed to elicit the opinions and feelings of 48 regular drivers regarding the task of receiving messages. Participants filled in questionnaires on driver acceptance, emotion and a custom-designed driver-to-driver communication questionnaire after each one of the five communication scenarios were presented to them in a video-based format. Participants were also asked to provide suggestions on how to improve the messages. Results were in accordance with the previous study, especially regarding lower acceptance of non-driving related communication scenarios.

Chapter 07 – The task of vehicle identification

Drivers must identify to the system which motorist(s) will receive the message. This is one of the main tasks required when sending a message to another vehicle. This chapter presents an on-road exploratory study, which took place in Nottingham. Ten participants were prompted by an auditory alert to choose a single vehicle close by and demonstrate

how they would identify that vehicle to a hypothetical system quickly, and in a natural and instinctive way. The results of this study highlight useful guidelines for the design of a vehicle identification system. Findings point to the use of speech based interaction with three main categories used by drivers, namely vehicle colour, location and classification or general type such as a saloon or van. The sequence in which these descriptors were used was also measured. Contrary to expectation, gestures were rarely used to identify vehicles.

Chapter 08 – Sending messages with the DDCD

Chapter 08 presents a study on the task of sending messages using the DDCD. The study aimed to investigate how drivers interact with two distinct HMIs to send messages to other vehicles in different situations. Twenty participants took part in the study, which took place in a medium fidelity driving simulator. Messages were sent in free-content form using speech or by selection of pre-defined categories on a touchscreen menu-navigation task. The communication scenarios were designed based on the criticality to send the message. Results from the previous study (Chapter 07) on the task of identifying a vehicle were incorporated into this study.

Results from this study highlight higher acceptance rates for the speech-based interface. Design recommendations for pre-defined messages and free content messages were also drawn from the results of this study.

Chapter 09 – Design guidelines for a DDCD

One of the fundamental aims of this research is to provide design recommendations for the DDCD. Design recommendations, based on the results of each study, are described at the end of each study chapter, i.e. in Chapters 05-08. Some of these recommendations

could also be applied to other devices such as in-vehicle informational systems. In contrast, Chapter 09 lists and describes a subset of design guidelines based on the results of this research, which are highly specific to the DDCD.

This chapter extends the driver-to-driver communication framework introduced in Chapter 04 by adding this list of design recommendations, which are specifically related to the DDCD. Each recommendation described in this chapter is linked to one or more variables or factors that have an effect on the communication between drivers. These variables are presented as part of the driver-to-driver communication framework introduced in Chapter 04.

Chapter 10 – Overall discussion and conclusions

Chapter 10 summarises the work presented in this thesis, draws conclusions, discusses the limitations of the research and proposes future work. This is an overview chapter, which provides a summary of the research results and the aims of the research accomplished.

1.4 Thesis structure

The structure of the thesis can be seen in Figure 1.1. The numbers in the green circles represent the chapters of this PhD thesis. The research employed a number of different methods to address the research objectives. The grey Research Methodology box indicates the methods used in this research including in which chapters they are presented. The methods were chosen as being the most appropriate to the stage of the research and the phenomena being studied. More details about the methodology used in this research can be seen in Chapter 03, which is connected to the grey methodology box.

The research also employed a number of different studies to address the research objectives. The figure shows which studies are presented in each chapter and how each one contributed to the overall research objectives.

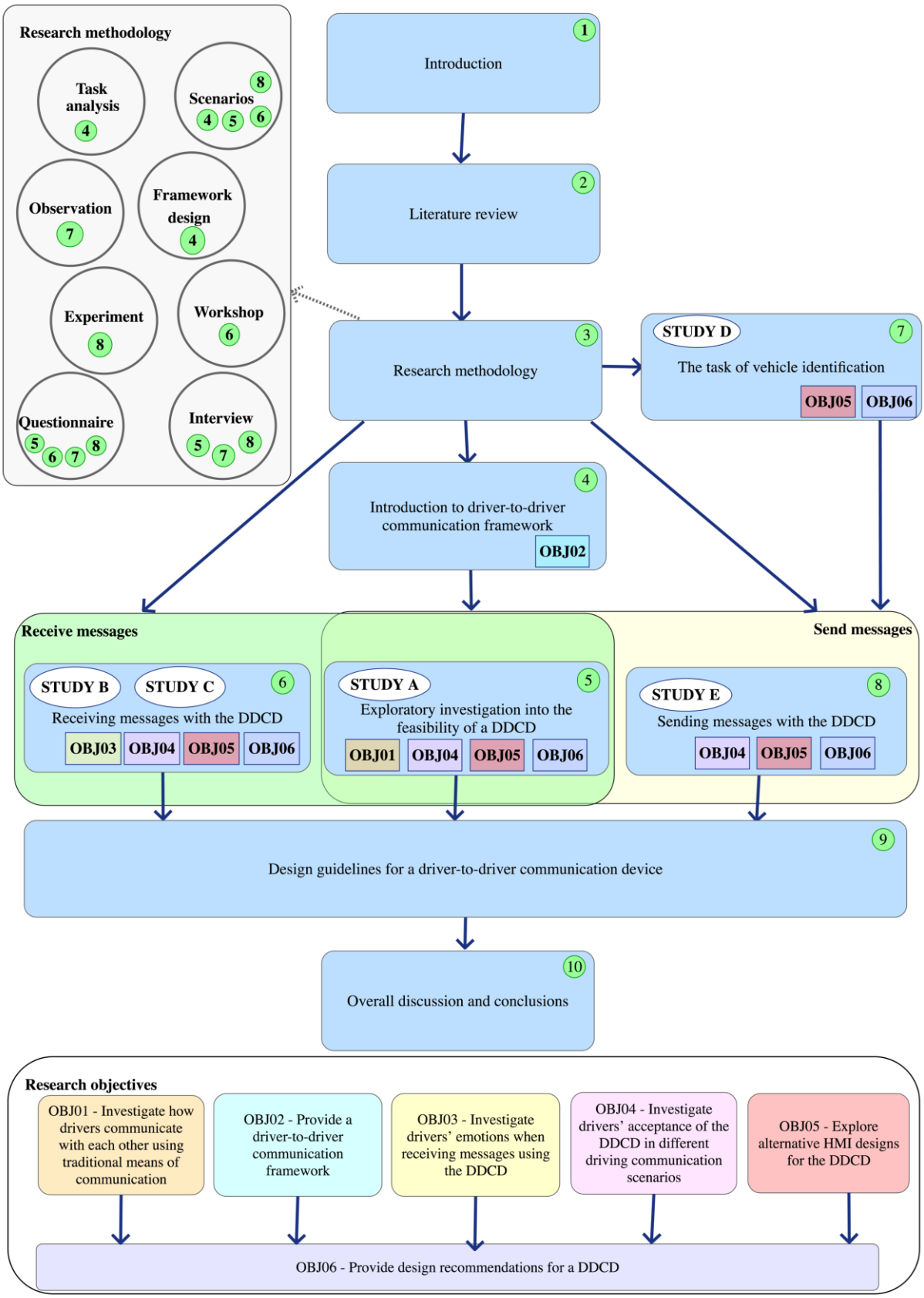


Figure 1.1. Thesis structure

1.5 Contribution to knowledge

The research work presented in this thesis contributes broadly to the understanding of the social context of driving, and specifically to our understanding of how drivers might interact with future electronic communication systems within vehicles. Several different relevant design aspects of a DDCD such as its usability, user acceptance and HMI were explored in detail throughout this thesis. An electronic communication device could aid drivers in situations in which some sort of communication is required and the technology already available in the vehicle does not help to make the message clear enough.

The review of the literature presented in the next chapter demonstrates that previous research has been carried out on different aspects of the social interaction between drivers. However, no research has yet been conducted to investigate the use of an electronic communication device to help drivers quickly communicate with each other with the main purpose of making their intentions clear. The most relevant and comprehensive research specifically on driver-to-driver communication dates back to 1976, a period in which technology was not advanced enough to be able to provide an efficient way for drivers to exchange messages with each other.

The PhD research presented in this thesis makes a significant contribution to the literature. The results of this research provide information and crucial considerations for the automotive industry when deciding whether or not to adopt this technology. This PhD research introduces and then expands on a driver-to-driver communication framework which is comprised of a diagram with the main elements and factors that have an effect on the communication process. A task analysis and a set of use case scenarios are also part of the framework. The last element of the framework is a set of design recommendations for an electronic communication device. This driver-to-driver

communication framework and the guidelines are especially helpful for designers and developers of systems for vehicles.

2 Literature review

2.1 Introduction

This chapter provides an overview of the literature, which has formed the basis for the research presented in this thesis. The relevant research literature includes diverse topics such as different forms of human communication and user acceptance of a new technology. Although the thesis draws inspiration from various areas such as social sciences and psychology, it is fundamentally grounded in HCI and HF/E, and therefore it is presented and reviewed from this perspective.

Communication between drivers is a form of human communication. The literature review starts with a structured progression of different forms of human communication. The first section covers basic human communication and a theory associated with this area called common ground. This section also covers some aspects of human communication relevant to this research, such as non-verbal communication and conflict resolution.

A DDCD is a form of technology to be used for communication, and therefore has specific characteristics. Technology-mediated communication, which is the use of technology in human communication, is therefore covered in the first section. Many aspects related to this area are particularly relevant to this research.

Driver communication is a form of social interaction. The third section moves on to the social interaction between drivers. Various aspects related to driver-to-driver communication are reviewed in this section, such as the concept of social car and models of driver interaction.

The fourth section describes and reviews models of user acceptance of new technologies and more specifically models of drivers' acceptance of new devices. It is very important in terms of cost and effort to investigate users' subjective experiences and attitudes towards new technologies in the early stages of design. The fifth and final section reviews human emotions and their importance in the road context. Figure 2.1 shows a diagram of the main topics presented in this review, with their section numbers and different colours to highlight the separate areas of research.

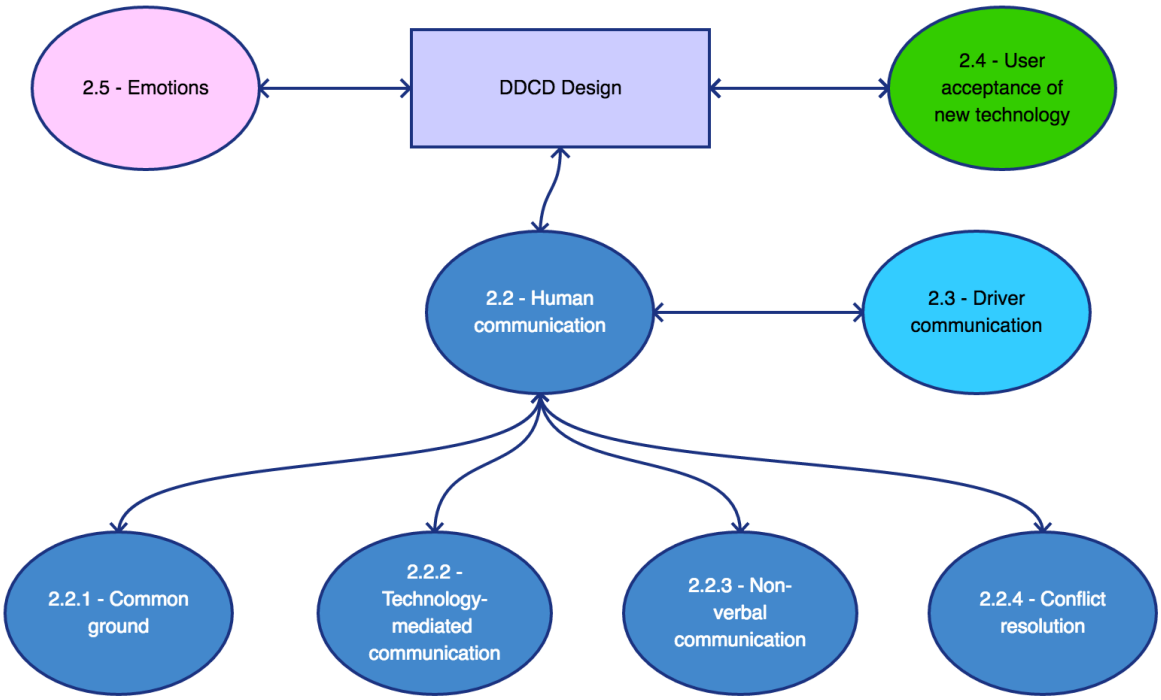


Figure 2.1. Literature review topics

2.2 Human communication

Human communication is basically the process of transferring information from one party called the sender to another party known as the receiver (Norman, 2013). Many different theories and models aim to explain human communication. This PhD research focuses on the specific concept of common ground, which is described in detail in the next

section. This concept is applicable to all sorts of human communication and highly relevant to the communication between drivers.

2.2.1 Common ground

One of the main concepts related to human communication is called ground in communication or common ground. Common ground is defined as a collection of mutual beliefs, mutual knowledge and mutual assumptions, which is required by two people to successfully communicate with each other (Clark & Brennan, 1991; Clark & Carlson, 1982; Clark & Marshall, 2002).

Communication is much more than one side planning and issuing utterances and the other side listening and understanding them. The parties involved in communication need to coordinate on content; the listener and the speaker must reach agreement that they are both referring to the same specific meaning of a word and not to other meanings (Grice, 1970). They also need to coordinate on process; the speaker must know when it is time for them to speak and the listener must make sure to provide cues to the speaker that they are following what the speaker is saying (Clark & Schaefer, 1987; Clark & Wilkes-Gibbs, 1986; Isaacs & Clark, 1987). These coordination mechanisms must take place every time there is a communication as grounding constantly changes. Asking a question, for example, is much more than uttering an interrogative sentence. The other party in the conversation must have understood the meaning of the question in order for the communication to be considered successful. Grounding is then achieved when all parties involved in the communication have reached mutual belief on understanding (Clark & Brennan, 1991).

There are generally two phases in grounding, the presentation of an utterance and the acceptance of the utterance (Clark & Brennan, 1991; Clark & Schaefer, 1987). Ambiguities

with grounding are often clarified at the acceptance phase. Evidence of grounding can take three different forms. In the first one, acknowledgement, the listener utters words such as “uh huh”, “mmm” or nods their head to confirm that the communication was understood and the conversation can continue (Clark & Brennan, 1991). In the second form of evidence, called relevant next turn, the listener responds to the speaker, either verbally or non-verbally, both taking turns. Questions and answers act as adjacent pairs as the second one is related to the first one. Acceptance of this evidence is only reached when a relevant utterance has been made in response to a previous utterance (Clark & Brennan, 1991; Clark & Schaefer, 1987). In the third and final form, evidence can be found from continued close attention to the speaker’s words. This can often be observed from eye contact or facial expressions. If the listener looks puzzled, for example, this may be a sign that the listener is paying attention, but the utterance has not been understood (Clark & Schaefer, 1987).

The principles of least effort states that participants in both phases of grounding try to minimize the total effort spent in the interaction by being brief and informative at the same time (Davies, 2007). One factor that shapes grounding is the collective purpose of communication, i.e. what people try to accomplish while communicating (Clark & Brennan, 1991; Grice, 1970). Grounding techniques should not be the same for all types of collective purposes, such as to get acquainted, to teach something or to plan an event. Clark and Brennan (1991) describe two types of content – references and verbatim. Some conversations aim to establish referential identity with a mutual belief that the parties involved have correctly identified the same referent. Several techniques are available for this type of content. The first one is to provide alternative descriptions so that the listener can confirm they have identified the same referent (Clark & Wilkes-Gibbs, 1986; Isaacs & Clark, 1987). For example:

A: That young guy from the office.

B: Do you mean the one with the beard?

A: Yes.

The second technique is to employ indicative gestures, to look at or to touch the referent (Clark, Schreuder, & Buttrick, 1983), for example:

A: What make is that car over there?

B: That blue one? (POINTING)

A: Yes.

B: It's a Toyota.

The third technique is to establish the identity of the referent by providing a description of it in order to make sure that the listener understands the meaning of the word used to identify the referent (Isaacs & Clark, 1987). The example below shows a conversation between a computer instructor and a learner:

A: Can you see the cursor – that the small flashing line on the screen that you move to mark the point where you are going to type or do something?

B: OK, yes.

A: Move it to the right-hand corner of the screen.

Another factor that shapes grounding is the personal medium in which the two-way communication takes place, e.g. face-to-face, telephone, email, teleconferencing etc. Different grounding techniques may not be available in one medium or may cost more in

another (Brennan, 1998). The main goals are to apply the least collaborative effort principle and to only employ techniques available for a specific medium. A framework was proposed by Clark and Brennan (1991) to account for the differences among these different media. A medium can impose eight different constraints on communication by two people (A and B), which are presented in Table 2.1(Clark & Brennan, 1991):

Table 2.1. Constraints on communication

Constraint		Description
01	Co-presence	A and B are not in the same physical environment, a.k.a. co-location.
02	Visibility	A and B cannot see each other.
03	Audibility	A and B communicate by speaking, but cannot hear each other clearly.
04	Cotemporality	A and B receive information produced by other members, with delay.
05	Simultaneity	A and B cannot send and receive information simultaneously.
06	Sequentiality	A and B do not receive information in a sequential, consecutive manner, e.g. in emails a message and their replies can be separated by other irrelevant messages.
07	Reviewability	A and B cannot review the information produced by each other. In face-to-face communication B might forget what A said, unless the conversation is recorded.
08	Revisability	A and B cannot review their own information to make it clearer before transmitting the message to the other one.

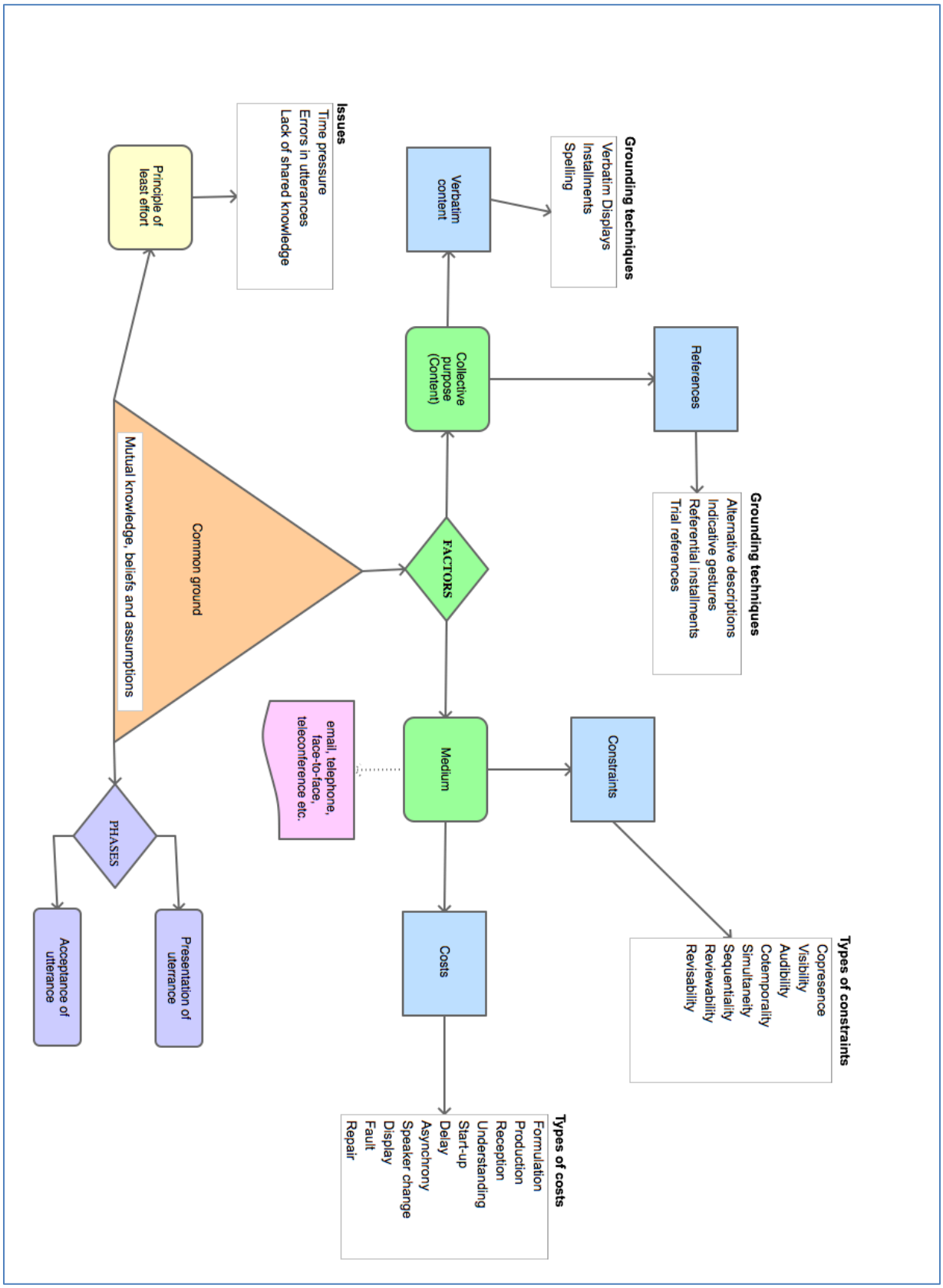
When the medium has one or more constraints, the cost for a grounding technique may become too high; therefore alternative-grounding techniques should be applied. There is a total of eleven costs that can vary and are not independent of each other. These costs are presented in Table 2.2 (Clark & Brennan, 1991).

Table 2.2. Costs in grounding techniques

Cost	Description	Paid by
Formulation	More time and effort required to create and revise utterances and to produce more complicated, unfamiliar and/or perfect utterances.	Speaker
Production	The effort required to produce information may vary according to the medium, e.g. speaking is very fast while handwriting is very slow.	Speaker
Reception	Generally listening is easier than reading. This cost also involves waiting while the speaker produces a message – i.e. high cost in keyboard messaging.	Addressee
Understanding	Higher costs when specific words or constructions are used.	Addressee
Start-up	The cost of starting a new conversation - cost involved in getting the addressee to notice that the speaker wants to speak with them.	Both
Delay	The cost involved in delaying the production of an utterance for a more careful detailed plan, revision and execution – delay costs small in email and letters, but high in face-to-face conversation.	Both
Asynchrony	The cost involved in the timing of producing and receiving messages in asynchronous media.	Both
Speaker Change	The cost associated with the effort required for one person to stop and the other person to start the communication. Low cost in media with co-presence, visibility and audibility.	Both
Display	The cost of displaying non-verbal cues, such as gestures, nods, eye-gaze.	Both
Fault	The cost involved with producing a wrong message.	Both
Repair	The cost associated with repairing a wrong message and producing a new, correct one.	Both

Figure 2.2 summarizes the two common ground factors and their concepts mentioned previously. Overall, human communication is a collective activity that requires coordinated actions from all parties involved (Clark & Wilkes-Gibbs, 1986; Isaacs & Clark, 1987; Brennan, 1998; Grice, 1970). The most important communication aspect to consider is that the addressee has received and understood the information as expected by the sender, therefore reaching the grounding criterion of mutual belief (Clark & Brennan, 1991). Different techniques, which vary according to the media and purpose of communication, can be used by group members in order to achieve this common ground.

Figure 2.2. Common ground factors and their concepts



2.2.2 Technology-mediated communication

The study of human-to-human communication mediated by the use of technology is relatively recent. It was not until the late 1960s that the Internet and computer technology were advanced enough to allow remote communication by users all around the globe. This was initially restricted to military uses, but it was then progressively expanded to computer scientists, academics, business people and finally to popular use in the 1990s (Schiffrin, Tannen, & Hamilton, 2008).

A new area of research was then developed – Computer-Mediated Communication (CMC). CMC is defined as a wide range of technologies that aid human communication and the sharing of information through computer networks (Barnes, 2002). The driving force in CMC is the Internet, which is described as a network of networks. Examples of CMC communication include email messages, newsgroups, instant messengers, multiplayer games, video-conferencing etc. (Herring & Androutsopoulos, 2015).

All the communication grounding concepts described earlier in terms of medium, constraints and costs are very relevant to CMC, and they form the basis of this area of study. Initial technology-mediated communication was asynchronous text-based in a poor medium with only a visual-textual channel of communication and with many of the constraints described earlier such as lack of co-presence, audibility and visibility (Schiffrin et al., 2008). This can lead to high costs in formulation and reception. However, technology has evolved at a rapid speed and nowadays it is possible to have a rich technology medium with not only visual but also gestural and audible channels such as video-conferencing, which can have almost the same attributes as a face-to-face conversation (Barnes, 2002; Herring & Androutsopoulos, 2015).

The type of technology-mediated communication and its purpose are directly interconnected. There is no technology-mediated communication that is suitable for all

purposes. Some types of conversation are preferred in one medium due to their costs (Finholt, Sproull, & Kiesler, 1990). People prefer to use email to coordinate activities, but prefer face-to-face interaction when they need to reach consensus. When more participants join the conversation, some costs may become greater and changes needed in the medium if it does not support more than two people.

Feedback in CMC enables the users involved in the communication to regulate the flow of messages by allowing the sender to know when and how a message was received (Barnes, 2002). This concept of feedback in CMC is closely related to the common ground costs of reception and understanding of a message.

CMC has other variables that can influence usage and the language used in communication. Some technology-mediated communication can impose limits on message size (Cherny, 1999), on whether anonymous communication is allowed (Selfe & Meyer, 1991) and on whether is possible to block specific users (Lunsford, 1996). Moreover, some types of communication can have different degrees of social accountability, i.e. whether messages are publicly posted to anyone or whether a restrictive type of subscription is required which limits the number of users with access to the message (Schiffrin et al., 2008). The cardinality of communication, i.e. if a message is sent to only one person or to multiple people, also has an effect on the language used to communicate (Baym, 1996).

The type of technology-mediated communication used and the situational context have an effect on the linguistic structure used to communicate, which is in accordance with the principle of least effort of ground in communication (Schiffrin et al., 2008). Therefore, the language used can be shorter with the use of abbreviations. Moreover, due to the lack of audio-visual and social cues in some media, users need to develop compensatory

strategies to convey their meaning (Schiffrin et al., 2008). An example of such strategy is the use of emoticons (i.e. smiley faces) to represent facial expressions and feelings.

Users may feel constrained in using technology to exchange messages with other users. According to Bos, Olson, Gergle, Olson, and Wright (2002), the CMC tasks that are most inhibited by the type of media used to exchange information are the ones that have a high affective component or where context plays a major role. Exchange of messages using a DDCD is highly influenced by the context and may show an affective component.

Some of the various factors described in the previous paragraphs, which influence technology-mediated communication, also have an effect on the interaction between drivers. These factors or variables are explained in detail in Chapter 04.

2.2.3 Non-verbal communication

Human beings can communicate with each other by using more than words (LaFrance & Mayo, 1978). They can speak with different tones of voice, intonation, pitch and volume levels. They can also be close or far from each other and have different body postures and movements. The external appearance, i.e. the way people dress and look can transmit information about their age, personality and economical, professional and social status (Gheorghiţa, 2012) and even send a message as to what kind of person they might be. All of this can be seen as nonverbal communication.

Therefore, nonverbal communication can be defined as a form of human communication that does not use spoken or written words (Knapp, 2012; LaFrance & Mayo, 1978). Nonverbal communication shows traits of a person's personality and emotional feelings (LaFrance & Mayo, 1978). Nonverbal communication is also used to manage the flow of interaction. Examples of nonverbal cues in human communication are attire, eye gaze, facial expressions, posture, distance, and listener responses.

According to Knapp (2012), when observing nonverbal communication, it is important to analyse the physical space, the characteristics of the communicator and their body movements (e.g. gestures, postures, touch, and eye movements). It is also crucial to analyse nonverbal communication together with any sort of verbal communication because one can substitute, conflict, complement, repeat or regulate the other (Kendon, Sebeok, & Umiker-Sebeok, 1981; Knapp, 2012).

Kendon et al. (1981) state that for a better understanding of nonverbal behaviour one must investigate how it became part of a person's collection of behaviours, in which situation it has been used and the rules explaining how it conveys information. The same nonverbal behaviour may have different meanings depending on how the person acquired that behaviour, the situation it is used in and what it means to the person. If the interlocutor does not pay attention to the conversation, a specific nonverbal behaviour could be misinterpreted as an emotional feeling whereas in fact it might be a cultural convention (LaFrance & Mayo, 1978).

Gheorghiţa (2012) points out that the way people dress has an effect on communication because it offers substantial information about them. A former US Secretary of State even used different brooches to express her moods and opinions. Similarly, people in the UK use a red poppy brooch every year to show their respect for members of the armed forces who have died on duty.

2.2.3.1 Non-verbal driver communication

Most communication between drivers is nonverbal. Drivers may opt to use a formal method of communication by using the vehicle indicators or an informal method (e.g. honking the horn, flashing headlights) to communicate to other drivers their intentions (Renge, 2000). Drivers can also use different gestures (e.g. raising the hand to say thank

you), which tend to vary among different cultures (Lorenz, 2002). When possible, eye contact is another important cue to promote safe driving and to predict other drivers' intentions (Rakotonirainy, Schroeter, & Soro, 2014). These formal and informal rules are reviewed in detail in section 2.3.1.

2.2.4 Conflict resolution

The world has always abounded with conflicts. There is a chance of a conflict being created whenever there is a difference in views between two or more people. Conflicts can take the form of one nation against the other (e.g. war), or between people from different cultural backgrounds (Deutsch, Coleman, & Marcus, 2011). Conflicts can occur professionally or socially, in families, in intimate relationships, in fact between any two or more people. No matter what type of conflict occurs, communication between both parts is essential for a resolution (Deutsch et al. , 2011).

Conflicts can also occur when a person has a subjective interpretation of an objective behaviour against them. The study by Smith, Phillips, and King (2010) investigated the nature of this low level interpersonal incivility which happens every day and everywhere, not only in poor violent urban areas. Incivilities like the ones studied by Smith et al. (2010) are often trivial and can happen in ordinary places where people usually go at least once a week (70%), and the perpetrator being considered quite respectable by most people (49%).

2.2.4.1 Conflict resolution in the driving context

Low-level incivilities are very common to the automotive scenario. Examples of low level driving incivilities are sudden lane changes, tailgating, driving too slowly, parking badly over two spaces or taking too long to respond to a green traffic light (Smith & King, 2013). According to Smith et al. (2010), 61% of all low level impolite encounters can be

categorized as a problem with movement or space management, with the most common places being streets (29.8%), supermarkets (10.4%), walkways (10.2%), highways (7.8%) and car parks (6.7%). Moreover, the study showed that almost 70% of all low-level incivilities happened while people were in the process of going to some place by walking, by using mass transport or by using their own transport. The study also found that in almost 50% of the cases, both the victim and the perpetrator were on the move (Smith et al. , 2010). Dromology, a crucial concept to the automotive scenario, was introduced by the French sociologist Paul Virilio. He states that our modern social lives are incessantly related to the ideas of speed and motion (Virilio & Polizzotti, 1986). Related to this concept, Urry (2000) mentions the importance to the social order of the flow of people between places. All of this is in accordance with the fact that movement is part of our lives and that people spend a great amount of time in motion.

As noticed by Smith and King (2013), there are three hypotheses that could explain incivilities specifically in the automotive scenario. The first one is related to the properties of the car (i.e. a metal cocoon with a barrier to visibility and communication) that removes the human aspect of an interaction, making it easier to have an aggressive behaviour or cause incivility (Rakotonirainy et al., 2014). The second paradigm, which attracts people to drive unsafely, is based on the cultural meanings of the car as a way for men to express their masculinity or one that promotes power and freedom (Sheller & Urry, 2000; Moeckli & Lee, 2007). The third approach focuses on the great power of routine activities and situational factors to understand these incivilities. The more time people spend on the move (i.e. the greater exposure they have to driving), especially during peak time, the more chance that they will experience some sort of automotive incivility (Smith & King, 2013).

The automotive scenario also has the specific characteristic of anonymity. For example, it is not appropriate to compare a fight in a bar, where two people can clearly see and verbally communicate with each other, with a driving incident. As pointed out by Smith and King (2013): "*Roadways are spaces of routine social mixings where gender, age and other characteristics are masked*" (Smith & King, 2013, p. 492).

2.2.4.2 Emotions in conflict resolution

In general, regarding people's emotional responses when meeting a rude stranger in a low-level incivility situation, Smith et al. (2010) point out that the most common reactions are surprise and anger. The surprise response is due to the fact that the incivility happens in an unexpected moment by an unexpected person. According to the study, almost 70% of the participants felt very surprised or quite surprised by the incident. Not only anger, but also fear, disgust and indifference were also observed in this study.

The study found that emotions had a short half-life. Very few participants still felt the same strong feeling of anger or disgust after the perpetrator had left. The feeling of indifference however, grew over time for the majority of the cases (Smith et al., 2010). As observed by Smith and King (2013), the feeling of disgust is not particularly common to the automotive scenario, probably because of the high speed of both victim and perpetrator and the lack of physical contact. However, the feelings of anger and fear are quite usual in the automotive scenario.

The study by Smith et al. (2010), correlates the emotional feelings of anger, disgust and indifference with people's behaviour, as stated by the following three social theories. The German theorist Georg Simmel developed a social theory linking both the behaviour and the feeling of indifference (Simmel, 1950). In his work, Norbert Elias correlates the feeling

of disgust to the action of avoidance (Elias, 1978). Finally, the father of sociology Emile Durkheim states that anger leads to a strong sanctioning (Durkheim, 1895).

2.3 Driver communication

The interaction between road users can be seen as a co-operative activity, as there are a number of actors involved (e.g. pedestrians, drivers, cyclists) who share a common resource, in this case the road, and by using this resource they have an impact on the other users as situations can change (Pillai & Ray, 2014; Schmidt & Simonee, 1996). Therefore, the act of driving involves intense forms of interaction and social participation in which drivers must constantly take note of the actions of the other road users (Swan & Owens, 1988).

Drivers can communicate with each other in many ways. They can use vehicle devices to perform actions such as flashing their headlights, using the indicator signals or honking the horn (Renge, 2000). Drivers can also make eye contact with other drivers and/or use hand gestures or any kind of verbal utterance or nonverbal communication that serves their purpose (Lorenz, 2002).

Drivers interact to make their intentions clear to others. These intentions could be to change lane, turn right or even to say thanks for an act of courtesy or to show how angry they are with the manoeuvre made by the other driver (Hutchinson, 2008). Interactions between road users can be characterized as a full circle, in which person A interacts with person B and this interaction affects person B in a way that person B responds creating a new interaction. Interactions between road users can also be unidirectional in which person A interacts with person B, affecting person B but a new interaction is not created (Wilde, 1976).

Driver communication can be triggered by the driver (e.g. flashing the headlight to give way to another road user) or as an external response to another motorist's action, such as braking or changing lanes (Kendon et al., 1981). The main concepts related to driver interaction lie in the perception and presentation of intent (Renner & Johansson, 2006). Driver interaction can also be seen as a presentation of action and a request for a reaction (Swan & Owens, 1988).

Compared to other methods of communication, which are predominantly based on verbal communication such as face-to-face, the interaction between two road users can be considered more anonymous because they are inside the vehicle, hidden and protected by this semi-private metal container, which inhibits the exchange of social interaction (Rakotonirainy et al., 2014). The interaction between drivers takes a much shorter time and there are not many opportunities to interact and make a point (Esbjörnsson, Juhlin, & Östergren, 2003a; Goffman, 2009). At low speeds, the driver can make eye contact with others, but at higher speeds, the driver must make use of the signalling devices available in the car. With limited interaction, it is difficult to verify the intent of other drivers. Therefore, if drivers are not aware of the others' real intentions this can lead to misunderstandings (Kim, Kim & Lee, 2016), which can then cause accidents and collisions, threatening the lives of drivers and passengers. However, it is still possible for drivers to have an understanding of traffic rules and use them to manage many conflicts with success (Renner & Johansson, 2006). A DDCD could allow drivers to send specific, clear messages of their real intentions, avoiding any possibility of misunderstanding.

Jonasson (1999) states that there are three types of social rules applied to drivers' interaction - the rules of continuity, competition and positioning - with courtesy being the behaviour that holds them all together. Road users can compete and cooperate with courtesy to deal with conflicts (Joshi, Bellet, Bodard, & Amditis, 2009). Drivers can also

make use of the legitimacy of their position to act more aggressively or to force a yield. For example, it is considered impolite if drivers try to interrupt the movement or flow of others, unless they have a legitimate position to do so and the other drivers have negotiated this interruption (Jonasson, 1999).

According to the results of one experiment, which focuses on a scenario of a car following another one, drivers change their actions if they notice that the behaviour of others becomes more unstable (Saad & Mundutéguy, 2002). If drivers cannot accurately predict what the next intentions of others are, they tend to intensify the monitoring and/or take some sort of action such as change lane or reduce speed.

As pointed out by Zaidel (1992), there are three ways in which social environment can have an effect on drivers. The first is when the driver notices the other driver's behaviour and uses it as a clue to what they should do. The second way is by using explicit communication between drivers, which can be highly beneficial to reduce conflicts and to make the actions of others clearer. This explicit communication can only be clearly and effectively made using a device such as a DDCD. In the third way, drivers can compare their behaviour to others. They may compare their way of driving or their speed (Zaidel , 1992).

Joshi et al. (2009) define the concept of accountability to understand vehicle movement in traffic. According to the authors, drivers make their actions observable to everyone in the road environment. An example of such an action could be to reduce speed to allow drivers to merge into their lane. Therefore, it is the responsibility of all road users to recognise what drivers are doing. Failing to do so can result in dangerous driving.

One driver might influence the others to do something. But this other driver might also imitate the first one, even if this was not their intention initially (Wilde, 1976). People who are imitating may have a strong belief that what they are doing is the correct action

and also must be sure they have the required abilities to perform the action (Zaidel, 1992). One study showed that drivers are like sheep imitating the behaviour of others, even when this behaviour goes against the formal rules (Wilde, 1980). Another study by the same author showed that when drivers used the right indicator before turning right on a street there was an increase in others doing the same if their objective was to turn right as well. This imitation was also performed by pedestrians that crossed the road on the red light when another person was doing the same(Wilde, 1980).

2.3.1 Formal and informal rules

The main objective of most road users is to reach their destination safely. In order to achieve this aim and move from point A to point B, they must share the road with other users. During this time, drivers must be able not only to avoid fixed obstacles such as trees and road signs but also movable ones like other cars, pedestrians and animals that may cross the road (Applin & Fischer, 2015; Björklund, 2005).

It is usually easy to predict the road, which does not change very often, especially if the driver uses the same road constantly (Riener & Ferscha, 2013). The other drivers' speed and direction of movement are constricted by the environment and therefore also fairly predictable. However, it is much more difficult to predict other drivers' intentions. Goffman (2009) defines traffic codes as a set of rules that allows vehicles independent use of roads in order to move from one point to another. The UK Highway Code establishes a set of formal rules about how to behave and communicate in certain situations, for example the use of indicators to turn left or right (Driving Standards Agency, 2013). However, not all drivers follow these formal rules (i.e. legal norms). Some drivers may violate these rules on purpose if they know the rule is not strict and if they think they might not be punished (Goffman, 2009). Others may use a set of informal rules

(i.e. social norms) or signs to enhance the interaction such as flashing the headlights (Lennon & King, 2015; Lurie, 1968; Wilde, 1980). This informal interaction may not be understood by all drivers and may lead to accidents when two drivers follow opposite rules (Björklund, 2005; Factor, Mahalel, & Yair, 2007; Fleiter & Watson, 2006; Pillai & Ray, 2014).

Cialdini and Trost define an informal rule as a norm understood by a group of people that limits social behaviour without the use of the law. This norm may not be explicitly stated and may be created based on common interaction between users. Any approvals for not following these rules explicitly come from social networks and not the legal system (Cialdini & Trost, 1998).

Informal rules may be used because other drivers have a lack of understanding of the formal rules, which can be unclear. The design of the road or the situation may not be appropriate to make use of a rigid formal rule (Björklund, 2005), or there may be a lack of explicit formal rules that could cover all kinds of situations experienced by drivers (Jonasson, 1999). There will always be events in which road users need to make their own best judgement.

Informal rules are sometimes referred as “driving etiquette” (Page, Jones, & King, 2013) or “courtesy” (Jonasson, 1999), due to the fact that these rules are usually employed in situations in which a driver needs to act politely to avoid moral judgements (Lennon & King, 2015). Renge (2000) classifies these informal rules not only in terms of social etiquette but also into four other categories – (1) orders, (2) notices, (3) emphases and (4) expressions of displeasure.

One problem with the current setup of formal and informal rules is that, similar to homonymous words, the same message (e.g. flashing of headlights) may represent different meanings such as “Your headlight is on”, “I want to overtake you”, “I’m letting

you in", "Thank you" (Renge, 2000). Even though the contextual variables narrow down this message, it may still be unclear to the other driver what the reason for the message is. The problem is caused not only by the limitation of the dashboard instruments of vehicles, but also because informal rules are usually not shared and known by everyone (Wilde, 1976).

Lurie (1968) mentions that are some scenarios in which a formal rule is more appropriate, while there are others in which informal rules could be used. A pedestrian may cross a road on a red light if they are sure no car is coming. As discussed by Lurie, some factors called "social disorganization" may lead to accidents. Examples of such factors may include drivers' inexperience, driving on an unknown road, unexpected weather conditions (e.g. sudden snowfall or icing over which makes the road slippery and dangerous), and contradictory rules such as the fact that drivers should flash their headlights to overtake but this may cause temporary blinding (Fleiter & Watson, 2006; Lurie, 1968).

There are situations where it is inappropriate to apply a formal rule. In heavy traffic, it is better for vehicles to maintain a shorter distance from the car in front than keep the same distance stated in the Highway Code. This is actually counterproductive because if the car keeps a greater distance, another vehicle might cut in and occupy the space (Wilde, 1980). Drivers should speed up to match the speed of traffic on a motorway. Driving too slow in this situation can be considered a dangerous action (Juhlin, 1999).

Wilde claims there are four different types of behaviour that road users may display and that can create a conflict (Wilde, 1976):

a) Behaviour in accordance with both formal and informal rules;
b) Behaviour in accordance with formal, but not in accordance with informal rule;
c) Behaviour in accordance with informal, but not in accordance with formal rule;

d) Behaviour not in accordance with any rule.

Drivers may become confused when they experience behaviour from other drivers which is not in accordance (i.e. not predictable) with their expectations (Juhlin, 1999). One real example of such a conflict of behaviours is of a middle-aged woman who had four accidents in four years, none of which was her fault. She was too cautious when crossing roads or entering roundabouts and other drivers ended up hitting her car from behind (Johnston, 1973).

Another example is of intersections, very common in Europe, when drivers are unsure who has the right of way. Drivers usually have the right of way on streets that are given a higher "status" by them. This informal higher "status" may be based on road width, pavement type, level of lighting, presence of shops etc. Drivers on busy, wide roads usually do not give way to others even if the others have the right of way (Wilde, 1976).

Drivers tend to communicate their intentions to others in advance to avoid possible conflicts and accidents (Tomasello, Carpenter, Call, Behne, & Moll, 2005). A combination of both formal and informal rules may be applied in this situation. For example, motorist A, driving on the left in the UK, wants to turn right at a junction with oncoming traffic but is unsure about when it is safe to turn. They can use their indicators (i.e. formal rule) and wait. Driver B, in an oncoming car, notices the intention of Driver A and reduces their speed (i.e. formal rule) while flashing the headlights (i.e. informal rule), which would indicate to Driver A that they can start turning right and safely perform the manoeuvre (Portouli, Nathanael, & Marmaras, 2014).

Differences may occur even in a population from the same country and culture (Lennon & King, 2015; Swan & Owens, 1988). Drivers from a region with many roads with heavy traffic in one part of USA (e.g. Boston) have different behaviours and usually do not give way compared to drivers from calm streets in a small city in Kansas where courtesy takes

an important part of driver interaction (Wilde, 1976). These different behaviours may create confusion and misunderstanding.

Other factors may also cause accidents even for drivers from the same area with similar behaviours. When the amber traffic light is about to turn to red at the moment the driver is crossing it, they must make a decision whether to stop or not. This could lead to different expectations from another driver behind them and a crash might occur (Wilde, 1980).

Goffman (2009) states that traffic coordination is not always dependent exclusively on explicit communication between drivers. According to the author, drivers may also provide progressive evidence to the other of their intentions of movement, a small step at a time, which can lead to sustained trust. These trust conditions are reassessed all the time. However, driver communication is still essential in other driving situations not explicitly related to course of movement, such as an apologetic response to unexpected driving behaviour (Goffman, 2009).

Informal rules can vary not only according to the infrastructure, but also according to the individual road users involved in the interaction. Young drivers may not have the correct mental model of the road. They are taught only the formal rules in driving school and they learn the informal ones by interacting with experienced drivers. This can lead to a situation where the experienced driver expects a different behaviour from the novice (Renge, 2000; Saad & Mundutéguy, 2002). Novice drivers in Norway learned when to reduce the main beam headlights from experienced drivers who flashed their headlights to them if they took too long to do so. The study by Saad and Mundutéguy (2002) states that most experienced drivers, with their extensive driving knowledge, may use more informal rules to understand other drivers' intentions and actions than novice drivers.

Dannefer (1977) defines identity-based rules in which drivers' behaviour in traffic coordination is affected by stereotypes of the make and model of the vehicle and if the other driver is a learner or an elderly person. Experienced drivers can become more helpful in traffic interaction when they noticed the other driver is a learner (Juhlin, 1999). A study by Doob and Gross (1968) determined that drivers become more frustrated and make more use of the horn if the car that stalls in front of them is an old vehicle or a vehicle driven by a man. Another study found that participants expected drivers of a sports car (i.e. Audi TT) to drive fast and overtake them (Portouli et al., 2014).

Lennon and King (2015) proposed a framework to establish the relationship between the use of informal rules and aggressive driving. The framework takes into consideration the notion of two-way responsibility (i.e. courtesy), acknowledgement and responses to breaking the informal rules. Overall, the framework shows that both positive and negative signalling directly affects the other drivers' perception of the informal rules.

With the advent of automated cars, informal explicit communication between occupants of two or more vehicles is still very important and necessary, especially in a mixed-traffic scenario. One piece of research showed that attendants of an autonomous passenger shuttles sometimes have to use non-verbal communication such as head nods, gestures and lip-reading to coordinate and manage the traffic situation with a manual car (Eden, Nanchen, Ramseyer & Evéquoz, 2017).

There are some situations in which road users might resort to informal rules if there are no formal rules defined by the Highway Code. Conflicts between drivers could be reduced in these situations and safety enhanced if drivers had a way to communicate with each other or to many drivers at once using a device that would be both similar to a walkie-talkie (i.e. a "drivie-talkie") (Wilde, 1976) and to a Citizens Band (CB) radio used mainly by truck drivers (Applin & Fischer, 2015; Dannefer & Poushinsky, 1979; Packer, 2002).

This device would reduce the ambiguity in the emission and reception of messages and can produce more effective and comfortable social interaction between drivers (Renge, 2000).

2.3.2 Models of driver-to-driver interaction

Driver modelling aims to explain and understand human performance (Renner & Johansson, 2006). This section presents an overview of several models found in the literature that are relevant to the interaction between drivers. These models are reviewed in order to have a clear understanding of how drivers interact with other drivers and also to understand if there are any gaps that could be filled by this research. Initially these models, presented in the next subsection, limited their focus to a single driver. Models that are more recent, such as the ones described in the subsequent subsections, describe coordination between two or more drivers, their interactions and behaviour. Some of the models reviewed, such as the LMDI model presented in section 2.3.2.2, have already been applied directly to driver-to-driver communication scenarios with success.

2.3.2.1 Joint-action control model

As mentioned in section 2.3.1, when travelling from point A to point B, drivers need to share the road with other moveable objects such as drivers and pedestrians, while at the same time avoiding fixed obstacles such as trees and signs. The first model reviewed aims at understanding the main tasks required while driving and how this interaction with different actors occurs.

Renner and Johansson (2006) proposed a model based on a combination of the extended control model (ECOM) by Hollnagel, Nåbo, and Lau (2003) and the action coordination

model by Clark and Brennan (1991). This combined model deals with both individual and coordinated activities that drivers require while driving every day.

A review first of the models which led to the ECOM will give a clearer understanding of how the model from Renner and Johansson was developed. The initial model proposed by Hollnagel et al. (2003) is called Joint Cognitive System (JCS). In this model, the system and humans are seen as a single whole system that can adapt and change to achieve a goal. Each component of the road scenario can be coupled to another to form a system and this system can be coupled to others, somewhat similar to the Russian Matryoshka dolls. To begin with, the drivers and their vehicles are a system. The drivers and their vehicles travelling on the road are another system. Drivers travelling on roads with other drivers are also another system. However, not all elements of the driving scenario can be considered parts of this whole system. The weather is considered an environment and drivers cannot change it (see Figure 2.3).

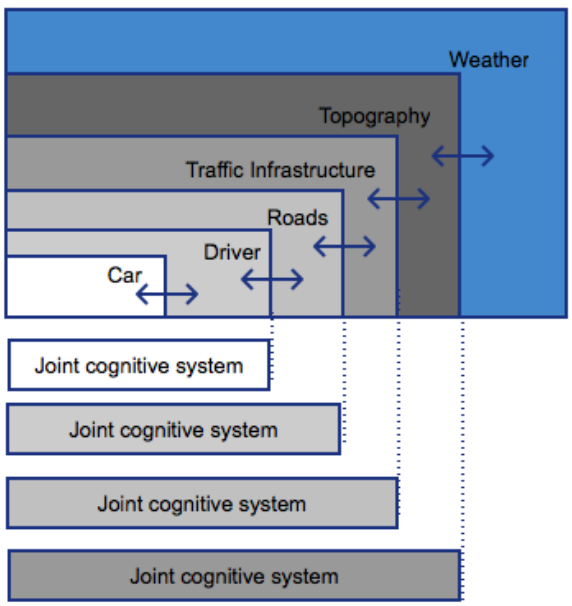


Figure 2.3. JCS model by Hollnagel et al. (2003)

Based on the JCS, Hollnagel et al. (2003) defined another model called Contextual Control Model (COMO). In this model, the humans or systems have a goal, which is described as a

construct. To achieve this goal an action must be taken. There will be a response to or feedback from this action, which can change or not their construct. This will then generate another action and the cycle continues. An extended version of this model was then proposed. This is called the Extended Control Model (ECOM) and focuses on a set of four tasks that are performed at the same time. The four tasks are targeting, monitoring, regulating and tracking. Each task creates an input for the next one. The first task, targeting, is mainly related to goals (higher or lower level goals) and their priorities. The second task refers to the act of monitoring the traffic and the system. The third one, regulating, is related to tasks such as checking speed while the last task, tracking, is related to the actions of changing lanes, gears and are performed automatically by most human drivers. The first two tasks are more anticipatory while the third and fourth are more compensatory (Hollnagel et al., 2003). Although in this model the other drivers are included as part of the process (i.e. environment), it does not take into consideration communication between drivers and how they state their intentions.

Clark and Brennan (1991) proposed a model based on the concept of common ground, which is more focused on the interactions between humans. This concept of common ground was thoroughly examined in section 2.2.1. Common ground in the road context is the knowledge of signals and traffic rules and depicts interactions that happen very quick and automatically.

Renner and Johansson (2006) combined the common ground model proposed by Clark and Brennan (1991), which focus more on human interaction, with the ECOM model proposed by Hollnagel et al. (2003). This newly created model is called Joint Action Control Model (JACOM), which can be seen in Figure 2.4.

Although this model is relevant to driver-to-driver communication, as it takes into consideration the interaction between motorists, it does not anticipate the intent of the

other drivers (Portouli et al., 2014). The next model reviewed tries to address the perception and presentation of drivers' intent, which is crucial for coordination in traffic and for effective driver-to-driver communication (Wilde, 1976).

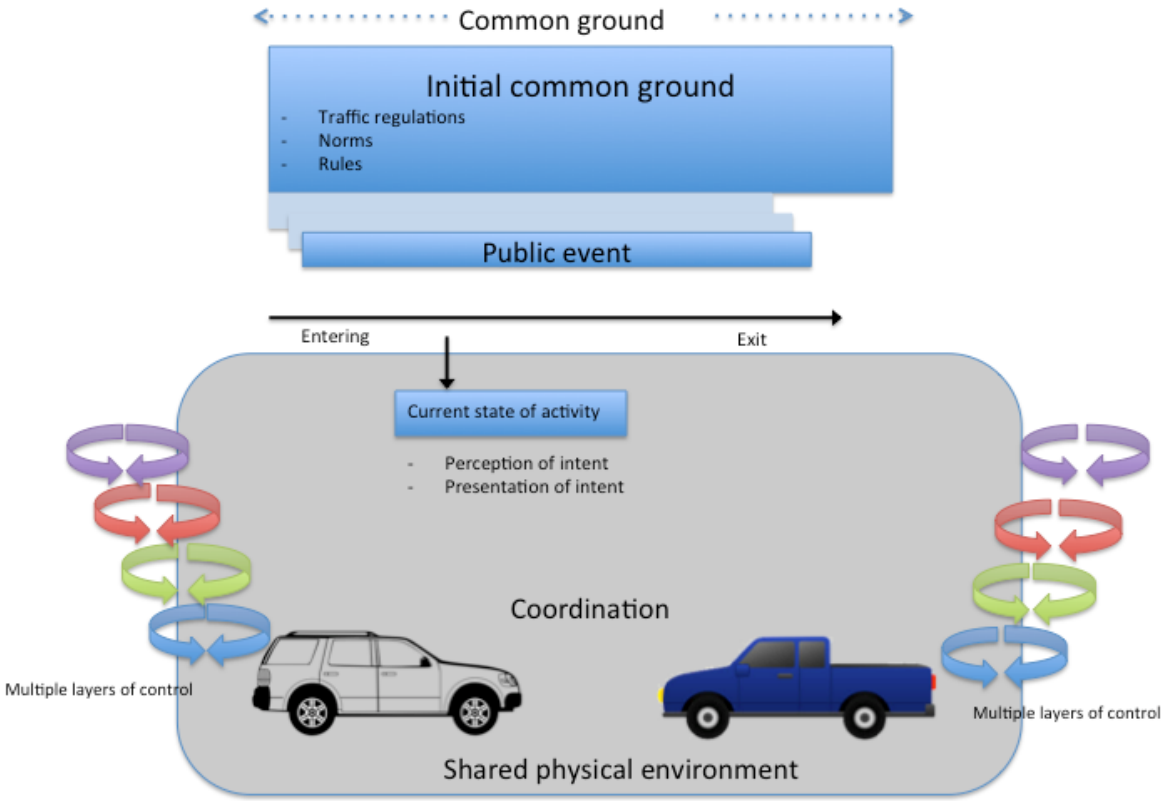


Figure 2.4. Joint action control model (JACOM) based on Renner and Johansson (2006)

2.3.2.2 Linguistic model of drivers' communicative interaction

Similar to the model discussed in Craig (1999), the model described by Portouli, Nathanael, Marmaras, and Papakostopoulos (2012) shows how interactions between two drivers operate (see Figure 2.5). First of all, the driver must show that they want to perform a manoeuvre. This can be considered as a request to the other drivers. Then, the other driver must notice that the driver making the request wants to perform a

manoeuvre. This process can be understood as a translation of the physical sign and the specific situation to an intended action (e.g. turning on the indicator means that the driver wants to overtake). The other driver must then show to the driver making the request that they have understood their intentions. This could be another action, such as moving to the hard shoulder or slowing down. The driver making the request would then notice that the other driver had understood their request and start making the desired manoeuvre. A similar three-part model of symbolic interaction was proposed by Swan and Owens (1988). In this model, driving interaction consists of (1) the indication of an action by one driver, (2) the interpretation of the action by the other driver and (3) their response as a result of this interpretation.

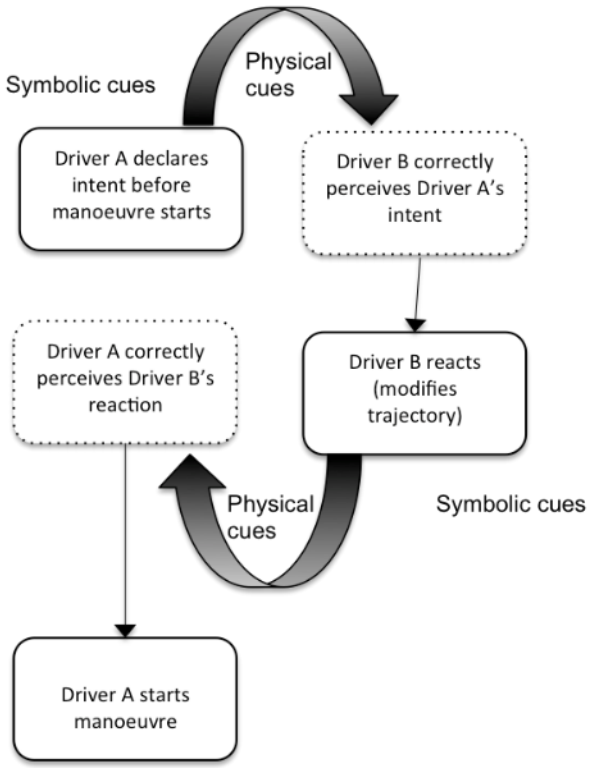


Figure 2.5. Linguistic model of drivers' communicative interaction based on Portouli et al. (2012)

The original model of cooperative interaction was revisited and updated by Portouli et al. (2014) and a new model based on speech act theory was then designed. According to the speech act theory, a locutionary act involves the speaker uttering words with a certain

meaning. At the same time a locutionary act occurs, an illocutionary act also takes place (Austin, 1975). The latter conveys a more general purpose and according to Searle (1975) can be classified as:

- Directive – act in which the person needs to take some action regarding the requests, commands or advice
- Commissive – act in which the person needs to commit to a future activity such as a promise or oath
- Declarative – act that changes the reality in accordance with a proposition
- Expressive – act in which the person shows their attitudes and emotions to a proposition
- Assertive – act in which the person is committed to the truth

In the driving context, illocutionary acts are mostly non-verbal and could be, for example, the use of horns or flashing headlights, while its related illocutionary act could be a request to free the lane. The linguistic model of drivers' communicative interactions (LMDI) models the interaction between drivers as a sequence of illocutionary acts which are easily transferrable to the driving context since these acts are finite and universal in nature (see Figure 2.6).

Most driving illocutionary acts could be classified as either directives (i.e. a request or a command), or commissives (i.e. acceptances or rejections of the directive). The result of the interaction can change the reality (e.g. the driver would start a manoeuvre based on the outcome of the interaction) and can therefore be considered as a declarative act.

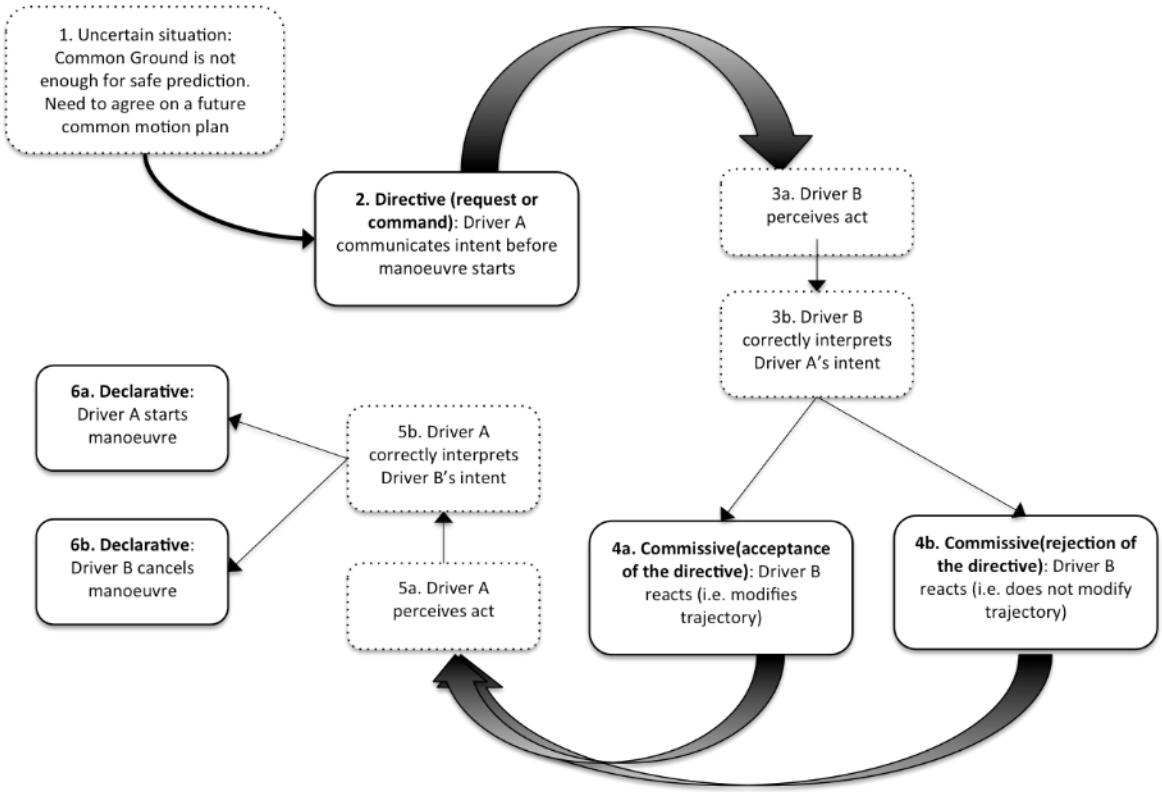


Figure 2.6. LMDI model based on Portouli et al. (2014)

This model was supported by empirical evidence of on-road observations and analysis of comments from drivers in several different communication scenarios. One scenario which was observed is the situation where a driver wants to turn right. Initially, driver A needs to submit a directive for to turn right to driver B using their indicators as an illocutionary act. Driver A needs to wait until driver B has responded to this directive before performing the manoeuvre. Driver B can acknowledge and respond to this intention of manoeuvre by flashing their headlights and slowing down. Driver A can then perceive this as an indication that driver B has accepted their directive act and can then start the manoeuvre.

The LMDI model takes into consideration mixed interactions between humans and driverless vehicles. This model was later evaluated in a study which found that, by using it, the design of cooperative driving support and highly automated systems can be enriched (Portouli et al., 2014). However, this model does not take into consideration

factors that can influence the communication between drivers such as risk estimation and context. The models reviewed in the next two sub-sections are based on some of these factors.

2.3.2.3 Models of drivers' behaviour

Drivers interpret other road users' intentions by interpreting their behaviour (Juhlin, 1999). Wilde proposed a model based on drivers' behaviour. According to his model, the driver receives information from the environment, which includes the physical structures of the traffic and also the informal and formal rules (i.e. The Highway Code). The driver also receives information from their own vehicle regarding speed, direction and information from other vehicles or road users (Wilde, 1976).

Based on all this information, the driver will generate a hypothesis about the environment, the behaviour of their car and other cars. After receiving more information, the driver may change their hypothesis or not. For instance, a driver may want to confirm their hypothesis that another driver who turned on their right indicator will indeed turn right by waiting to see if the car slows down and starts to turn to the right.

Whether this hypothesis is confirmed or not, it will generate a Subjective Estimation of Danger (SED) (Forlizzi, Barley, & Seder). If the level of SED is less than what is acceptable to the driver they will continue to drive without altering the path of the vehicle. However, if the level of the perceived risk is higher than expected, the driver will then make a decision about which action(s) to take in order to reduce this level of SED. The decision they make will lead to long term, short term and/or momentary action(s) that are inputted into the vehicle, which will then respond accordingly. This makes a change in the scenario and the loop then starts again with the driver receiving information from the environment, their vehicle and other vehicles.

The accuracy of execution of all the actions in this model depends on the cognitive state and the motivational state of the driver. These two factors depend on the modulating factors (e.g. age, sex, personality, preoccupation level, drug consumption, alcohol consumption, fatigue etc.). These modulating factors also reflect on the levels of perceived risk tolerated by the driver. There is a relation between the modulating factors and accidents. Some of them are known whereas others are less well known and according to Wilde (1976) this model could be used to analyse them.

2.3.2.4 Driver-to-driver interaction model

Ba and Zhang (2012) propose a framework of driver-to-driver interaction in which, similar to the previous model by Wilde (1976), states that individual factors (e.g. age, gender, experience) and external factors (e.g. technology, context) have an effect on the interaction between drivers. The authors also state there are four attributes associated with the driver-to-driver interaction process, two of which relate to the relation process and the other two relate to the emotional process:

- Attitude – a clear attitude (either positive or negative) about any driving behaviour, can have a positive effect on changing the behaviour;
- Attribution – drivers are subject to attribution biases towards other drivers as pointed out by Björklund (2005). For example, drivers who perceive other drivers speeding up are more likely to speed up than drivers who do not have this perception.
- Stress – driver interactions in complex traffic environments can increase stress levels which can also increase the number of errors, lapses and violations (Westerman & Haigney, 2000).

- Emotion – drivers' behaviour can be altered as a result of their emotions and the interaction between drivers is a source of different emotions.

The interaction process also differs if the drivers are in a hurry to reach their destination or not (Ba & Zhang, 2012). This interaction process is affected by the other drivers' behaviours, which then has an effect on the response of the main driver (Nass et al., 2005). This process occurs following traffic rules (either formal or informal). The framework can be seen in Figure 2.7.

This model does not take into consideration the use of any specific electronic communication device to manage and improve the communication between drivers. The last model reviewed focuses on the interaction between humans and technology to improve the interactions between drivers, vehicles and the environment.

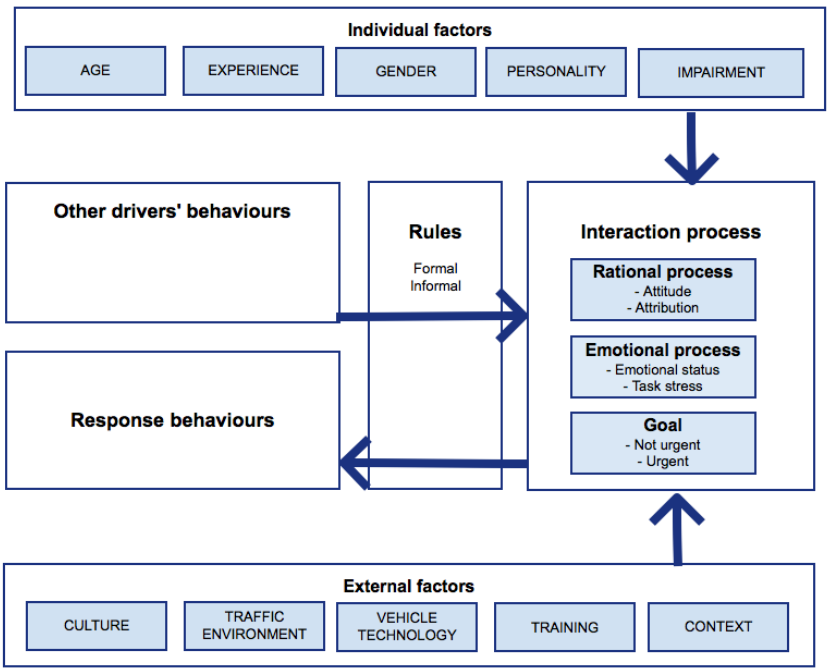


Figure 2.7. Driver-driver interaction model based on Ba and Zhang (2012)

2.3.2.5 Driver-vehicle confluence model

None of the models previously discussed provides details on the input/output modalities used by motorists while driving, and the information exchanged between vehicles and between a driver and their vehicle. This is one of the main aspects of the driver-vehicle confluence model proposed by Riener (2012a), which is presented in Figure 2.8. The model is based on the concept of human-computer confluence, which aims to investigate the relationship between humans and technology to propose novel forms of interaction. The model combines all information coming from drivers, vehicles and the environment in order to improve the interaction between all actors involved in the process. However, contrary to the other models in which the driver is responsible for perceiving a situation and reacting to it, in this one the aim is for the vehicle to implicitly recognise the behaviour of the driver and react to it accordingly.

The model describes different input and output modalities. The model proposes the use of implicit input such as the use of Brain Computer Interface to minimise driver distraction and workload in the interaction between the drivers and the vehicle controls. Alternative output channels are suggested, for example the use of tactile and subliminal feedback or olfactory stimuli in order to reduce the overused visual channel.

Similar to all other models, this one is closely linked to the idea of social interaction on the road. Two driving scenarios were evaluated in which the concept of driver-vehicle confluence can be applied. In both scenarios, information about the environment (i.e. weather and road conditions) was shared with motorists in order to make their driving experience more relaxed.

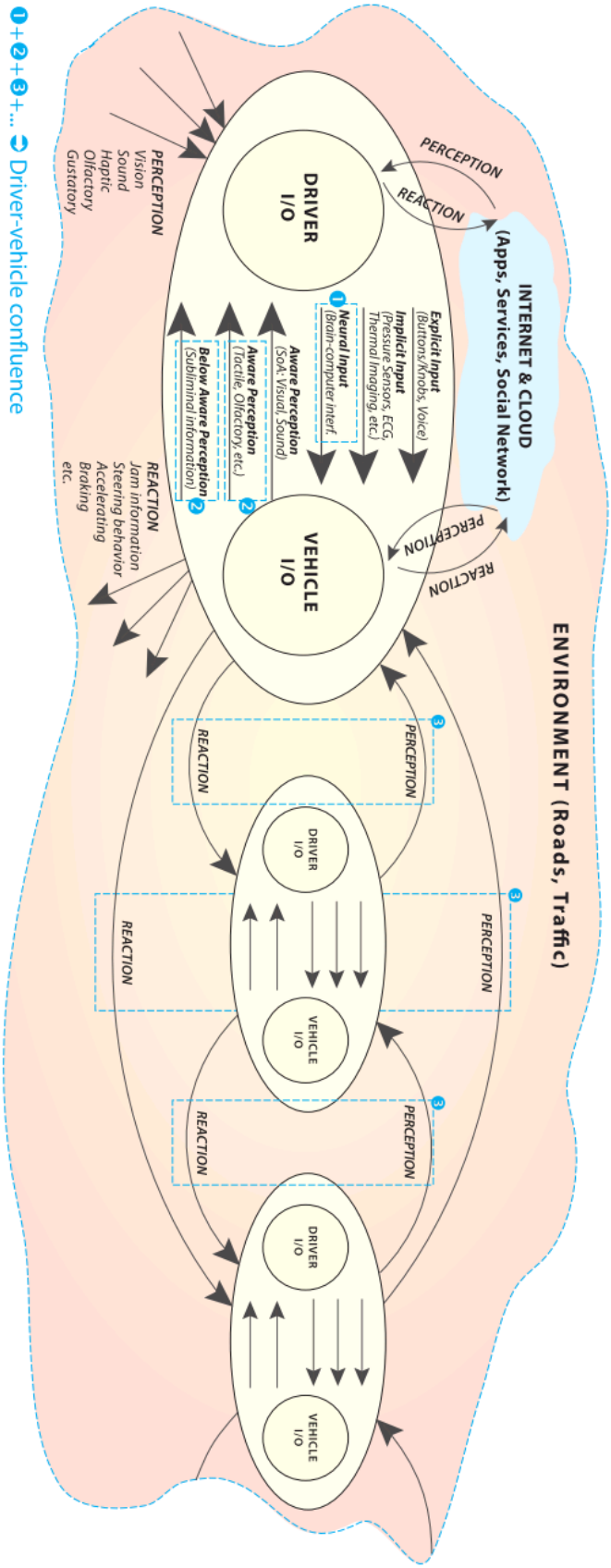


Figure 2.8. Driver confluence model from Riener (2012a)

2.3.2.6 Overview of models of driver-to-driver interaction

All the models reviewed in this thesis cover relevant aspects of drivers' interaction. Some models, such as the ones reviewed in sections 2.3.2.1 and 2.3.2.2 aim to represent the coordination mechanisms between drivers. They are based on already established communicative theories such as common ground, reviewed in section 2.2.1. Other models, such as the ones reviewed in sections 2.3.2.3 and 2.3.2.4, focus on a set of variables that have an effect on drivers' interactions which are also highly relevant. However, there is no model that covers both coordination mechanisms and all the internal and external factors that may be involved in different communication scenarios. Moreover, no model reviewed takes into account the use of a specific communication device to improve the interaction between motorists. Different factors may have an influence on driver communication via an electronic communication device.

By reviewing these models, it was found that there is a gap in knowledge regarding the use of an electronic communication device to improve the social context of driving. This PhD research aims to provide, as one of its objectives, a framework with factors which influence the interaction between drivers using an electronic communication device not currently available in vehicles.

2.3.3 Social car

The cost of the Internet and cloud storage has decreased and become widely available over recent years. This advance allows users to access data and connect to the Internet from anywhere, including in a vehicle. Research shows that 20% of active social network users make use of these services while in a vehicle, posting content related to the road environment such as information about traffic updates (Riener, 2012a). Therefore, there

is considerable potential to use socially inspired mobility services since nowadays there are more than 35 million vehicles licensed for use on roads in the UK.

A social or connected vehicle can be defined as a vehicle that uses technology to share any information to promote social awareness to surrounding road users (Rakotonirainy et al., 2014). According to Riener, Jeon, Alvarez, and Zambonelli (2014), social cars must create true value to drivers by tackling important areas such as the ability to resolve issues in mass traffic, optimise driving time and vehicle efficiency, protect the environment by reducing CO2 emission and ensure safety on the road. Research carried out by Chowdhury (2015), showed that connected vehicles also have the potential to reduce driver aggression and improve road courtesy.

Connected vehicle could improve communication between all road users (i.e. driver-to-driver, driver-to-passenger, passenger-to-passenger, driver-to-pedestrian, and agent-to-agent) (Schroeter, Rakotonirainy, & Foth, 2012). The technology to share this information can be transmitted between vehicles (V2V) or between vehicles and the road infrastructure (V2I). Drivers could broadcast their information to everyone or just share it with a specific driver(s).

The research presented in this thesis is based on the concept of social cars. A DDCD could use the infrastructure provided by connected vehicle technology to exchange messages between drivers. Pioneering research has recently been carried out which covers several different aspects of social cars. Several examples of diverse areas are presented in the following paragraphs.

Research has been conducted to investigate ways that drivers can express their current emotions, state or mood to all drivers around such as being in a hurry or in an emergency situation (Schroeter et al., 2012; Soroa, Wollstädterb, & Rakotonirainya, 2014; Wang, Gu, Terken, & Hu, 2014). Driver aggression could be reduced by the use of alternative in-car

communication systems. Drivers' current state or emotion could be shared with other drivers in many different ways, such as via textual communication, visual representation (Liu et al., 2015; Kim et al., 2016) or even a snapshot of a situation which drivers disliked (Soroa et al., 2014).

Drivers can also share with others any type of information that is initially available only inside their vehicle, such as which song they are listening to at the moment (Juhlin, 2010; Soroa et al., 2014; Wang, Gu, et al., 2014), or their current speed (Schroeter et al., 2012). Music has a powerful effect on emotions with several studies reporting it to have a positive effect on reducing aggressiveness and contributing to a pleasant experience (Soroa et al., 2014; Wang, Gu, et al., 2014). Information about the high frequency of use of the brake pedal on a specific road area can be shared with non-local drivers to warn them about dangerous spots (Riener, 2012a).

Research has been conducted on drivers sharing information about the road environment to other road users. Drivers can share information about road conditions (Wang, Gu, et al., 2014), such as road works, accidents (Lequerica, Longaron, & Ruiz, 2010; "Waze," 2014) and traffic jam (Tan, Zhao, & Wang, 2012). Information about the road can be presented visually as a camera snapshot of the car in front (Soroa et al., 2014; Wang, Gu, et al., 2014) or as a hazardous note pinpointing a specific location on the road (Riener, 2012a). Drivers could also share information about points of interest, such as restaurants or attractions, which could be presented as a communication between driver and passenger (Matsumura & Sumi, 2014).

Research has also been carried out on sharing drivers' personal information, such as their contacts (Esbjörnsson et al., 2003b), their profiles on social networks (Wang, Gu, et al., 2014), and any shared interest to other drivers (Esbjörnsson et al., 2003a; Schroeter et al., 2012; Wang, Gu, et al., 2014). However, research shows that drivers do not want to

allow other road users to invade their personal space too much and become intrusive (Soroa et al., 2014; Wang, Gu, et al., 2014).

Social cars can improve pro-social driving behaviour and reduce dangerous driving (Rakotonirainy et al., 2014). Research has been conducted on sharing motivational comments for pro-social driving (Knobel et al., 2013), and a gamification approach to achievements (Schroeter et al., 2012) for eco-driving (Soroa et al., 2014), and positive driving behaviour (Bergmans & Shahid, 2012; Kim et al., 2016; Schroeter, Oxtoby, & Johnson, 2014; Soroa et al., 2014; Wang, Terken, & Hu, 2014). An avatar with eye movements has been used to increase drivers' social awareness of other drivers and their sense of social presence and feelings of intimacy, thereby decreasing anonymity (Rakotonirainy et al., 2008).

Finally, detailed research on communication between road users has also been carried out in the last few years. Research focused on free communication between bus drivers (Juhlin & Normark, 2000), and tourists driving on a road trip, i.e. motorcade (Knobel et al., 2012; Thiel, Foth, & Schroeter, 2015). Research has also been conducted on easy ways to create visual contact between driver and passengers in the same vehicle, either the passenger in the back (Tai, Kern, & Schmidt, 2009) or in the front (Gärtner, Meschtscherjakov, Maurer, Wilfinger, & Tscheligi, 2014; Maurer et al., 2014; Perterer, Sundström, Meschtscherjakov, Wilfinger, & Tscheligi, 2013; Perterer, 2016). However, innovative and ground-breaking research is still required on the use of connected vehicle technology to help drivers communicate with each other to make their intentions clear.

2.4 User acceptance

User acceptance can be defined as the willingness of a group of people to use a specific piece of technology for a set of tasks, which the system was originally designed to support

(Dillon & Morris, 1996). User acceptance covers not only users' subjective experiences but their attitudes towards technology (François, Osiurak, Fort, Crave, & Navarro, 2016). Early assessment of user acceptance can be beneficial in terms of cost and effort and is vital for the success of any system (Meschtscherjakov, Wilfinger, Scherndl, & Tscheligi, 2009). It is not productive to invest considerable effort in designing a system if it is never or rarely switched on by users (Van Der Laan, Heino, & De Waard, 1997). It is of high importance to investigate acceptance issues in the very early stages of the design process of new systems, especially in safety critical contexts like the automotive one, which is traditionally replete with emotions (Adell, 2010; Meschtscherjakov et al., 2009; Regan, Horberry, & Stevens, 2014). Many studies have investigated technology acceptance in the automotive context, such as evaluating the effectiveness of automatic speed limiters in reducing accidents (Comte, Wardman, & Whelan, 2000). Acceptance of advanced traveller information systems has also been fully investigated (Dillon & Morris, 1996).

There are several models and techniques to measure user acceptance that have been extensively employed in the automotive context. One specific model and one technique were applied in this PhD research and, for this reason, are reviewed in the next subsections. The acceptance model reviewed is the Car Technology Acceptance Model (CTAM) which was used in STUDY E, a driving simulator study with low-fidelity prototypes presented in Chapter 08. The CTAM is specifically focused on the automotive context and is derived from two well-stablished models, i.e. Technology Acceptance Model (TAM) and the Unified Theory of Acceptance and use of a Technology (UTAUT). The technique used in this PhD research is the Van der Laan's acceptance method (section 2.4.2), which was adopted in STUDY C presented in Chapter 06.

2.4.1 Car technology acceptance model

According to Osswald et al. (2012), general models of technology acceptance do not take into consideration relevant contextual factors specifically related to vehicles, such as environmental conditions, motion and the properties of in-car systems. Firstly, contextual information such as speed and position of the car are crucial to the driver and are not specifically supported by these models. According to the models reviewed in section 2.3.2, the context of communication with social and environmental factors can have an effect on drivers' interactions. Secondly, the drivers' interaction with the system often takes place while travelling, when the user has limited free mental resources, and when safety is an important issue. This is even more relevant to the driver-to-driver communication context as there is an extra task involved. Finally, high reliability of in-car systems is very important to reduce anxiety. Therefore, the models of acceptance presented earlier needed to be reworked and not simply slightly altered to take these factors into consideration.

A specific version of the UTAUT models was then designed to be used specifically in the automotive context. The car technology acceptance model (CTAM) model takes into account contextual situation to provide a way to explain drivers' acceptance of in-car systems. This model expands the UTAUT model by adding to it the determinants of perception of safety and anxiety. The effect of safety on in-car technology acceptance with the focus on risk and control has also been investigated by Joshi et al. (2009) and they found high acceptance of the system being evaluated.

The CTAM uses six determinants from the UTAUT model, which play a major role in the automotive context: performance expectancy, effort expectancy, social influence, facilitating conditions, self-efficacy, and attitude towards using a technology. The CTAM

is depicted in Figure 2.9 with these eight factors and their relationship with the two behavioural constructs of intention and usage of technology.

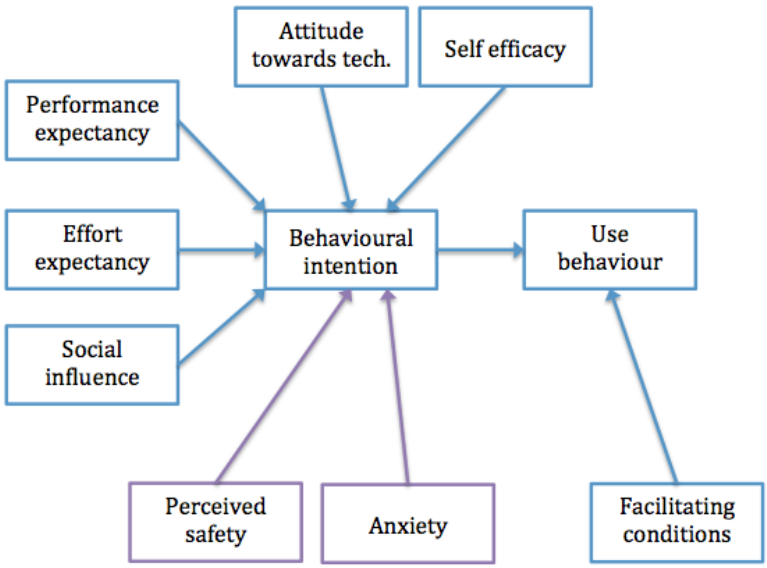


Figure 2.9. Car technology acceptance model by Osswald et al. (2012)

Performance expectancy can be defined as the degree to which drivers believe that the in-vehicle technology will aid them to achieve their driving performance objectives. Effort expectancy is closely related to the ease of use of the system. The attitude towards the technology is drivers' overall affective reaction after using the system. The effect of other people's opinion on drivers' own opinions is measured through the social influence construct. The fifth construct is facilitating conditions, which can be defined as the degree to which drivers believe that a resource, either technical or human, is available to help in the use of the system. Self-efficacy is related to drivers' own abilities and competencies to use the system. Anxiety, a specific construct for the CTAM, is how apprehensive and uneasy the driver feels when responding to a situation. Finally, the last construct, perception of safety, is defined as the degree to which drivers feel that by using the system they will improve their well-being and their sense of safety (Osswald et al., 2012). The authors developed a CTAM questionnaire to measure the acceptance of in-vehicle

technology with good internal consistency for almost all scales, i.e. Cronbach's alpha higher than 0.8.

The CTAM has advantages when compared to the other models. The model is more flexible, as it can be used with or without a prototype version of the system. Moreover, since it can be used without a prototype it can cost less by allowing modifications to the system very early on in the design process (Osswald et al., 2012). Based on these factors, the CTAM was used in a driving simulator experiment described in Chapter 8. Rodel, Stadler, Meschtscherjakov, and Tscheligi (2014) used the CTAM dimensions of perceived ease of use, behavioural intention, perceived behavioural control and attitude towards the technology to investigate driver acceptance of different levels of vehicle automation.

2.4.2 Van der Laan's acceptance method

This research also used one of the first methods presented to assess user acceptance in the driving context. According to Van Der Laan et al. (1997) any advanced transport telematics systems can be positioned along a continuum. At one extreme, this continuum represents systems that are purely informative such as a radio data system that transmits messages about road works in which the driver can simply decide whether to accept this information or not. The other extreme of the continuum is represented by complex systems that can take control of parts of the driving task such as an automatic braking system, which can be activated in case the driver is too close to the vehicle in front (see Figure 2.10). For systems at this extreme of the continuum drivers' behaviours are more restricted and, according to the author, tend to be less accepted (Van Der Laan et al., 1997). However, no supporting evidence for this was provided. Based on this concept, the author developed a simple and inexpensive technique to measure driver acceptance of advanced transport telematics by direct attitudes towards the system.

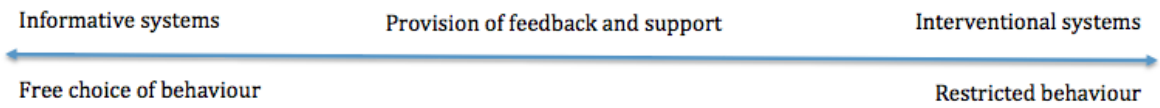


Figure 2.10. Van Der Laan et al. (1997) continuum

Van der Laan's driver acceptance method consists of nine items on a 5-point rating scale. The items on the scale comprise of pairs of bipolar adjectives covering several judgements such as effectiveness, pleasantness and desirableness. In contrast to the CTAM, which defines acceptance in terms of eight contributing factors, the results of the Van der Laan's scale items are presented in two output scales. One output represents the usefulness of the system with more practical aspects, whereas in the other one, the pleasantness of the system is mirrored in the user satisfaction. Paay and Kjeldskov (2005) have stressed the importance of usefulness to any system when dealing with its acceptance. Subjective criteria related to user satisfaction such as aesthetics, pleasure and fun, is dependent on willingness of use (Sharp, Rogers, & Preece, 2007).

This technique had been evaluated with different types of systems such as intelligent cruise control, collision avoidance systems, and systems that monitored driving behaviour. The technique was used in different stages of the design process. For some of these systems, participants had been previously exposed to a prototype version of the system whereas for others, they were asked to imagine a hypothetical device explained to them.

2.5 Emotions

One of the objectives of this PhD research is to investigate drivers' emotions when receiving messages via the DDCD. Emotion can be defined as "a strong feeling deriving

from one's circumstances, mood, or relationships with others" (Oxford English Dictionary, 1989). Research on emotions is very broad and encompasses many areas of knowledge. This section focuses specifically on human emotions in the driving and computer-mediated communication (CMC) contexts which are specifically related to the work presented in this thesis.

The effective communication of emotions is an important aspect in CMC. Emotions can be transmitted in CMC environments using verbal cues (e.g. words or phrases in spoken/written language using either explicit emotional words or linguistic markers, or nonverbal cues such as body language, qualities of voice such as volume, tone etc. or facial expressions (Harris & Paradice, 2007). Although ways of communicating emotion in CMC may be different from face-to-face (F2F) communication, research shows that this does not make CMC less emotional or personal. In fact, when differences were found, these tended to be more frequent use of explicit communication of emotion in CMC when compared to other media (Derks, Fischer & Bos, 2008). The nature of CMC also allows for an exchange of more intimate questions and disclosure when compared to F2F (Tidwell & Walther, 2002).

Extensive research has been carried out on the harmful impact of negative and uncontrolled emotions on the road. Sadness can decrease attention leading to driver distraction, and anger can increase road rage causing accidents (Frasson, Brosseau, & Tran, 2014; Grimm, Kroschel, Harris, Nass, Schuller, Rigoll & Moosmayr, 2007). Driving safety can also be affected by fatigue, stress, confusion and nervousness (Eyben et al., 2010; Grim et al., 2007). A driving simulator study aimed at capturing the effects of anger, fear and happiness associated with four types of driving errors including aggressive driver, lane keeping, traffic rules and collision (Jeon, Walker, & Yim, 2014). The main results suggested that emotions should be considered when designing a scale beyond the

simple valence and arousal domains. A study by Kim et al. (2016) with 92 participants found that emotions that drivers most want to express are appreciation (24 occurrences), anger (17 occurrences), apology (16 occurrences) and surprise (9 occurrences). The research presented in this PhD thesis adopts different driving communication scenarios to understand some of these drivers' states such as an apology for blocking a junction, anger for being cut in front of by another driver, fear of an aggressive tailgate motorist, happiness to share a common interest and appreciation of being made aware of adverse road conditions.

Emotions in the driving context were also investigated in a car-following scenario designed in a simulator with findings showing that emotions made drivers change their driving behaviours (Higgs & Abbas, 2014). Recent research has also been carried out in how drivers' emotions could be managed by the vehicle. According to Eyben et al (2010), secure driving can be supported by either adapting the vehicle to the current driver state or by attempting to direct drivers' emotion to a neutral state.

One of the most effective ways of enriching non-verbal cues in certain types of CMC is by using graphical representations of facial expressions, a.k.a. emoji, emoticons or relational icons. Research shows that, in order to achieve socially oriented communication, emoticons contributions in email messages were outweighed by the verbal content (Walther & D'Addario, 2001). In the road context, emoticons have been successfully used in a prototype for the purpose of investigating driver's feedback to four different types of emotions displayed graphically on the back windshield of a car (Kim et al., 2016). A similar approach has been used on the commercial device Drivermotion (2010).

This PhD research investigated emotions in two studies with a different approach in each one. Emotions were investigated in STUDY B for each one of the visual-based driving communication scenarios. Participants were asked to write on post-it notes their feelings

when receiving a specific message from other drivers in different driving communication scenarios (see page 145). In STUDY C, the Self-Assessment Manikin (SAM) was used as a practical tool for measuring emotions (see page 157). This tool provides a fast and easy way to respond and it is totally visual, so it can be used with participants from different cultures and also children (Dormann, 2001; Morris, 1995). SAM has been successfully used to measure emotions in different contexts such as web page evaluation for e-commerce (Dormann, 2001) and an affective evaluation of facial expressiveness prompted by a wide range of images (Lang, Greenwald, Bradley, & Hamm, 1993). More specifically related to the driving context, SAM was adopted in a driving simulator experiment to explore a performance and emotion relation model constructed on an arousal-valence plane (Cai & Lin, 2011).

2.6 Summary of literature review

This chapter has reviewed the literature from three main distinct areas of research: human communication, emotions and user acceptance. There is extensive research on human communication from theories and models such as common ground to different aspects of human communication such as users' interaction mediated by different types of technology. There is also relevant research on the social interaction between drivers, without an electronic device, including several different models of interaction that aim to cover different aspects of these encounters. However, there is not enough recent research on driver-to-driver communication, especially using an electronic device to make drivers intentions clear. Wilde, as long ago as 1976, envisioned the idea of a driver-to-driver communication device using a form of walkie-talkie, but the technology had not been sufficiently developed at that time to enable research on this as the concept of connected vehicles, and all the technology that supports this, is relatively new. There is currently a

gap in research on the use of an electronic device to improve driver-to-driver communication. The research presented in this thesis will draw from the research in the fields of human communication and drivers' interaction to investigate how a DDCD could be designed, and provide a framework for the use of an electronic device to support driver's communication.

Before a new technology becomes available to the general public it is crucial to investigate the acceptance of potential users. This research reviewed several models of user acceptance of a new technology, which have been used in some of the studies presented in Chapters 05-08, and also reviewed the effect of emotions on driving behaviour and on technology-mediated communication.

The next chapter describes in detail the methodology used in this research. Different methods were employed throughout this research in order to achieve the objectives of each investigation study. Information about the relevance of the methods for each stage of the research and their benefits and limitations are also examined.

3 Research methodology

3.1 Research methods

Throughout this research, a combination of methods was employed to understand the different aspects of driver-to-driver communication. The methods were chosen according to their appropriateness for the specific stage of the research. In the beginning of this research, for example, it was deemed important to design a task analysis to understand the main tasks required by users when interacting with a DDCD. However, in the later stages of the research, a driving simulator study was required since it was necessary to measure specific tasks in a controlled environment. Figure 3.1 shows the methods used throughout this research and in which chapters of the thesis they are presented. All the methods are reviewed in detail including their benefits, limitations and importance during each stage of this PhD research.

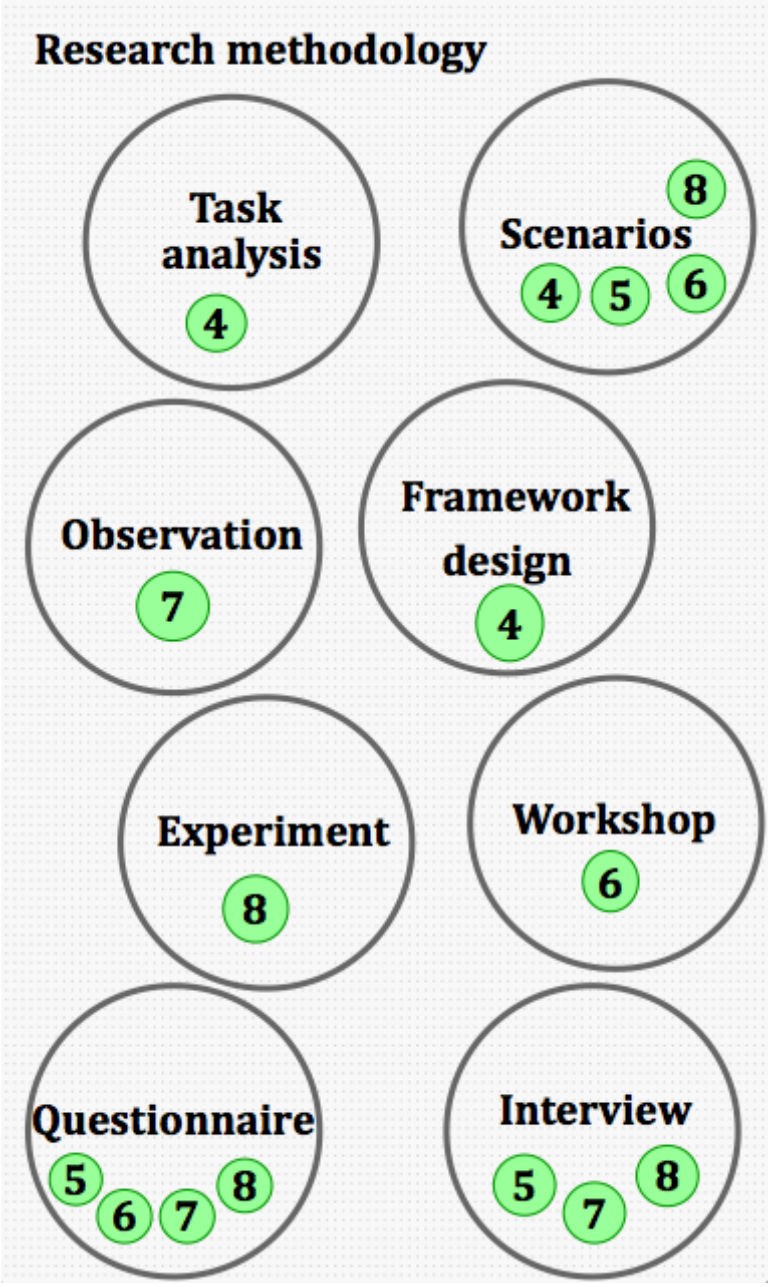


Figure 3.1. Research methodology with thesis chapters

3.2 Task analysis

Task analysis is a set of methods that can be used to obtain information about characteristics of a working context that have an effect on human performance (Shepherd & Stammers, 2010). The information gathered from a task analysis provides a solid foundation that allows researchers to design new tasks or build new requirements (Sharp

et al., 2007). Task analysis covers many different methods to investigate cognitive processes and physical actions. The method used in this PhD research is called Hierarchical Task Analysis (HTA), and it is one of the most widely used types of task analysis. HTA has been used for many applications, not only limited to interface design, which is the main application to this research, but also applied to workload assessment, job aid design and error prediction (Stanton, 2006).

The first step of an HTA is to define the users' goal. After this, the main tasks required by users to achieve this goal are identified. In HTA, a main task required by a user can be broken down into subtasks, which can then be subsequently broken down into sub-subtasks and so forth. This process can go on until it reaches a low level step, which could, for example, be represented in a screen sketch (Sharp et al., 2007). Not all subtasks may be required by all users, or not all subtasks may be required in any particular order. Therefore, these peculiarities can be represented in textual form in an HTA by the use of plans, which are related to each task and its subtasks.

HTA was employed in the early stages of the research presented in this thesis. It was considered fundamental at this point to understand the tasks required by users to interact with a DDCD. The HTA helped in the design of the set of use case scenarios that were used throughout this research. The HTA is also part of a driver-to-driver communication framework, which can be a powerful tool to aid designers and developers of a DDCD in the early stages of the design process.

The main goal of drivers in this research is to be able to successfully exchange messages with other motorists. This goal was split into the two main general tasks of sending a message with a DDCD and receiving a message with a DDCD. Therefore, two graphical versions of HTA with a box-and-line notation were designed. New sub-tasks were then identified and the process continued with the identification of more sub-subtasks and the

description of plans for some of the tasks. The two HTA diagrams designed are presented in the next chapter.

The main criticism of HTA is that it may not adequately represent some real tasks, which can be highly complex. An HTA representation of such tasks would become disproportionate and disorganised. Moreover, HTA does not allow the design of tasks that are executed in parallel or with interruptions. However, HTA has several advantages, the main one being to facilitate good design by providing a clear understanding of users' interaction with a system at any level of abstraction (Sharp et al., 2007). Task analysis can be advantageous if it answers any questions in the design or evaluation of a system in a way that not only improves the design but also leads to better insights (Shepherd & Stammers, 2010).

In this PhD research, the HTA was designed by the researcher with his theoretical knowledge of driver-to-driver communication. The HTA was further validated in the subsequent studies in the chapter.

3.3 Framework design

Frameworks are tools used by designers to make sense of complex ideas by creating diagrams or graphic models that structure the information in an explicit way, highlighting the relationship between these ideas in a simplified form (Kirk, McClelland, & Suri, 2015). These ideas can represent many different concepts such as user behaviour, activities, task sequences and variables. Frameworks can reveal the strengths in the relationship between ideas, but also gaps in knowledge and opportunities for improvement. Frameworks can be a powerful stimulant for communication between members of a design team (Kirk et al., 2015). They can also be seen as a reference tool offering advice to designers as to what to look for (Sharp et al., 2007). Frameworks can be developed

using a combination of different tools, which vary according to the design needs, such as task diagrams, journey maps, network maps and affinity diagrams. Framework development is a very common method in HCI and HF/E with many frameworks covering different aspects of user experience being published in highly ranked academic journals. One example of such a framework is the relationship between the design of a conceptual model and users' understanding of it as developed by Norman (2013).

The research presented in this thesis developed a driver-to-driver communication framework, which is presented in detail in the next chapter. The framework aims to help designers understand the main actors involved in driver-to-driver communication and the variables that may influence this communication. A set of communication scenarios was designed based on this framework. The framework comprises of a diagram, which depicts all these elements in a graphical way. The framework also consists of a task analysis with the main tasks required by users to interact with the DDCD.

3.4 Scenario-based research

This research was based on driving communication scenarios, which are specific stories used to present information and elicit opinions from participants. Carroll (2000) describes scenarios as an informal narrative description, which can be defined as a way of representing a story that can be used as the starting point for discussion with users. This informal representation makes scenarios a natural way for users to understand a situation (Sharp et al., 2007). Scenarios can have four distinct purposes: they can be used to illustrate the use of a system, to evaluate the functionality of a specific system, to design system attributes, and ultimately to test theory (Campbell, 1992). The elements that can be represented in a scenario include individual users with specific profiles, the tasks

required in system interaction, the context of use, and the design of the system (Kirk et al., 2015; Sharp et al., 2007).

Scenario-based studies have been used not only for HF/E automotive research (Konstantopoulos & Crundall, 2008; Lennon, Watson, Arlidge, & Fraine, 2011), but also for other areas within HCI (Carroll, 2000), and can be considered a powerful design tool. Scenarios can be used to explore potential issues with the use of a proposed technology, in this case an in-vehicle communications device, before implementation. The technique generates predictions about emergent behaviour arising from the user-device interaction and leads to design recommendations to support future product development.

According to Kirk et al. (2015, p. 249), "*Scenarios should not be just fantasies, but carefully constructed projections of anticipated usage situations that are based on available evidence*". The set of driving communication scenarios used throughout this thesis was developed based on a driver-to-driver diagram and a task analysis of a DDCD, which had been designed earlier in this PhD research. They are all described in detail in the next chapter.

Scenarios can vary in scope and scale. They can be designed, for example, to include detailed lengthy processes or to portray storyboarding representations of interactions with the product (Kirk et al., 2015). The scenarios presented in this thesis are vignettes, which are short descriptions of a single event. According to Robson (2002) vignettes present a fictional situation based on a real event in which participants are invited to give comments on their feelings and opinions. Even though the stories adopted in this PhD research are vignettes, the more general term communication scenario is used throughout this document.

The stories in scenarios can take many forms, such as sketches, cartoons, videos or live enactment (Kirk et al., 2015). The same set of driving communication scenarios adopted

in this research was presented in different forms in each study. The choice of form of presentation is closely related to the research stage of each study. Scenarios were presented in a text narrative in STUDY A because of its exploratory nature. In STUDY B, scenarios were presented graphically on paper, similar to a cartoon, because it was considered more appropriate for the setup of the study, which involved a group of experts working together to answer four questions about the scenarios. Participants watched videos from the set of scenarios in STUDY C. Scenarios were presented in video in this study, not only as progress from the previous study, but also as a way to evaluate some of the results obtained. Scenarios were also presented in video in STUDY E, which took place in a driving simulator. However, contrary to STUDY C, in STUDY E participants not only watched the scenarios unfold before them, but they also played a major role in the situation. Participants were also directly affected by the outcome of the scenario.

3.5 Interviews

Interviews are a guided conversation between the researcher and one or more respondents about a specific topic or issue. Interviews are an efficient and effective way of gaining in-depth qualitative data by asking the right questions that allow the researcher to explore a vast range of issues regarding a particular topic (Lazar, Feng, & Hochheiser, 2010). They are a valuable data collection method for all stages of the design process, with an inherent involvement of participants (Sharples & Cobb, 2015). Interviews can be conducted with only one participant at a time (i.e. one-to-one) or with a group of participants, the latter also known as focus groups.

One of the main challenges of interviews is the amount of time required for the data analysis, which might impose a limit on the number of participants recruited and the duration of the interview. According to Robson (2002), one hour of audio recording can

take as much as 10 hours just to transcribe the data. Interviews also rely on the expertise of the interviewer, who should be able to ask the right questions at the right time to provide effective communication with the interviewees.

One-to-one interviews can be categorised into three main types: structured, semi-structured and unstructured (Robson, 2002). In structured interviews, the interviewer follows a script with a set of predetermined questions, which are recorded on a standard form. In contrast, unstructured interviews are more informal and are similar to a conversation. Semi-structured interviews are situated between the previous two, with the interviewer having a set of points around which to build the interview, but more questions can be asked in order to acquire a deeper understanding of a particular topic.

This research adopted one-to-one semi-structured interviews in all three studies in which they were used. In STUDY A, which is an exploratory investigation of the DDCD, the interview was the main method adopted alongside the use-case scenarios. The main reasons for using interviews at this early stage were to facilitate the exploration of driver-to-driver communication questions with regular motorists, and at the same time for the researcher to familiarise himself with this complex domain. In STUDY D and STUDY E, a short interview was used only at the end of the process with the main purposes being to understand some of the observed behaviours of participants throughout the study (STUDY D) and to clarify their opinions (STUDY E).

3.6 Workshop and expert knowledge elicitation

Workshops are an agile and flexible tool that supports participants' creativity by allowing researchers to explore specific activities, situations and/or environments (Droumeva & Wakkary, 2006). Workshops can help move the design process forward by clarifying specific aspects of the design, which are being investigated. Designers can then reduce

the scope of the system and possible functionalities that users may need. Workshops are also helpful in earlier stages of design to brainstorm a situation and to get an initial understanding of a particular problem or domain (Robson, 2002).

A workshop can be represented as a system. The main elements of this system are the participants, the facilitator, the tasks and the place. The facilitator arranges the workshop, sets up the place and establishes the tasks required by the participants. The participants are then grouped in this place and must work together to accomplish all tasks given to them under the supervision of the facilitator. The facilitator must also make sure that the workshop runs according to the aims of the study (Numa, Toriumi, Tanaka, Akaishi, & Hori, 2008).

The main outcome of the workshop comes from the collaboration and sharing of knowledge. Participants can acquire new ideas from other participants as information is shared amongst them. This collaboration helps to strengthen the views of the participants. Workshops enable participants to create new concepts by allowing them to work together to accomplish the shared tasks in a shared space (Droumeva & Wakkary, 2006; Numa et al., 2008).

Knowledge elicitation comprises of a set of methods to elicit the knowledge of domain experts usually by having some type of interaction with these experts (Shadbolt & Smart, 2015). In this PhD research, a workshop was used as a method to elicit knowledge from the participants. This workshop was designed and planned as part of the second study of this research (STUDY B), which is the first study presented in Chapter 06. This study was the first one that focused specifically on the task of receiving messages with a DDCD.

Participants in this workshop were all academic experts in HF/E and HCI with a broad range of knowledge in the automotive context and in other contexts such as rail, flight, healthcare and manufacturing. Academic professionals are chosen in knowledge

elicitation methods when the researcher is interested in thorough theoretical expertise in an area (Shadbolt & Smart, 2015). Workshop-based approaches in which participants have expertise in one specific subject domain have been used successfully in other areas for hands-on concept development, for example in the design of exhibitions in museums (Taxén, 2004).

One study in this research aimed at capturing knowledge from academic experts as the first part of a two-part process in understanding the task of receiving messages with a DDCD. The first part, which was investigated in STUDY B, aimed to ask several questions to experts related to message content and modality of message presentation using the workshop-based approach. The results of this study were then used in the subsequent one (STUDY C) to present messages in video-based scenarios to regular drivers as participants.

3.7 Questionnaires

The use of questionnaires or surveys is a method commonly adopted in scientific research to collect users' personal data, subjective interpretations, attitudes or opinions either in quantitative or qualitative form. Questionnaires can be distributed either online or on paper with differences between them in terms of flexibility, range of use, data storage and bias in sampling (Sharples & Cobb, 2015). In order for the data to be analysed efficiently, questions in the questionnaire should be clearly worded, especially when there is no researcher close to the participant to clarify any misunderstandings (Sharp et al., 2007).

Surveys can be designed with different formats of questions, such as check boxes, ranges, rating scales or open-ended queries. The choice of format will vary according to the type of answer expected by the researcher. Check boxes or ranges are commonly used in

demographic questionnaires, for example, when personal information about the gender or age of the participant is required. In contrast, rating scales are frequently used to collect participants' subjective opinions. They are appropriate for asking participants to make judgements about something, such as how difficult a task is (Sharp et al., 2007). The two most frequently used types of rating scales are Likert and semantic differential scales.

Likert scales (Likert, 1932) are designed in such a way that participants should select their level of agreement to a statement, for example "The message made the intention of the other driver clearer". Likert scales usually present a set of statements in which participants must select their level of agreement to each statement individually. The scale in which participants should choose their level of agreement is usually anchored with verbal descriptions with the two extremes of the scale being, for example, 'strongly disagree' and 'strongly agree'. The other points in the scale may contain verbal descriptions such as 'agree', 'disagree' or numerical values. Whichever form of representation is chosen, it must help participants to clearly understand the incremental differences between each adjacent point in the scale.

In semantic differential scales, participants are presented with a scale in which the two extremes are bipolar adjectives (Osgood, Suci, & Tannenbaum, 1964). Contrary to Likert scales in which the set of statements can cover different questions, in a semantic differential scale each set of bipolar adjectives is only about one specific item, for example driver acceptance of a new technology. Participants make their response by placing a cross in a position between the two extremes.

The number of response levels used in any rating scale varies widely with some scales using an odd number of options to allow the inclusion of a neutral level in the middle. There is much debate about what the optimal number of levels should be. Five or seven

levels are the most frequently adopted range with a few surveys presenting up to eleven items if such fine judgement is possible (Sharples & Cobb, 2015). According to Preston and Colman (2000) the number of levels in a survey may affect the reliability and validity of data collected with a lower number of levels providing higher mean scores. Despite this fact, Preston and Colman (2000) recommend the use of a seven-point scale based on Miller's research on the capacity of human information processing and short-term memory (Miller, 1956).

The main criticism regarding rating scales is that several bias issues may arise in the level of agreement with the statements. Central tendency bias may occur when participants purposefully avoid selecting the extremes in the scale and prefer to choose values in the middle even when they have extreme opinions about the statement. Participants may also represent themselves in a more favourable way than they really are, over reporting good behaviour or under reporting bad behaviour i.e. social desirability bias. Finally, participants may agree with all the questions in a survey to show a positive connotation, repeating the answers to previous questions even when in doubt. The latter issue, called acquiescence or question bias, may be reduced if there is a balance of positive and negative statements, preferably in an alternate way (Couch & Keniston, 1960). However, according to Paulhus (1991) the former two biases, social desirability and central tendency, are very difficult to be addressed in questionnaire design, if not impossible.

The analysis of Likert scales is another topic of much debate in the academic field. Discussion arises on whether the results of Likert scales should be analysed as interval or ordinal data. Many authors treat this data as ordinal because participants may not perceive the difference between adjacent levels in the scale as equal (Bertram, 2007; Jamieson, 2004; Kuzon Jr, Urbanchek, & McCabe, 1996; Robertson, 2011). The opponent group presents evidence dated from early years that suggest that Likert scales could be

successfully analysed as interval data using parametric tests (Aaker, Kumar, & Day, 2008; Burns & Bush, 2000; Norman, 2010). However, according to Knapp (1990) the researcher should initially and most importantly decide what level of measurement is in use by checking the sample size and if the distribution is normal. Moreover, the researcher should be able to justify with confidence that the data can be classed as interval. Therefore, based on the considerations described by Knapp (1990), the Likert-scale data presented in this thesis have been treated as ordinal data with the analysis using non-parametric tests.

This PhD research employed different types of surveys at different stages of the PhD process. Most surveys used in this research are pre-existing questionnaires (e.g. Self-Assessment Manikin), which have been widely tested and validated for many years in academia, some of them in several areas not only related to HF/E and HCI (Morris, 1995). These questionnaires were carefully considered because they seemed the most appropriate ones to cover users' opinions and attitudes at a particular stage and context. However, a driver-to-driver communication questionnaire was designed by the researcher in STUDY C. This bespoke questionnaire was an original design, as the researcher did not find any pre-existing questionnaire that would cover all the information needed. Many considerations were made when designing the questions in the driver-to-driver communication questionnaire, especially to avoid acquiescence bias and to provide a clear wording of the statements.

Table 3.1 shows the main characteristics of all questionnaires adopted in this research with the studies and chapters they are used in and the appendix where they are available.

Table 3.1. Questionnaires

Name	Type	Chapter	Study	Appendix
General demographic questionnaire	Open-ended / Checkboxes	5	A	iii
General demographic questionnaire	Open-ended / Checkboxes	6	C	iv
Driver-to-driver communication questionnaire	Likert scale	6	C	v
Self-Assessment Manikin (SAM) (Morris, 1995)	Rating scale	6	C	vi
Van der Laan user acceptance scale (Van Der Laan et al., 1997)	Semantic differential scale	6	C	vii
General demographic questionnaire	Open-ended / Checkboxes	7	D	viii
General demographic questionnaire	Open-ended / Checkboxes	8	E	x
CTAM (Osswald et al., 2012)	Likert scale	8	E	ix
NASA-TLX (Hart & Staveland, 1988)	Rating scale	8	E	xi
Simulator Sickness	Rating scale	8	E	xii

3.8 Direct observation in the field

Observation is a useful and effective method in any stage of the design process. In the earlier stages of design it can help the research to understand the users' task, goals and context, while in the later stages it can be used as an evaluation of how a prototype version of a device can support these tasks and goals (Sharp et al., 2007). In this PhD research specifically, an observation study (STUDY D) was conducted with the main purpose of an exploratory investigation of a specific task involved in the driver-to-driver communication process, i.e. the identification of vehicles that will receive a message.

One of the major advantages of observation is that the researcher watches what the participant is actually doing instead of just asking users to report what they would do in

such a situation (Robson, 2002). However, there is a serious concern that the researcher, as an overt observer, may exert a possible negative effect on the situation being observed. This could be avoided in covert observations, but in many cases, there is no practical way for the researcher to be hidden from the participants' view. Another key issue with observation is that it is usually very time consuming, especially if the researcher needs to be immersed in the field for a long period of time (Robson, 2002).

Participants can be observed either in a controlled environment, such as a usability laboratory or in the field. In this research specifically, an on-road study (STUDY D) was designed with direct observation as a method to explore how drivers would naturally identify vehicles around them.

On-road studies have been used extensively in the HF/E automotive area, with both quantitative and qualitative data being captured to measure several different variables, such as fatigue (Hanowski, Wierwille, & Dingus, 2003), driver distraction (McEvoy, Stevenson, & Woodward, 2006) and also communication between drivers (Portouli et al., 2014). To avoid the possibility of high cognitive workload, distraction or even anger caused by driving an unknown vehicle, it was decided to ask participants to sit in the passenger seat. For this study, one authorised member of staff acted as driver for all participants.

Field studies are a valuable way of acquiring a thorough understanding of a particular area or domain in an extensive manner (Bisantz & Drury, 2005). The use of qualitative observations in the field can provide a context for tasks, and by doing so, can produce relevant data about why an activity happens the way it does (Sharp et al., 2007). Moreover, observations in the filed can provide extra pieces of information or nuances that may not be captured by other sources of investigation.

A clearly defined goal of observation must be established beforehand as a lot can happen at the same time in the field. This goal could be a specific behaviour of the participant, e.g. where they are looking at the moment, or a task undertaken by them such as pressing a button. In this specific study, the researcher was interested in which verbal and/or gestural descriptions were used by participants when they were required to identify a vehicle.

Observational data can be collected in various ways, from low-tech pen and paper to the use of computer-supported data collection. In this specific on-road study, video recordings were adopted to facilitate the observation. Video recordings are particularly useful when the researcher is not present at the moment data is being collected or if the researcher does not have a clear view of the participant. According to Robson (2002), by using video recordings to capture data from field studies, researchers are able to analyse and review the activities performed by participants as many times as they want with great accuracy. Video recordings were used in this PhD research to capture gestures, expressions and eye movement of participants. The latter was recorded using an eye-tracking device. Video recordings of eye tracking and system interaction were also adopted in the experimental study, which is described in the next section.

3.9 Experimental research in a driving simulator

Experimental research is used when the researcher wants to investigate and explore a hypothesis in a controlled and isolated environment. Well-designed experiments can help to answer questions defined in the hypotheses and to identify causal relationships between variables that are being measured and variables that are being controlled by the researcher (Lazar et al., 2010). According to Rolo and Diaz-Cabrera (2005), experimental research in HF/E is being used mainly to help quantify an improvement in a human-

machine interaction and/or to carry out a structured comparison between a set of pre-defined designs.

Towards the end of this PhD research it was deemed important to investigate the task of sending messages with the DDCD. Therefore, an experimental study (STUDY E) in a driving simulator was considered the most appropriate at this stage. This study is presented in Chapter 08.

Driving simulators are frequently used in the HF/E automotive area, both in industry and in academia. They are a popular tool to investigate driving performance, driver behaviour and driver interaction with in-vehicle devices under different road conditions. Driving simulators supply a safe and convenient environment for researchers to observe and measure driving behaviour under controlled conditions, which otherwise would be highly impractical and unsafe in the real world (Kaptein, Theeuwes, & Van Der Horst, 1996). Driving simulators are also flexible and simple to setup with the researcher being able to change easily from one condition to the other.

The concept of validity is very important for driving simulators as it is concerned with the success with which the real-world is replicated in the simulator (Blaauw, 1982). There are many types of validities, and these were carefully considered before deciding to design an experimental study in a driving simulator. These are briefly explained below. Physical validity concerns the physical controls in the simulator and their level of similarity to the controls of a real vehicle. The controls in the vehicle may not respond, as the participant would expect from a real car. Behavioural validity relates to how close the driving experience in the simulator is to driving on a real road (Olson, Hanowski, Hickman, & Bocanegra, 2009).

Drivers have different reasons or motives for travelling from point A to point B, and these motives can have an effect on their driving behaviour. Different driving behaviour can be

experienced by one driver travelling on holiday with their family and another driver late for work. Psychological validity can be defined as the extent to which the tasks performed by the participant are similar to the reasons for their real driving (Ranney, 2011).

There is also an important difference between relative and absolute validity in a driving simulator. Absolute validity can be defined by the extent to which the absolute size of the effect measured in a driving simulator can be compared to the absolute size of the effect in reality (Kaptein et al., 1996). Relative validity is the extent to which the relative size of what is being measured is the same as in reality. Relative validity is appropriate for most studies provided that the researcher is not investigating the effect of changes in the absolute value (e.g. vehicle speed) of any measures (Riener, 2010). This was the case of this particular PhD research.

Two other types of validity related to experiments in driving simulators are internal and external. Internal validity is the recognition of the relation between the manipulation of a condition or variable and the effect obtained (Kaptein et al., 1996). Driving simulators have high internal validity as the environment can be controlled and therefore there is little chance that the effects are due to differences in experimental conditions (Riener, 2010). However, a simulator with limited resolution can have lower internal validity if an action, such as changing direction, prove unrealistically hard when compared to the real world. External validity is the extent that the results obtained from one specific study can be generalised and is closely related to the design of the experiment. According to Riener (2010), results from driving simulator experiments could be applied to real world scenarios if an extra task is added to the simulator study or if the simulator complexity is increased to represent more accurately the real-life situation.

One issue with simulators is the possibility of many unpleasant physical symptoms that some participants may exhibit while driving. These include motion sickness (nausea),

dizziness, headaches and eyestrain. Simulator-induced motion sickness is caused by a mismatch between the visual perception and the vestibular sensation of motion (Carsten & Jamson, 2011). This issue can impose some difficulties, as not all people are fully aware beforehand that they might experience this symptom. They only discover this symptom while undertaking a drive in the simulator, which forces them to suddenly stop and discontinue the study. This might require the researcher to recruit more participants. Research also found that simulator sickness has a natural tendency to affect driving performance and behaviour, e.g. participants closing their eyes when travelling around a corner (Bittner Jr, Gore, & Hooey, 1997).

3.10 Qualitative data analysis

This research produced an abundance of qualitative data from all the different studies. A formal iterative analysis technique for qualitative data based on coding was used throughout this research (Hignett, 2010). Coding is the process to relate the data with the researchers' ideas about them (Coffey & Atkinson, 1996). The coding process can be divided into two stages. In the first stage, the researcher should fully understand and interpret the data so that in the second stage the data can be presented to others in a meaningful way (Gough & Scott, 2000).

This analysis process focuses on the assignment of codes or categories to the data. Codes are tags that are attached to words, short sentences or whole paragraphs in the data. These codes give a meaning and significance to the data to which they are assigned. Codes can be developed in many ways, for example by taking into consideration the acts, activities and relationships under investigation (Lofland & Lofland, 2006), by factors such as the settings and context (Bogdan & Biklen, 1997) or by the relevant literature (Miles & Huberman, 1994). Lazar et al. (2010) suggest focusing on specific types of statements

that can produce valuable information, when generating a list of codes. These statements may include objectives, causes, actions and consequences.

The analysis process in this PhD research followed a coherent structure. Data was initially collected in either audio, text or video. Before the analysis, the data was then transcribed verbatim. The first step in the analysis process was to produce a comprehensive list of main codes based on the study setup. The researcher then analysed the transcripts according to codes defined. Due to the iterative nature of this analysis technique, more codes were created during this process. The final data was reduced to a set of codes or themes linked back to the research aims. Table 3.2 shows in which studies this analysis technique was adopted.

Table 3.2. Coding analysis

STUDY	**QUALITATIVE METHOD**
STUDY A	Exploratory interviews
STUDY B	Expert knowledge elicitation
STUDY D	On-road observation
STUDY E	Post-trial interviews

3.10.1 Taxonomies

Taxonomy can be defined as a branch of science, which focuses on the hierarchical classification of things (Oxford English Dictionary, 1989). It was originally used in biology to classify organisms. It was subsequently expanded to any area of knowledge as a classification of concepts and underlying principles. Taxonomies represent an organised way to understand the world around us. They provide a common understanding of terms and classifications. Taxonomies have been used in Computer Science to bridge the communication between researchers in academia and practitioners in industry

(Engström, Petersen, bin Ali, & Bjarnason, 2016). Taxonomies have been used specifically in HCI, for example, to describe a set of specific gestural interaction techniques (Angelini et al., 2014; Scoditti, Blanch, & Coutaz, 2011; Wolf, Naumann, Rohs, & Müller, 2011).

A taxonomy scheme has been developed in this PhD research to produce a list of the main descriptors used by drivers to identify vehicles. This taxonomy was created based on the data collected in STUDY D, which is presented in section 7.7.

3.11 Mixed-methods research

Mixed-methods research can be defined as "*research in which the investigator collects and analyses data, integrates the findings, and draws inferences using both qualitative and quantitative approaches or methods in a single study or a program of inquiry*" (Tashakkori & Creswell, 2007, p.01).

The concept of mixed-methods research, in which more than one method is used as part of the validation process, was first introduced in 1959 using the term multiple operationalism (Johnson, Onwuegbuzie & Turner, 2007). The authors explain that mixed-method research can be seen in its pure form as being at the centre of a quantitative-qualitative continuum with both types of data adding insights to the research question. A triangulation of methods aims to overcome the weaknesses of only one single method in addressing specific research questions (Wiklund-Engblom, Bengs & Högväg, 2012).

Mixed-method research can be viewed in terms of two different dimensions which relates to the time ordering of the qualitative/quantitative methods or the degree of importance of those data within the same study (Wu, 2011). This PhD research followed the latter approach in which each study has a combination of both quantitative and qualitative data. The decision as to which method to use was mainly based on an iterative process rather than a strategic decision.

Tashakkori and Creswell (2007) also state that the qualitative and quantitative approach can be divided in terms of the research questions, the sampling procedure, the methods employed, the type of data analysis and the conclusion. According to Van Turnhout et al. (2014), there are many reasons to combine multiple methods in HCI following the sequential dimension, such as one study delivers a result, space or context which can then be further explored, validated or expanded in a follow-up study. This was also the case for this PhD research in which all studies were planned in an iterative sequential way. For example, one of the results from STUDY B was further investigated in a subsequent study.

There are many advantages to following a mixed-method approach. According to Bouchard (1976), the convergence of findings stemming from two or more methods "*enhances our beliefs that the results are valid and not a methodological artefact*" (Bouchard, 1976, p. 268). Mixed methods can generate relevant unforeseen research questions while providing answers to those new questions (Pettersson, Frison, Lachner, Riener & Nolhage, 2017). The authors also suggest that rich data collected by applying different methods could help to understand the reasoning behind the concept of user experience (Pettersson et al., 2017). Abowitz and Toole (2009) mention that mixed-method research should be considered whenever possible as it improves not only the validity but also the reliability of the results. Causal inferences are also strengthened as the researcher can observe the convergence or divergence of the data when testing the hypothesis (Abowitz & Toole, 2009).

Mixed-methods research also has its own contentious issues. Johnson et. al (2007) point out that mixed-method research lacks a clear set of philosophical beliefs to support it with pragmatism being currently the most useful position. Johnson et. al (2007) also state that a typology of broadly-agreed mixed-method designs must be established with

different sets of design being created according to the most predominant type of research in question (quantitative or qualitative). The diversity of ideas in mixed-method research should be assessed in a reflective way in order to avoid duplication of concepts, inconsistent terminology and chaotic classification (Tashakkori & Teddlie, 2010). According to Wiklund-Engblom et al. (2012), another important aspect to consider when doing a triangulation of methods is how to find the most appropriate process for collecting, analysing and presenting the results of the study.

4 Introduction to a driver-to-driver communication framework

4.1 Driver-to-driver communication framework diagram

There are several models reviewed in Chapter 02 that aim to represent the interaction between two drivers (see section 2.3.2). Various aspects of the interaction are depicted in these models. However, there is no framework which covers the factors involved in the communication between two drivers via an electronic communication device. This chapter introduces a driver-to-driver communication framework which addresses this issue in detail.

The first part of the driver-to-driver communication framework consists of a diagram (see Figure 4.1), which presents the main elements involved in a driver-to-driver

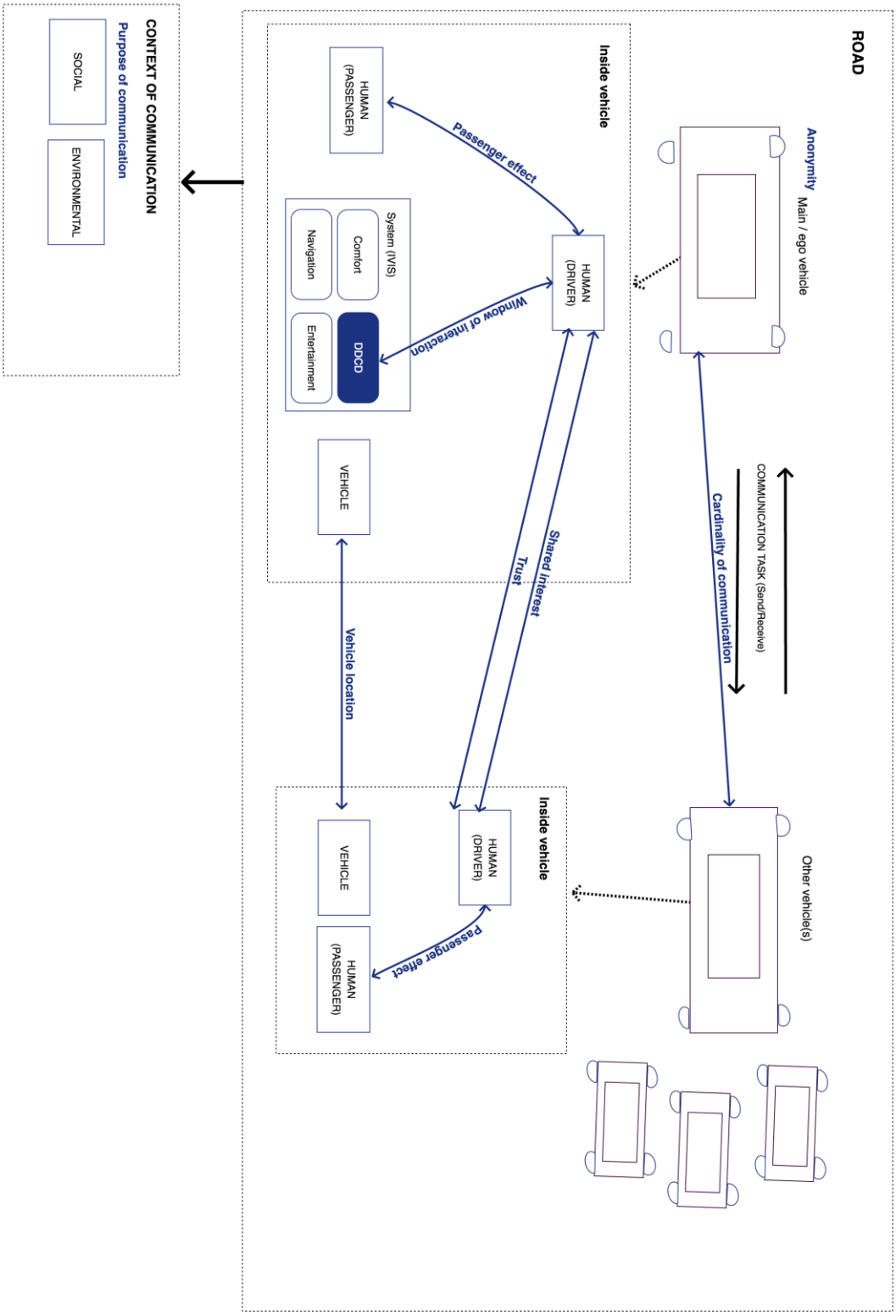


Figure 4.1. Framework diagram

communication, i.e. the user, the task and the context. A set of variables or factors that can have a direct effect on the driver-to-driver communication process is also presented. This diagram is based on other related approaches such as the ergonomics onion model (Grey, Norris, & Wilson, 1987) and the human-machine systems perspective as presented in Figure 4.2 (Wickens, Lee, Liu, & Gordon-Becker, 1998). In both these models, components of the system represent combinations of human, machine or environment. The application of these models is to represent users who need to perform a particular task with a specific piece of equipment or machine, which could vary according to the environment or context (physical, social or organisational).

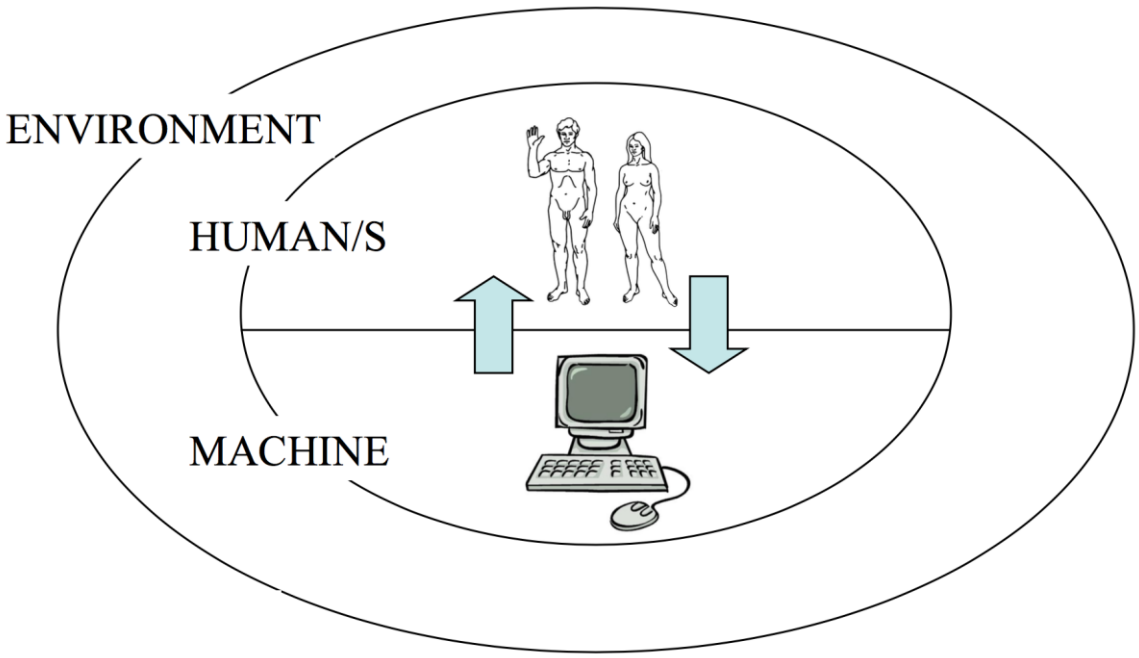


Figure 4.2. Human-machine systems perspective (Lawson & Burnett, 2015)

The first element of the diagram shows the communication task carried out by the users. The main task involved in a driver-to-driver communication is the exchange of messages. This exchange of messages can then be divided into sending messages to one or more drivers and/or receiving messages from one or more drivers.

The second element in the diagram comprises the users involved in the communication process. There are two main different categories of users. The first type of user is the driver of the main (i.e. ego) vehicle who starts the process of sending the message, and is called the sender or the main driver. The other user is the one who is driving the other vehicle. This user can be more than one if the same message is sent to multiple vehicles. They will be the receiver of the message, also referred to as the other driver. Another human element that may have an effect on the communication process is the passenger of either the main vehicle or the other vehicle.

The third element of the diagram is the road environment. This road environment will determine and influence the context of communication and the ability to communicate. Drivers can exchange messages for many different reasons. The topic of the message is directly linked to the specific social and/or environmental context of the road users. For example, if a driver has just performed an unexpected driving manoeuvre, they may want to send an apologetic message, whereas a driver who has just driven past an accident may want to inform others of this incident.

Another important element related to communication between drivers, which is presented in the diagram, is the vehicle itself. A few variables that affect driver-to-driver communication are directly linked to the vehicle, such as the location of the vehicle and the cardinality of the interaction.

The diagram also depicts the interaction between the driver with the DDCD to either receive or send messages. The last part of the diagram presents all the variables that may affect driver-to-driver communication. They are presented in blue in the diagram. These variables will be described in more detail in the next section.

4.1.1 Variables

Many factors can affect the communication between users of an electronic communication device. For example, research has already been carried out on establishing a set of variables that influence communication in virtual communities (Baym, 1998). However, due to the nature of driver communication, not all the variables that influence one form of CMC can be applied in the same way to an electronic communication in the driving context. Moreover, many variables may influence the interaction between drivers. It is not the purpose of this PhD research to produce an extensive list of all these variables. Therefore, only a small set of variables or factors that can affect drivers' communication were investigated. These variables provide the foundation of the driver-to-driver communication framework presented in this chapter. They have a clear purpose as they are closely linked to the design recommendations presented in Chapter 09. The underpinning concepts of most of these variables come from the area of CMC reviewed earlier in Chapter 02. All the variables are presented in Table 4.1 with a short description of each. The variables are then further explained and justified in the following subsections.

Table 4.1. Variables

Variable	Description
Purpose of communication	What is the main purpose of communication between drivers?
Cardinality of communication	Interaction between main driver and only one other driver (one-to-one) or between the main driver and a group of other drivers (one-to-many)
Window of interaction	Time constraints imposed to successfully be able to communicate with other drivers
Vehicle location	Location of both vehicles involved in the communication (e.g. in front of each other, next to each other)
Shared interest	Is there a common, shared interested between the drivers involved in the communication?
Trust	Trust issues regarding the validity of content of the message received
Anonymity	Is the sender required to identify themselves when sending a message?
Passenger effect	If the passengers in any of the vehicles involved in the communication may have an effect on the act of sending and / or receiving the message

4.1.1.1 Purpose of communication

The purpose of the communication, i.e. what people try to accomplish while communicating, is closely related to the social context involved (Clark & Brennan, 1991). As mentioned in Chapter 02, the purpose of communication shapes the common ground in human communication and different grounding techniques are required for different purposes (Clark & Brennan, 1991; Grice, 1970). Grounding techniques may not be the same if the purpose of communication is different, for example, to get acquainted, to teach something or to plan an event.

Research in CMC also examined the effect that the communication purpose had in shaping language use (Baym, 1998; Schiffrin et al., 2008). It was found that contractions were used more in informal communications than in serious formal messages. Moreover, different forms of norms or rules may apply to one specific context of communication (Smith, McLaughlin, & Osborne, 1997). Different tasks types may require the additional transmission of values, interests or personal commitments (Hollingshead & McGrath, 1995).

The purpose of communication may also have an effect on users' willingness to accept or reply a message, especially when they are not interested in the specific topic of communication. This concept is similar to when users receive unsolicited and irrelevant messages over the Internet (Barnes, 2002). In the road environment, messages not related to the driving context or messages that do not add any new information may be considered irrelevant by some users.

This PhD research investigated several situations in which drivers are required to communicate with other motorists to make their intentions clearer. An example of such a scenario is when the main driver wants to send apologetic messages for their unwitting and unwilling driving behaviour when blocking a junction or cutting in front of another driver.

4.1.1.2 Cardinality of interaction

Drivers can send electronic messages to only one vehicle or to multiple vehicles at the same time. This research adopts the term cardinality of interaction to establish if the communication between drivers is one-to-one, i.e. one driver sending a message to only one other driver or one-to-many in which one driver sends the same message to multiple drivers at the same time.

The communication between drivers using an electronic device strongly resembles CMC in this situational factor defined broadly as participation structures (Baym, 1996). According to Baym (1996), there are several situational factors that constitute the context of communication and that can condition variations in electronic mediated discourse, with the cardinality of interaction being one of those factors.

Various technologies exist in CMC to support these diverse mediated forms of communication. These technologies may operate in a variety of ways and therefore the interaction and its outcome may be different (Barnes, 2002). Moreover, there may be variations in the language used, the target audience and the context of communication (Schiffrin et al., 2008). The use of email to send a message to one person can be different from taking part in a discussion list where the message is visualised by many participants with distinct demographic characteristics over which the sender does not have total control. This might also be relevant when a driver sends a message to multiple vehicles.

The PhD research presented in this thesis focuses mainly on one-to-one communication, although a few scenarios used in studies A, B and C describe situations in which more than two vehicles are involved in the communication process. Technically, one-to-many and many-to-one interactions would be easier to implement due to some of their characteristics. Firstly, these forms of communication do not necessarily imply bilateral communication as the sender may be broadcasting a message and not waiting for a response from the receivers. However, some types of one-to-one communications may require turn-taking approaches in which a person replies to the other and a flow of communication is established. Secondly, it was deemed important to fully understand how drivers would identify a single vehicle as part of the communication process. Interactions which involve many vehicles would require other forms of recipient identification or no identification at all. Therefore, it was decided that the main focus of

this PhD research would be on one-to-one interactions even though the framework was designed to allow for all types of cardinalities of communication.

4.1.1.3 Window of interaction

The theory of common ground defines asynchrony as one of the costs involved in any form of human communication. Asynchrony is the cost involved in timing of producing and receiving a message in asynchronous communication (Clark & Brennan, 1991). Asynchronous communication is characterised by the fact that all the participants involved may not be simultaneously online at the same time the message is sent and can read and respond to messages at different times (Walther, 1996).

According to Baym (1998) the temporal structure of CMC is a variable that can affect patterns in communication, such as the availability of immediate feedback, the number of participants involved in the communication and the meaning of pauses in non-verbal technology-mediated communication. The temporal structure varies according to the type of CMC.

The temporal structure of a driver-to-driver communication is mainly characterised by asynchronous messages closely related to the driving context (Applin & Fischer, 2015). The exchange of messages occurs on the road while all participants involved are in their vehicles. Drivers must focus their cognitive resources on the primary driving task and as a secondary task, they may need to send a message to the other driver about something that just happened on the road. This secondary task must not be delayed for too long, otherwise the message may no longer be relevant. Moreover, several other events may have already taken place on the road and the receiver of the message may not be able to identify the sender or to link the message to a specific situation. Therefore, there is a high

asynchrony cost involved in driver-to-driver communication for both sender and receiver.

Drivers may have different time constraints to be able to communicate with other motorists effectively and successfully. This research adopts the term "window of interaction" to describe the period of time required by one driver to send a message so that when the message reaches the receiver it is still relevant. This factor is closely related to the temporal structure of an electronic driver-to-driver communication and its asynchrony cost.

The window of interaction can depend on several other variables. The window of interaction can vary according to the speed and location of both vehicles involved in the communication, the cardinality of the interaction, the task, the workload and the social context. This factor has a significant influence on driver communication, and is a key issue for this research.

4.1.1.4 Vehicle location

Most forms of CMC are mainly characterised by having no physical space limits since users can easily communicate with others no matter where they are (Barnes, 2002; Walther, 1996). Virtual communities, for example, allow participants from different parts of the world to discuss shared interests (Baym, 1998). The sender of an email does not need to know the location of the receiver, as this is irrelevant to the success of the communication. Therefore, the specific location of participants at the moment of communication have no effect whatsoever on the outcome of the communication.

Contrary to most forms of CMC, the location of drivers at the moment of social interaction can have a decisive effect on the communication, because this takes place on the road and is inextricably related to the road environment. The location of the vehicle/s which are

going to receive the message are therefore of immediate relevance to the outcome of the communication and to the interaction process. For example, drivers may not have enough time to send messages to oncoming vehicles. If a vehicle is not in the direct field of view of the main driver, they may not be able to clearly identify the receiver of the message. Various parameters influence vehicle location such as heading, movement trajectory and vehicle dynamics (e.g. speed and braking behaviour).

4.1.1.5 Shared interest

Social closeness is a construct from CMC which can be defined as the experience of positive emotions towards another person or group of people (Ratan, Sarkar, & Tsai, 2012; Ratan & Tsai, 2014). The concept of social closeness is related to the concept of interpersonal attraction, which is a shared interest in another person that could lead to friendship. According to Ratan and Tsai (2014) social closeness in the driving context can improve road safety by reducing the number of accidents due to the fact that drivers who are socially close to other drivers feel more considerate towards their safety. Therefore, social closeness and trust are related constructs (Podobnik, Striga, Jandras, & Lovrek, 2012).

This PhD research investigates social closeness in driving communication from the perspective of a shared interest between two drivers that could lead to further communication and then friendship. The DDCD could be used to connect the drivers based on this shared interest.

4.1.1.6 Trust

There is a plethora of definitions for trust applicable to a variety of different situations. This research uses one abstract definition, which establishes that trust is the willingness of a person to be vulnerable based on positive expectations about other people's actions

(Bos et al., 2002; Corritore, Kracher, & Wiedenbeck, 2001; Riegelsberger, Sasse, & McCarthy, 2003). Trust is required when a person does not know the exact motives of others and therefore a risk factor is involved since it is not possible to predict their actions (Riegelsberger et al., 2003). Handy (1995) states that "trust needs touch" which is difficult to establish in any context other than face-to-face.

In CMC, the lack of relational cues, which are mostly given nonverbally, can lead to poor interpersonal dynamics such as attentiveness, warmth and trust (Jarvenpaa & Leidner, 1998; Walther & Bunz, 2005). The lack of visual and vocal cues also contributes to the decrease in trust (Walther & Bunz, 2005).

This PhD research is based on the exchange of messages by drivers using an electronic communication device. Specifically regarding trust, this research investigates asynchronous trust situations (Riegelsberger et al., 2003) in which the receiver may or may not trust that the message sent by the other driver actually represents their genuine intentions and/or feelings at that moment. The receiver acts as a *trustor* of the message sent by the other driver, called the *trustee*. The decision not to trust the message may lead to different actions or reactions, which can vary according to the situational context. This action could be for example a change in driving behaviour. This variable is also closely related to the abuse of the technology as untrustworthy content may be created from abusive use.

Research in CMC states that trust can be established after longer periods of communication with an exchange of several messages between users (Jarvenpaa & Leidner, 1998; Walther & Bunz, 2005). Response also has a powerful effect on establishing trust in CMC as response suggests involvement and can strengthen a relationship (Jarvenpaa & Leidner, 1998). However, the temporal structure of driver communication can be classified as a form of CMC in which participants exchange

messages only once and for a very short period of time (Hollingshead & McGrath, 1995). Because in most scenarios both drivers are travelling to different destinations, the chance of them communicating with each other again is very low. Therefore, it is exceedingly difficult to establish trust without social closeness in such a short period of interaction, unless the DDCD offers the drivers a way to engage in further communication after their initial encounter. However, the DDCD could offer alternative ways to establish trust, for example through a system of ratings based on driving behaviour (Wang, Terken, Hu, & Rauterberg, 2016).

4.1.1.7 Anonymity

As described previously in the literature review, the communication between drivers can be considered more anonymous than other forms of communication such as face-to-face, because they are inside the vehicle, hidden and protected by this semi-private metal container, which limits the potential for social interaction (Rakotonirainy et al., 2014). Drivers may not be able to make constant eye contact, which is a solid foundation of social skills and which has the power to promote pro-social behaviour, regulate social encounters and improve the feeling of self-awareness (Argyle, 1969; Kendon & Cook, 1969). Therefore, this difficulty in establishing true social interaction between drivers may result in anti-social behaviours such as aggression and selfish driving (Rakotonirainy et al., 2008).

An electronic DDCD has the potential not only to make drivers' intentions clearer, but also to reduce aggressive behaviours. Drivers could send messages to other drivers either anonymously or not. There are positive and negative aspects of anonymous communication. On the one hand, research in CMC shows that the ability of users to exchange anonymous messages in an electronic communication can contribute to

misbehaviour (Barnes, 2002). Schiffrin et al. (2008) indicate that the degree of anonymity available in any electronic communication system can have a decisive effect on language use. On the other hand, one positive aspect of anonymous communication in CMC is that it can remove visual cues such as gender, age, ethnicity, and social-economic status (Barnes, 2002), or in the case of the road environment, the physical characteristics of the vehicle of the sender such as its colour, make and model. Walther (1996) argues that the social currency in CMC is the information exchanged and not the visual traits of the sender. However, anonymity in message communication can lead to trust issues, which was described previously. An anonymous message can influence the outcome of the interaction and the appropriate use of a communication device. Therefore, the anonymity of the sender is one important variable related to driver communication.

4.1.1.8 Passenger effect

Passengers can influence drivers in different ways. The presence of passengers can have an effect on drivers' behaviour, increasing their responsibility of being competent, leading to either cautious or risk-taking behaviour, depending on the other passenger/s (Dannefer, 1977). Young male drivers may be cautious when they are with their parents, but show risky behaviour in the presence of their peers (Doherty, Andrey, & MacGregor, 1998).

The research presented in this thesis, investigated the effect of passengers on the communication exchanged between road users. More specifically, this research investigated if drivers would be willing to receive and send some types of messages with language, which could offend the passengers with them. The content of the message exchanged between drivers may be unexpected or inappropriate at the time. One example of such a scenario, which was discussed in STUDY A, is drivers receiving

messages about aberrant driving behaviour when they have children in the car. Some people can be negatively influenced by violence and bad language on mass media (Comstock & Paik, 1991; Potter et al., 1995) or by conversations using technology-mediated communication that can be inappropriate for the time and place (Ling, 1998). Therefore, passengers may influence the use of a DDCD in several situations.

4.2 Task analysis

The use of task analysis is explained in section 3.2. The main aim of this HTA was to understand all the tasks required by users when interacting with a DDCD. The creation and selection process of the communication scenarios employed in this research was possibly due to a thorough understanding of the task analysis. Ultimately, the HTA also contributed to the recommendations for a DDCD, which are presented in Chapter 09.

The first step when conducting this HTA was to split the actions required by users into the two main general goals of receiving and sending a message. Therefore, in order to make it clearer, two separate task analysis diagrams were designed. The formal HTA of receiving a message is presented in Figure 4.3 and the HTA with tasks required to send a message is presented in Figure 4.4. However, these two diagrams are not totally independent. One of the tasks that may be required by users when receiving a message may involve the reply to this message, which is presented in detail in the HTA of sending a message.

The HTAs designed in this research not only show this interconnection between the two main general tasks of sending and receiving messages but they also have some similarities. For example, in both HTAs there is some form of feedback or confirmation from the system of the outcome of the sub-task or the existence of a new task to be performed. The identification of the other vehicle is also presented as sub-tasks in both

HTAs. The notification that the message was successfully received by the other driver is available in both diagrams.

The plans presented in both diagrams show that some sub-tasks necessary to interact with the DDCD are mutually exclusive such as tasks 2.3.1. and 2.3.2 in the SEND HTA which are either selecting a message from a pre-defined list or composing a free content message. Others sub-tasks presented in the diagrams depend on the outcome of another task. For example, a confirmation of message sent is only displayed if the driver confirms to the DDCD that they actually want to send the message.

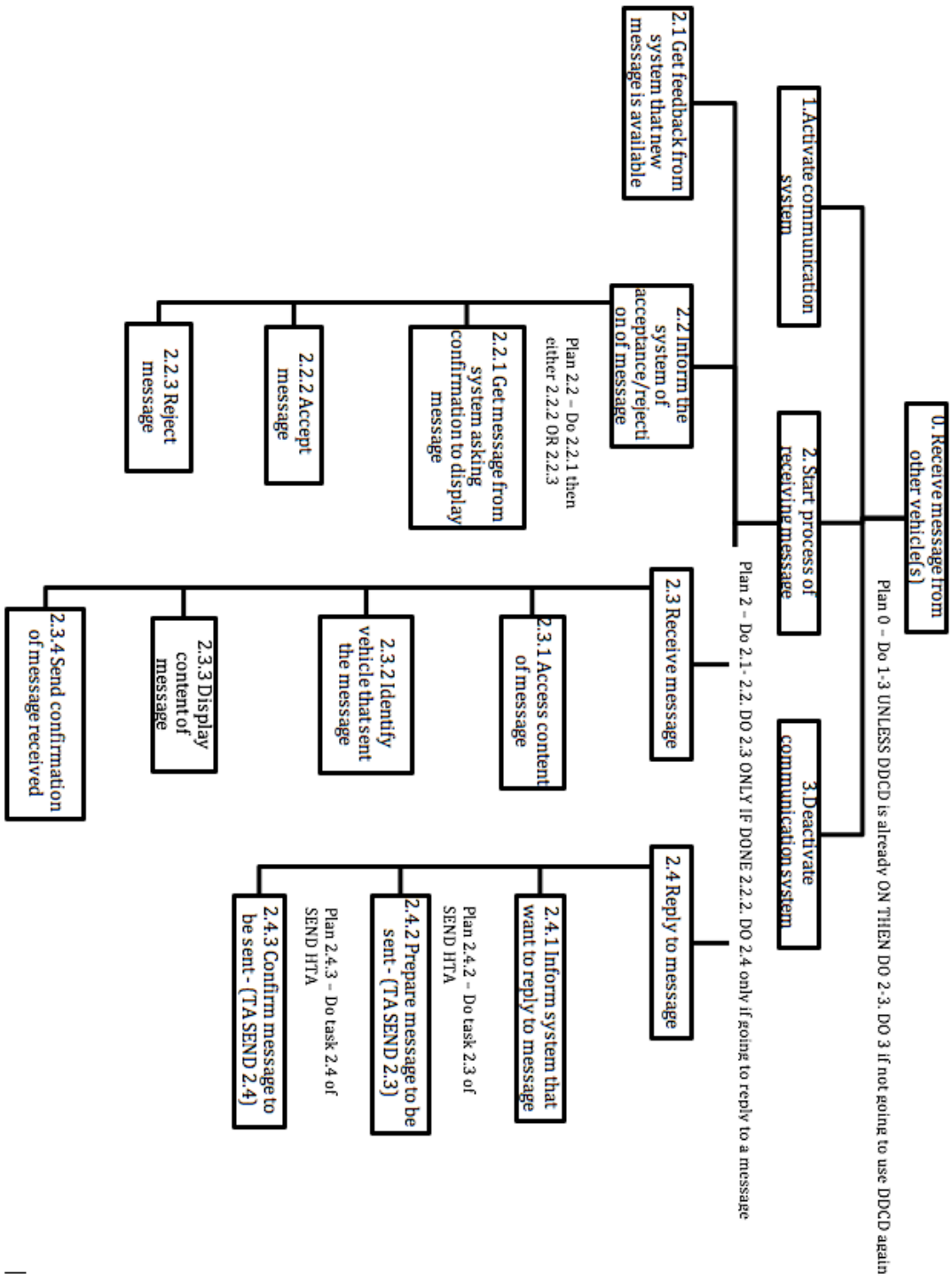


Figure 4.3. Hierarchical task analysis of receiving messages with a DDCD

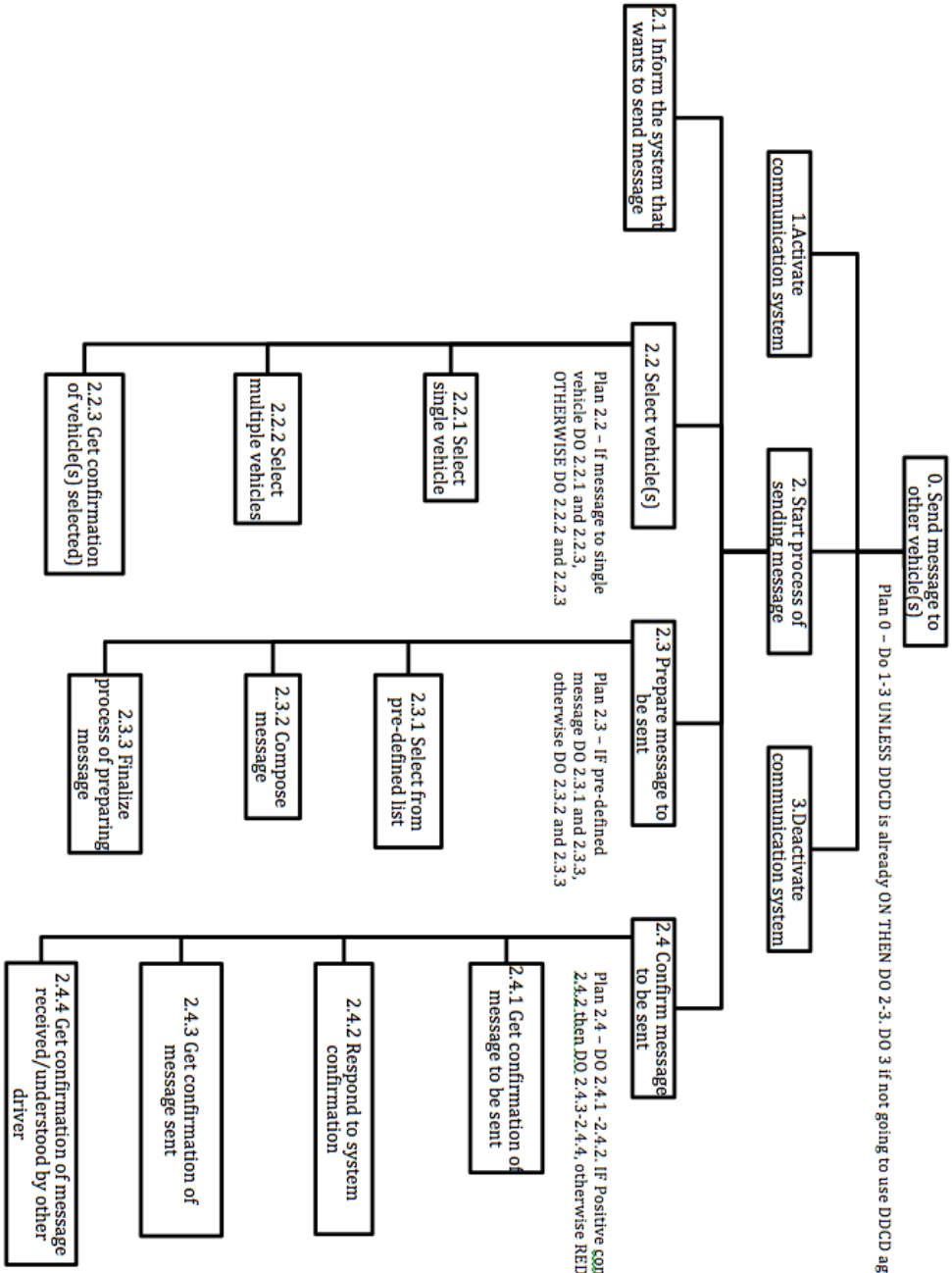


Figure 4.4. Hierarchical task analysis of sending messages with a DDCD

These HTAs are not linked to any specific HMI as the DDCD can be designed using different types of interfaces and the driver can interact with the device in many different ways. This is also in accordance with the driver-to-driver communication framework diagram presented at the beginning of this chapter and the design recommendations described in Chapter 09.

4.3 Use case scenarios

One of the initial steps in this research was to produce a comprehensive list of common driving scenarios in which there is some form of communication between drivers. Scenarios are a helpful tool to aid researchers in the design process and are explained in the methodology chapter (see section 3.4). These use case scenarios were created by the researcher based on the diagram presented in section 4.1 and the task analysis presented in section 4.2. Each driving scenario was then further analysed and grouped, based on the list of variables presented in section 4.1.1. According to the similarities and differences of each scenario of this full set, a sub set of seven scenarios was then developed. With this set of specific scenarios, it was possible to cover a wide range of different forms of communication between drivers. For the purposes of the studies investigated in this PhD research and the analyses carried out, it was necessary to select a very specific scenario. It is important to note, however, that each one of these specific scenarios is representative of a wide range of similar situations in which this kind of communication might be necessary. The Table 4.2 presents a brief description of the social/environmental context involved in each scenario. This table also presents information regarding which chapters of this thesis the scenarios are described in and in which studies they were investigated. A more detailed description of each scenario, including which variables they are related to, is presented in the next section.

Table 4.2. Use case scenarios

Use case	Title	Task	Social/environmental context	Chapters	Studies
UC_01A	Slow vehicle	Send	Inquiry about unexpected driving behaviour	05, 08	A, E
UC_01B	Slow vehicle	Receive	Driver status as acknowledgment of unexpected driving behaviour	05, 06	A, B, C
UC_02	Social interaction	Send	Friendly, non-driving related interaction	05	A
		Receive		06	B, C
UC_03	Vehicle problem	Send	Vehicle status as acknowledgement of driving behaviour	08	E
		Receive		05, 06	A, C
UC_04	Give way	Send	Acknowledgement of direction of movement and giving permission to pull in front	05	A
		Receive		06	B
UC_05	Block junction	Send	Apologetic message as acknowledgment of unintentional driving manoeuvre	05	A
		Receive		06	B
UC_06	Incident info	Send	Broadcast of environment status	08	E
		Receive		06	B, C
UC_07A	Cut in front	Send	Inquiry about unexpected driving behaviour	08	E
UC_07B	Cut in front	Receive	Apologetic message as acknowledgment of dangerous driving manoeuvre.	06	C

4.3.1 Description of scenarios

The list of use case scenarios selected for this research does not cover all possible situations, but they were narrowed down so that all the variables affected in the communication process are covered in at least one of these scenarios. Table 4.3 shows

how each use case scenario relates to the variables that affect driver-to-driver communication.

Table 4.3. Variables and use case scenarios

Variable	Scenarios								
	UC_01A	UC_01B	UC_02	UC_03	UC_04	UC_05	UC_06	UC_07A	UC_07B
Cardinality	X	X	X	X	X	X	X	X	X
Window of interaction			X	X	X	X	X	X	X
Vehicle location	X	X		X	X	X	X	X	X
Shared interest			X						
Trust issues		X	X	X		X	X		X
Anonymity of sender				X				X	
Passenger effect	X	X	X					X	X
Purpose of communication	X	X	X	X	X	X	X	X	X

4.3.1.1 UC01 – Slow vehicle

This use case scenario depicts a situation in which the main driver is behind a slow vehicle travelling below the speed limit. In this scenario, both vehicles are travelling on a single carriageway with a steady flow of oncoming vehicles, which makes it very difficult for the main driver to overtake the slow vehicle. In addition, if there is no place for the slow vehicle to pull over, a long queue of vehicles behind may soon be formed.

This use case scenario is very relevant to the road environment, as research shows that driving too slowly, especially on high-speed roads is very dangerous and can cause accidents (Aberg & Rimmo, 1998). In particular, there is the potential for drivers behind

the slow vehicle to become angry, subsequently negatively affecting their driving behaviour. However, not all countries have specific laws regarding driving below a minimum speed limit. In the United Kingdom, drivers are just advised not to drive too slowly (Driving Standards Agency., 2013).

This use case scenario is divided into two possible situations, which vary according to the slow driver being the one responsible for sending the message or the one receiving it. In the first situation, the slow driver is not aware that they are driving too slowly for that type of road and they are informed or reminded about this (UC01_A). In the second situation, the slow driver is aware of their speed and wants to inform other vehicles the reason for driving so slowly (UC01_B). For this second situation, three possible reasons for driving too slowly were investigated. The first reason might be a problem with the vehicle; the second reason might be that the main driver is an elderly person and the third reason is that the main driver is lost.

In scenario UC01_A, the cardinality of communication is one-to-one, in which the main driver sends a message to the slow driver in front. Conversely, in scenario UC01_B the slow driver sends a message to multiple vehicles behind them.

4.3.1.2 UC02 – Social interaction

This use case scenario depicts a situation in which the main driver is travelling in the left-hand lane on a motorway, travelling at no less than 60 mph. The main driver then moves to the middle lane and they are about to overtake the vehicle in front when the main driver notices something about the car in front that attracts their attention, such as a sticker on the back. This could indicate a shared interest such as a football team they both support or that the other driver comes from the same town as the main driver. Bumper stickers are a ubiquitous part of modern society and allow drivers to share their ideas,

values and identities with others (Case, 1992). The main driver would then like to let the other driver know about this shared interest (Esbjörnsson et al., 2003a).

4.3.1.3 UC03 – Problem with the vehicle

This use case scenario depicts a situation in which the main driver is travelling on a motorway in the middle lane about to overtake the car in front. The main driver suddenly notices that the other car has a problem, such as a deflated tyre, a passenger door not properly closed, or a broken backlight. The other driver apparently is not aware of this problem. The main driver would then like to alert this other driver about the problem, so they can make an informed decision about what to do. Depending on the problem of the vehicle, this could lead to a serious accident and the other driver should pull over as soon as they can. This form of brief traffic encounter relating to sharing information about the other vehicle has been used previously as part of an investigation of different road design spaces (Östergren, 2006).

4.3.1.4 UC04 – Request to give way

This use case scenario depicts a situation in which the main driver is leaving a car park, but they have to stop at the exit because there is a traffic light at the end of the street, which is full of stationary vehicles waiting for the red light to change. This exit is also located right in front of a zebra crossing and the main driver cannot stop their car on it. Moreover, this is a very busy street and the main driver knows that if they do not enter the road immediately the traffic light turns to green, it will be difficult to have another chance to drive into the road. The main driver then decides to inform other drivers on the road right in front of them that they want to pull in in front of them as soon as the traffic light turns to green. Therefore, the main driver seeks the approval of the other motorist for their manoeuvre, without which this could be viewed as an aberrant driving

behaviour (Aberg & Rimmo, 1998) leading to an aggressive reaction from the other driver (e.g. honking the horn) or even a collision.

4.3.1.5 UC05 – Apology

This use case scenario depicts a situation in which the main driver is crossing a junction when suddenly all the cars in front of them stop for no apparent reason. This is something the main driver was not expecting and they do not know what has happened in front. Traffic comes to a standstill and the main driver's car stops in the middle of the junction unable to move. The traffic lights for the other road turn green and the main driver notices that their car is the only one blocking the cars coming from this road. The main driver feels bad about this and starts thinking about the reaction of the other drivers. The main driver would then like to send an apologetic message to all oncoming vehicles explaining that it was not their fault in order to avoid any aggressive reaction from the oncoming motorists, for example, honking the horn (Shinar, 1998).

4.3.1.6 UC06 – Incident on the road

This use case scenario depicts a situation in which the main driver is travelling on a single carriageway and notices an incident on the other side of the road. This incident could be, for example, an accident, animals crossing the road, a pothole or changes in weather conditions (Normark & Juhlin, 2005). The main driver would like to alert all oncoming vehicles about this incident.

4.3.1.7 UC07 – Cutting in front

This use case scenario depicts a situation in which a driver cuts in front of another car, forcing the driver to suddenly reduce their speed. This scenario is also divided into two possible situations. In the first situation, UC07A, the main driver is the driver who cuts in front of the other and would like to send an apologetic message. This scenario is similar

to UC05 with differences in terms of the cardinality of interaction. In the second situation, UC07_B, the main driver is in the vehicle behind and would like to alert the vehicle in front of their dangerous driving behaviour. A very similar scenario has been successfully used before to investigate whether road rage is triggered by driving behaviour or characteristics of the aggressive driver (Dukes, Clayton, Jenkins, Miller & Rogers, 2001).

5 Exploratory investigation into the feasibility of a driver-to-driver communication device (STUDY A)

5.1 Introduction

This chapter describes in detail the first study of this research (STUDY A). This study is an exploratory investigation into traditional means of driver-to-driver communication and the effectiveness of a hypothetical electronic communication device on the outcome of interactions between drivers. The general aim of the study was to investigate various communication issues raised while driving a car, and how a hypothetical electronic device could address these issues. Participants were asked to give their opinions on several different driving scenarios involving communication between drivers.

Three objectives were identified for this study in order to accomplish this general aim. The first objective of this study was to investigate ways, either formal or informal, in which drivers communicate with other motorists without the use of an electronic device (OBJ 01).

The second objective of this study was to explore participants' views on a hypothetical DDCD. Driver acceptance (OBJ 04) was briefly investigated as participants were asked if they would use the device to exchange messages in each one of the scenarios presented to them. Participants also reported their opinions on the main advantages and disadvantages of a DDCD, on message presentation and system interaction with the DDCD (OBJ05).

The last objective was to understand some of the factors that influence the driver-to-driver communication process. Some of these factors are presented in the driver-to-

driver communication framework described in section 4.1.1. Finally, based on the results, design recommendations are described at the end of this chapter (OBJ 06).

This study was published in the proceedings of the 2014 Automotive User Interface Conference (Lamas et. al, 2014a). A different paper focusing on the technological aspects of the DDCD found in this study was also accepted as a social vehicle workshop paper for the same conference (Lamas et. al, 2014b).

5.2 Method

5.2.1 Participants

A sample of 24 participants, 15 male and 9 female, took part in the study. Participants (male and female) had owned a valid driving licence for at least five years (mean = 25, SD=14.1) and drove regularly at least three times a week. Almost all of them (92%) drove regularly for at least 60 minutes a week on average. Participants' ages ranged from 22 to 64 (mean=42, SD=16.5). All participants finished the study and were not paid to take part in it.

5.2.2 Driving scenarios

This was the first study in which the set of driving communication scenarios described in Chapter 04 (see section 0) was used. As described in section 3.4, scenarios are a powerful design tool to elicit opinions from participants. The scenarios in this study were presented in textual form, each one on a separate sheet of paper. At this early stage of the research, this form of presentation proved to be particularly appropriate to conduct an initial exploratory investigation of a hypothetical device. The subset of six scenarios specifically used in this study with their reference number is described briefly in Table 5.1.

Table 5.1. STUDY A - Driving scenarios

Scenario	Nature	Description
01	Slow vehicle	The main driver is late for an important appointment due to heavy unexpected traffic. When they are about to reach their destination, they come up behind a very slow driver on a single carriageway, and are therefore unable to overtake.
02	Tailgate	The main driver is driving calmly on a single carriageway on a Sunday morning when an apparently angry driver starts tailgating them.
03	Social	Friendly interaction between the main driver and the other driver on a motorway. Several examples of situations were presented to the interviewee such as seeing an old school friend, a celebrity or a person with the same interest as them (e.g. football team supporter, TV show).
04	Problem	The main driver notices a problem with the other driver's vehicle (e.g. deflated tyre) while overtaking.
05	Manoeuvre	The main driver is leaving a building (e.g. car park). The exit is located near a zebra crossing on a very busy street and in front of red traffic light with a queue of stationary vehicles waiting for the traffic lights to change. To be able to enter the road, another driver needs to let them in.
06	Apology	Due to traffic stopping suddenly and unexpectedly, the main driver is stuck in the middle of a junction blocking vehicles coming from the other direction.

5.2.3 Procedure

A pilot interview was conducted before the beginning of the study, not only to evaluate the questions but also to confirm that there would be enough time to cover all the scenarios. Participants initially read an information sheet containing details about the steps involved in the study. Participants then read and signed the study consent form. After that, participants filled in a short demographic questionnaire (see Appendix iii page

370) containing general questions about their gender, age, driving experience and competency with technology.

The researcher did not explain to the participants what the hypothetical device would be like and left it open to their imagination without any further information. Participants were only asked to imagine an electronic device available in the vehicle, which would allow them to exchange messages with other drivers. Participants were then presented with one detailed driving scenario at a time on a separate sheet (see Appendix ii page 364). After reading the scenario, the participants were allowed to ask the researcher any questions to make sure they had fully understood it before the researcher started asking questions about the scenario.

The interview process was semi-structured and was audio recorded. The researcher asked participants questions regarding the scenario they had just read based on the interview script designed beforehand (see Appendix i page 359). Depending on their previous answers, further probing questions were also asked to clarify their meaning or elicit further information. After all the questions regarding the scenario had been answered, participants were then presented with the next scenario and the same process started again. All participants answered questions based in the same set of six scenarios. The scenarios were presented to each participant in a different order. The following same questions were asked first for each scenario:

1) What would you do in this scenario without the device? (All scenarios)
2) Would you send a message to the other driver using a hypothetical device? If so, what would you say? (All scenarios except scenario number two)
3) Would you accept a message coming from the driver behind you? (Scenario number two only)

The researcher then asked the participants other probe questions, more closely related to each scenario, such as:

1) Would you engage in a prolonged conversation with the other driver if the device allowed you to do so?
2) Would you do anything different if there was a passenger (e.g. child, boss, mother, client etc.) with you in the car?
3) Would you send the message to the other driver anonymously?
4) Would you consider sending this message to all drivers waiting for the traffic lights to change?

After the questions from all six scenarios had been answered, the researcher then asked all participants the same following general questions, mainly regarding the hypothetical electronic device and other driving scenarios:

1) How do you think would be the best way for you to interact with this electronic device?
2) Have you ever experienced any other situation, not mentioned previously, in which you wanted to communicate something to the other driver but could not or felt that the communication was not effective?

5.3 Results and discussion

The results of this study are presented in three sections, each one covering one of the main objectives of this study. The first section describes the results regarding the different ways that drivers interact with other motorists without the use of a DDCD. In the second section, participants' views on a DDCD are identified. The opinions in this section are specifically about the advantages and disadvantages of a DDCD and the use and interaction of the device. The last section of the results focuses on factors involved in

driver-to-driver communication such as the cardinality of interaction, passenger effect and vehicle identification.

5.3.1 Traditional means of communication

For all scenarios, the researcher initially asked what participants would do without the hypothetical device. The term traditional means of communication refers to all forms of interaction between drivers without the use of an electronic device. This essentially means using the vehicle signalling tools (e.g. indicators, lights), but can also refer to other forms of communication such as gestures, eye contact and movement of the vehicle. Participants reported many ways of communication, mainly because each scenario involved a unique context, i.e. different communication issues in different road environments (e.g. motorway, single carriageway).

The means of communication reported by participants were grouped in six general categories, which are displayed in Table 5.2. These categories depict all the forms of communication (or lack of them) in the six driving scenarios presented to the participants.

Table 5.2. Categories of traditional means of communication

General categories	
NA	No action/contact
GS	Gestures
SD	Signalling devices
MV	Manoeuvre
EC	Visual contact
VC	Verbal contact

All the traditional means of communication mentioned by the participants are displayed in Table 5.3 grouped according to the general categories. Almost all of them are considered informal ways of communication not defined by official driving authorities (Björklund, 2005; Cialdini & Trost, 1998; Wilde, 1976). When trying to communicate with the other driver, participants reported using more than one of these means of communication. For instance, when letting the driver behind overtake (tailgate scenario), participants reported they would, for example:

1) Slow down;
2) Use the indicator to inform the other driver when it was safe to overtake them;
3) Pull over when/if it was safe for them to do so;

For this reason, the values in Table 5.3 add up to a figure much greater than the total number of participants. Some means of communication were mentioned by participants much more than others. For example, some participants reported that they would honk their horns or flash their headlights in all scenarios except in two of them (tailgate and apology). On the other hand, some means of communication such as raising the hand to say sorry or shrugging are much more specific and are related to only one scenario in which the main driver wishes to apologise to others.

Further analysis of these means of communication reveals that some of them have a more aggressive connotation, such as tailgating, shouting to other driver and showing the fingers. They are employed in the first two scenarios (slow and tailgate) where the main driver is more likely to feel angry.

In addition, Table 5.3 shows that in some driving scenarios, a broader range of ways of communicating from one specific group are more used than others. In scenario number four (problem - deflated tyre), participants reported they would use more signalling devices and gestures than any other category. In scenario number two (tailgate), on the

other hand, participants would try to communicate with a broader array of ways using their vehicle (i.e. manoeuvre related) and gestures.

These traditional means of communication follow the models of drivers' communicative interaction reviewed in section 2.3.2.2. In the original model of Portouli et al. (2012), Driver B (i.e. the participant) responds to an indication of action started by Driver A. This response is the means of communication presented in Table 5.3 and this varies according to the context of interaction (i.e. different use case scenarios). For example, five participants reported they would wave a hand out of the car in response to an action of a tailgate vehicle. By doing so, those drivers expect that the driver behind would overtake them.

Table 5.3. Traditional means of communication in each scenario

GENERAL CATEGORY	MEANS OF COMMUNICATION	DRIVING COMM. SCENARIOS						
		Slow	Tailgate	Social	Problem	Manoeuvre	Apology	Total
NA	Avoid car/ Avoid eye contact				3		8	11
	Wait					7		7
	Do nothing	4		8	3		5	20
	Close window						2	2
	Total	**4**		**8**	**6**	**7**	**15**	**40**
GS	Raise hand						6	6
	Shrug						5	5
	Wave			10				10
	Hand out of car to signal to overtake		5					5

GENERAL CATEGORY	MEANS OF COMMUNICATION	DRIVING COMM. SCENARIOS						
		Slow	Tailgate	Social	Problem	Manoeuvre	Apology	Total
	Show finger		1					1
	Signal to calm down through rear view mirror		1					1
	Point to hard shoulder				2			2
	Point to tyre				13			13
	Thumbs down				1			1
	Hand gesture asking permission					15		15
	Thumbs up			2				2
	Total		**7**	**12**	**16**	**15**	**11**	**61**
SD	Honk the horn	11		9	7	5		32
	Flash headlights	12		1	4	1		18
	Indicators		5		1			6
	Hazard lights	1			1			2
	Total	**24**	**5**	**10**	**13**	**6**		**58**
MV	Edge car forward					7	11	18
	Speed up		2					2
	Slow down		5		1			6
	Tailgate	1						1
	Pull Over		13					13

GENERAL CATEGORY	MEANS OF COMMUNICATION	DRIVING COMM. SCENARIOS						
		Slow	Tailgate	Social	Problem	Manoeuvre	Apology	Total
	Let other driver overtake		17					17
	Overtake	3						3
	Total	**4**	**37**		**1**	**7**	**11**	**60**
EC	Eye contact				1	3	3	7
VC	Say sorry						4	4
	Say something				2			2
	Shout at other driver	1						1
	Total	**1**			**2**		**4**	**7**
Total of responses per scenario:		38	51	30	39	38	49	

It was apparent from the analysis that the meaning of these traditional means of communication is not clear and in most cases useless, according to two participants.

"[Without the device] I definitely would honk my horn and point to where the problem was and then pointing over to go to the hard shoulder insinuating that there was something wrong with the car and he needs to go over. But if the driver is in the middle lane and there is nothing in the slow lane they might think I've been abusive with them being middle lane hoggers, because there are so many of them." (P21)

"…if the other driver flashes his headlights at you it could mean a lot of things like an animal on the road, police check, problem with your car. Sometimes the driver is just saying hi to you or he mistakes you for someone else. You don't know what to do for a while, you even

reduce your speed. When nothing happens ahead on the road you start wondering why the other driver flashed his headlights at you." (P05)

5.3.2 Driver-to-driver communication device

5.3.2.1 Driver acceptance of a DDCD

One of the objectives of this research was to investigate drivers' acceptance of the DDCD. This objective was initially investigated in this study as the willingness to use the device to send/receive messages. For all scenarios except the tailgate one, the researcher asked if participants would send a message using the hypothetical electronic device. For the tailgate scenario, the researcher asked if participants would accept a message through the device coming from the driver behind. The results are displayed in Figure 5.1.

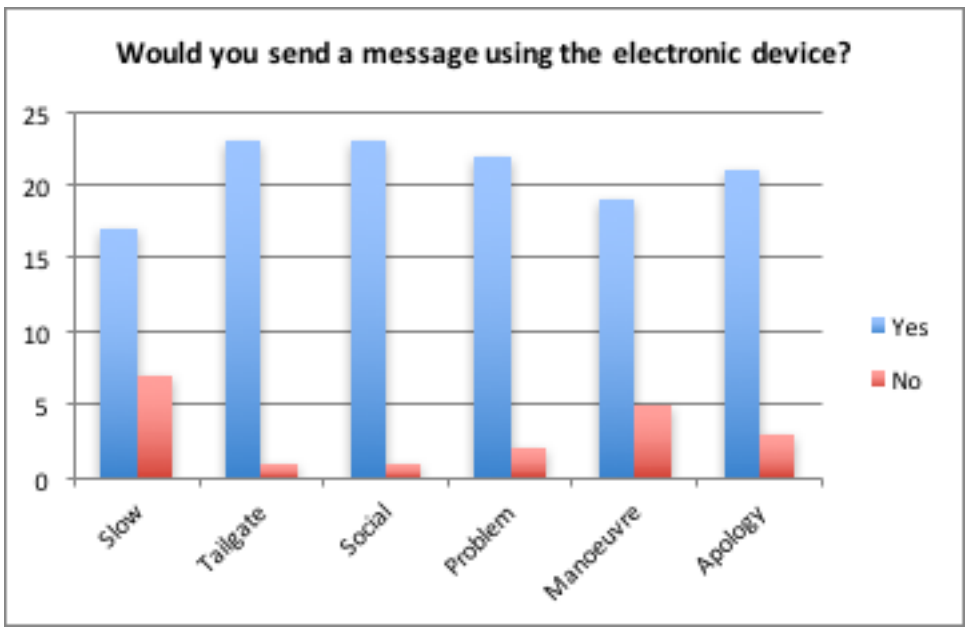


Figure 5.1. DDCD acceptance

Some of the reasons reported by participants for sending or not sending a message using the electronic device are displayed in Table 5.4:

Table 5.4. Reasons for sending/not sending a message using DDCD

Reasons for sending message	Reasons for not sending a message

Calm down own embarrassed feeling by being able to say sorry and explain it was not their fault	Participants emotional feelings at the moment (e.g. too stressed to send a message)
Other driver is not aware of main driver's intentions	Reaction of the other driver (e.g. angry, aggressive)
Possibility of clearly alerting other drivers of what is going on so they could be informed and take appropriate action (e.g. change their route)	Acceptance that the message would not change the situation
If traditional means of communication take longer to be executed or proved to be unsuccessful.	Effectiveness of the traditional means of communication, i.e. something that it is already being done without the device and proved to be working successfully.

5.3.2.2 Advantages and disadvantages of a DDCD

During the interview, participants made many comments about the advantages and disadvantages of using the device for the driving scenarios. According to the participants, the most important quality of the device is that it makes the drivers' intentions clear. Drivers can say exactly what they want instead of flashing their lights or honking their horns, which can be unpleasant.

"I think it is unnecessary to use the device alongside other means of communication. If the device emits an audio signal when receiving a message, you don't need to honk the horns to the other driver. The device alone is an elegant and efficient means of communication" (P01)

The device was also considered by participants to be particularly useful to inform drivers or attract their attention without being too distracting. It was felt that it could be used to draw their attention to something they may not have realised they had done, such as cutting in front of the other driver or driving way below the correct speed limit for the road. It could also be used to make drivers aware of safety issues like a deflated tyre or an accident on the road. According to participants, the device is also very appropriate to alert other drivers of an emergency situation. The DDCD can be used when drivers cannot

make visual contact with the other driver, for example at night. This could also be the case of a lorry driver or if the other cars have tinted windows.

In an aggressive scenario such as tailgating, which is a type of low level incivility, the outcome of the interaction with a DDCD could be positive, but it could also be very negative if the message was sent with an aggressive tone. Most participants reported that they would think carefully about how to phrase the message to avoid making the other driver angry. They would avoid making an aggressive situation even worse by interacting with the other driver and possibly antagonising them. According to the review of the literature in conflict resolution, the avoidance of action is strongly related to the feeling of disapproval in low level incivilities (Smith et al., 2010).

Some other issues related to the device were also noted by participants. Drivers could abuse the device, not using it for its real purpose.

"Say, for example, if they want to overtake you in a fast lane, they could just say: You've got a problem with your car, you need to pull over." (P22)

According to participants, this abusive use could lead to trust issues regarding the content of the message and on the real intentions of the driver. Trust is of paramount importance and influences driver-to-driver communication. This variable is described in the framework presented in Chapter 04 (see section 4.1.1.6).

The device could also be used in frivolous communication, which could lead to an overload of messages causing driver distraction and potential dangerous. Therefore, one participant (P17) mentioned it is important to establish a set of rules of etiquette for using the device similar to those which already exist for the Internet (Shea & Shea, 1994).

Another limitation of the device mentioned by participants is related to the short window of the interaction in some situations. This is a relevant variable described in the driver-to-driver communication framework (see section 4.1.1.3). For some scenarios, it could

take longer to use the device to send a message than to use any of the traditional means of communication. This could be due to several factors such as the speed of both vehicles (e.g. overtaking on a motorway) or to the nature of scenario (e.g. quick change of traffic light, vehicle blocking others for a short period of time). The effort required to produce information is one of the costs described in Table 2.2 to establish common ground, which varies according to the media type.

Using the device does not necessarily mean that drivers have to abandon the traditional means of communication that they have been using for so many years. According to participants, the traditional means of communication could still be used in situations where the device is not effective. Alternatively, a combination of both forms of communication (i.e. traditional and DDCD) could be used.

"In this scenario [Scenario 06 - Apology] I think that the combination of the device and hand signal would be more effective" (P01)

"In this case I would flash my headlights to get the other driver's attention and then send a message using the device" (P03)

"If the other driver didn't reply to me I would honk my horn because in this case the interval period is too short" (P07)

"I would flash my headlights first because it's quicker. I would then send a message in case it didn't work" (P09)

5.3.2.3 DDCD interaction and messages

At the end of the interview, participants were asked how they imagined the best way to interact with the hypothetical electronic device would be and what the content of the message should be. Most participants (18 out of 24) considered themselves competent or highly competent with technology.

5.3.2.3.1 System interaction

During the interview, participants were asked how they imagined the most effective way to interact with the hypothetical device to send and receive messages, considering all scenarios. The results are displayed in Figure 5.2.

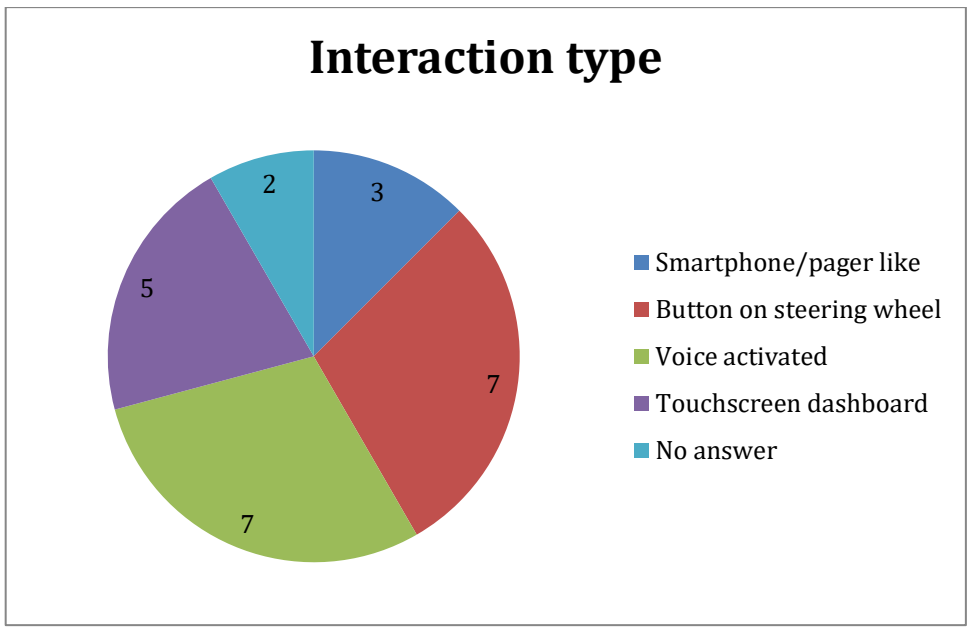


Figure 5.2. Participants who mentioned specific ways of interacting with a DDCD

Since communication with other drivers is potentially distracting from the driving task, participants reported that they would only interact with the device by speaking. The driver would say a command out loud such as "Send Message" and the device would understand and execute it. However, according to one participant this current technology needs to be perfected, as the device might not capture exactly what was said.

Drivers could also interact with the device by pressing a button. This button could be located on the steering wheel or as part of a touchscreen multimedia centre on the dashboard of the vehicle. It was also suggested that the electronic device could be a smartphone with a specific app or a pager-like device that could flash when a message was received.

A combination of two methods was also suggested. The driver could press a button on the wheel to activate the device and then say out loud the command to be executed or message to be transmitted.

One interaction issue was found when the user needs to send the same message to multiple drivers. Using a device similar to an IVNS, drivers could see other vehicles closer to them and touch on the vehicles on the device to select which ones they would like to send a message to. However, no matter which method is used, this task is likely to be particularly hard to accomplish. One possibility would be to send the message to all drivers within a specific range from the main driver (e.g. 500 meters). However, a driver located in a place not affected by the incident would still receive the message.

5.3.2.3.2 Message content

The content of the message being relayed is of prime importance. This could be either a free content (FC) or the content could be fixed and selected from a predefined list (PDL). For the latter, the driver would just select the topic of the message and the device would send a predefined standard message, while for the former the content could be anything the driver wants. Each one has advantages and disadvantages and both were mentioned by participants.

On the one hand, devices with FC functionality could be used in all scenarios and are very suitable for unique emergency cases. Moreover, the intentions can be clearer if drivers can explain with their own words. However, it is important that the user phrases the message in the correct way to get the desired results and tries to use a friendly tone to avoid aggressiveness. Also, drivers should avoid using complex grammar and difficult vocabulary which could have a higher cost for understanding in terms of establishing grounding techniques as presented in Table 2.2.

On the other hand, a device with PDL functionality could only be used for the specific situations for which it was designed. The predefined messages could be grouped by scenarios such as Traffic Jam, Friendly Message with sub-menus like Alert, Ask for Permission etc. A PDL device would be very appropriate to avoid aggressive content or bad language, which would lead to unpleasant and uncomfortable situations. Participants stated that it would be good to have both forms with the PDL being a shortcut (i.e. quick interaction) and the FC being an option to cover scenarios not available on the PDL menu.

5.3.2.3.3 Message type

Another concept related to the HMI of the device concerns by which means a message should be received by the drivers, which could be auditory and/or visual. An auditory message could be transmitted with the drivers' actual voice or a synthesized voice (i.e. computer-generated voice). Most participants would prefer the latter, especially if they do not know how the other driver would interpret the tone or qualities of their voice or react to the voice of a driver from a different social / cultural background or a person from a different nationality. One participant mentioned (P03) that it would be important to have a female and a male voice to differentiate the gender of the driver. The message with the actual voice of the drivers would carry their emotions (e.g. aggressive, polite, and sad). There is relevant literature showing that synthesized voices can have an positive or negative effect on people's emotions and behaviours (Nass & Lee, 2001). This could lead to different outcomes, for example, the situation could be dealt with or the other driver could become angry resulting in a road rage scenario. In terms of establishing common ground, auditory-only messages can have a lower cost of reception when compared to textual messages, but can have a much higher cost to display some

non-verbal cues such as gestures and nods when compared to graphical messages (see Table 2.2).

Participants mentioned a multimodal output in which a short message (e.g. Thank you, Sorry) could be heard and displayed visually. Different external factors may affect the way a driver would want to receive the message. If a message is long it should not be provided visually but by audio Wickens (1992). Short messages, on the other hand are better provided visually.

"I would prefer to receive a message in text form if it is short. When I am driving and listening to the radio, I wouldn't like to receive an audio message from the other driver. It should have an option to choose how the driver would prefer to receive a message. Depending on the day you would not want to listen to audio messages." (P09)

No matter how the message is transmitted, it is crucial for the driver to receive some form of alert that the message has been successfully sent and that the other driver has read/listened to the message. This is a very important step towards reaching the grounding criterion of mutual belief which is the main concept behind common ground reviewed in section 2.2.1. One participant (P03) suggested it would be good to have a similar form of confirmation available on a mobile message app ("WhatsApp," 2014) which shows an image of one tick when the message has been transmitted and two ticks when the message has been read.

5.3.3 Factors influencing the driver-to-driver communication process

During the interview, participants were asked several questions related to factors that may influence driver-to-driver communication. Some of these factors are particularly relevant to specific scenarios. The factors investigated in this study are part of the driver-

to-driver communication framework introduced in Chapter 04 (see section 4.1.1 page 93).

5.3.3.1 Shared interest

Scenario number three (Social) depicts a situation in which there is a shared interest between the two drivers. Specifically, in this scenario, participants were asked if they would engage in a prolonged conversation with the other driver if the device allowed them to do so. A total of 13 participants said they would prefer to give the other driver their contact details (e.g. email, mobile number) or invite them to stop at the next service station to talk rather than use the device to communicate for a longer period. The main reason for not using the device to engage in a prolonged conversation would be the cognitive demand associated with this interaction, which can reduce driving performance and increase driver distraction. This is in accordance with the literature that proves that brake reaction time (e.g. to a lead vehicle slowing) is increased when drivers engage in a conversation using an electronic device such as a mobile phone even if it is hands-free (Consiglio, Driscoll, Witte, & Berg, 2003; Strayer, Drews, & Johnston, 2003).

5.3.3.2 Cardinality of interaction

One crucial factor involved in the driver-to-driver communication process, as with any form of technology-mediated communication, is the cardinality of interaction. Drivers can send a message to only one vehicle or to multiple vehicles. This variable, which is part of the driver-to-driver communication framework presented in section 4.1.1.2, was also investigated in this study.

In scenario number five - Manoeuvre, (i.e. the main driver wants the other driver to give way) participants were asked if they would send a message only to the driver next to

them or to multiple drivers waiting for the traffic lights to change. The main reasons for sending a message to multiple drivers or only to the ones next to them are displayed in Table 5.5.

Table 5.5. Reasons for sending messages to only one or multiple drivers

MULTIPLE DRIVERS	ONLY ONE DRIVER
Good to let other drivers know about main driver's intention.	Only the driver next to main driver may see them
If one driver does not give way maybe the one behind will.	Only the driver next to the main driver needs to take action
The manoeuvre could affect more than one car, i.e. the main driver may need to go in front of more than one car, perhaps in another lane.	

The main reason for drivers to interact with each other is to make their intentions clear (Björklund, 2005). For this reason, according to the participants it is important to let all drivers be aware of the main drivers' intentions especially those who may be affected by the manoeuvre.

5.3.3.3 Passenger effect

One factor that could have a significant effect on the interaction between two drivers is the presence of passengers in the vehicle. None of the driver communication models reviewed in Chapter 02 includes passengers. This PhD research aims to build on these models by exploring this factor. Passenger effect is presented as one important variable in the driver-to-driver communication framework in Chapter 04 (see section 4.1.1.8). Participants were asked if they would do anything differently if they had a passenger with them in the car, imagining this passenger could be anyone (e.g. family, friends, colleagues

etc.). This question was asked in scenario number two, which depicts a tailgating situation.

Most participants said they would not do anything differently if they had a passenger with them in the car. One participant said they would feel more inhibited to react if there was a passenger with them. Another participant reported they would feel more stressed experiencing the same situation with a passenger, while another one mentioned they would feel the need to be more sensible because they would be risking other people's lives.

One participant said that if they had an adult passenger, they would ask them to send the message using the electronic device to the other driver, in order to avoid being distracted from driving while using it (P13). However, the same participant reported they would act differently if there was a child in the car. They would only send a message in this case if it involved the safety of anyone in the vehicle. Four participants would not reply or send a message in the first case because they would want to avoid their passengers witnessing an aggressive scenario, especially if the passengers were their spouses, children or older parents:

"If I had a passenger I would be more likely to not do anything at all. Not send any message. I would be more likely to send a message if I was driving on my own. Especially because my passenger would be a child or a woman." (P17)

"If I had a passenger with me I wouldn't accept the message in the first place just because I didn't want to create any negativity with the person. Depends on what it is, if it's my partner that's not a problem but if it's my mother, she would be really upset by foul language so I would probably reject the message" (P20)

These results are in accordance with the literature. According to Dannefer (1977), the presence of passengers can have an effect on drivers, increasing their responsibility of

being competent, leading to either cautious or risk taking behaviour depending on who the other passenger is.

Two female participants reported they would feel more secure if they were with a male passenger (P08, P15). Only in this situation would they be willing to send a message to a driver who they thought had done something wrong.

"If I had a male passenger with me maybe he would send a message back. But on my own, definitely not. Not if it was an aggressive message" (P15)

The female participants both explained that the reason for this is that they would feel afraid of a possible aggressive reaction from the other driver. However, a specific study found no significance difference on less serious forms of victimization by gender (Smart, Mann, & Stoduto, 2003).

This result links directly to the review of the literature presented in section 2.2.4.2, which states that the feeling of fear in conflict situations in the automotive context is very common. Drivers prefer to avoid any sort of conflict with other motorists even when this feeling has a very short half-life after the event.

5.3.3.4 Vehicle identification

Vehicle identification is an important task in the process of sending a message, according to the task analysis presented in section 4.2. Therefore, one highly significant point initially raised by this study is how the vehicle should be identified. This could be by the last 3 digits of the number plate of the vehicle or the whole number plate, for example "Driver RV13 RXW says Thanks".

One participant mentioned it would be good to inform not only the number plate but also the colour, make and model of the vehicle (P01). However, another participant reported that, depending on the scenario, the driver might not be able to see the number plate of

the other vehicle making it difficult to identify which driver sent the message (P06). There could also be more than one vehicle with the same colour, make and model nearby. Two participants then suggested the device could be similar to a satnav in which the vehicle that sent the message would be displayed or highlighted on the display (P06, P10). An on-road exploratory study (STUDY D) was designed to cover this specific task of vehicle identification (see Chapter 07 page 197).

5.3.3.5 Anonymity of sender

The vehicle that sent the message could also remain anonymous and not be identified in any way. The anonymity of the recipient is another highly relevant variable in the communication process, which is depicted in the driver-to-driver communication framework on page 89. The researcher asked participants if they would send a message anonymously to the other driver if the device allowed them to do so. This question was asked in scenario three in the context of sending a message to the other vehicle about something that negatively attracted the participant's attention, such as throwing rubbish out of the car window. A total of 11 participants would send a message anonymously, while eight participants would not. Five participants reported that this would depend on several factors. Table 5.6 shows the pros and cons of sending anonymous messages according to the participants along with some examples of factors which would influence the decision to engage in an anonymous communication or not.

Most of the reasons reported by participants for not identifying themselves is to maintain the anonymity of the automotive context. However, this anonymous nature is one of the main reasons for the high level of incivilities on the road, as reviewed in section 2.2.4.1.

Table 5.6. Anonymous messages pros and cons

Pros	Cons	Depends
To say something that does not require a reply from the other driver	It could lead to abusive use	How dangerous, dishonest or unreliable the other driver looked
To avoid an aggressive response from the other driver that could lead to a road rage scenario	The other driver would probably know who sent the message	How the other drivers would react to the message
	The participants would always like to identify themselves	The level of offence committed by the other driver

5.3.3.6 Driver status

The electronic device could have a functionality that allows drivers to add their status at that particular moment. The driver status could provide contextual information to help other drivers to understand the situation and assist them in their decision-making process. At the same time, the drivers who share their status can feel more connected by allowing their social expression (Rakotonirainy et al., 2014) and this would also promote social awareness to other drivers. This is one of the main concepts of the area of social vehicles which is reviewed in section 2.3.3. This status could be any of the following:

- Emotional feelings (e.g. happy, sad, excited, angry);
- Reason for driving behaviour (e.g. they are lost / novice drivers / foreigners/ elderly drivers, have a sick passenger, have a problem with the car);
- Anything else they want to share with others (e.g. what they are thinking, what they are going to do etc.);

This status would be displayed on the device to other drivers. A similar concept has been implemented on Drivemotion ("Drivemotion," 2014). The researcher then presented to

the participants the hypothetical situation in which they would have access to the current status of the other drivers. Fifteen participants declared that if they had access to this information beforehand they would act differently in some of the communication scenarios.

Participants reported they liked this functionality mainly because it would be good to understand the reason for the other driver acting that way. For instance, it would be positive and relevant to know that a driver is travelling slow because they are lost or because they have a child passenger with motion sickness or that a driver is travelling too fast because they are in an emergency situation. One participant even mentioned that they would like to use this functionality when driving abroad on unfamiliar roads (P03).

The participants also mentioned they would think twice before sending a message if they knew the other driver's emotional status beforehand. They reported that they would probably change the tone of the message, rephrase it or would not send it in the first place if they knew the other driver was in a bad mood.

Six participants mentioned the drivers' status would have no effect on them in the first scenario (i.e. slow driver in front) because they would be in a hurry trying to reach their destination and they would not be paying attention to it. Another participant did not particularly agree with the idea of sharing their status with others, which can be considered personal information (P20). One participant reported having no concern for others' feelings and therefore it would not have an effect on them (P23).

During the interview, two participants (P01, P02) spontaneously suggested the use of graphical messages where they could show smileys or emoticons the same way they would when sending messages via mobile applications. According to these participants, there should be an extra button on the steering wheel with shortcuts to the most common

smileys (e.g. happy face or sad face). Another participant suggested there should be a "like" icon with the thumbs up, similar to the one used on social network websites (P03). The results presented in this section contribute to the theoretical social car research described in the literature review by collating relevant opinions from a wide range of regular drivers regarding several different ways that information could be presented to them.

5.3.3.7 Driver-to-driver communication scenarios

One factor that influences the use of a DDCD is the content available to drivers. Messages should cover a wide range of situations if they are presented as a PDL. Therefore, at the end of the interview, participants were asked if they could remember any other scenario, not previously mentioned, where they needed to communicate something to another driver and the communication was not successful. Participants were encouraged to think of any situation they might have experienced before in real driving situations. All the scenarios reported are very relevant to the road environment and could be used by designers of DDCD in future research in this area. The most common situation mentioned by participants involved sending a message with information to the other driver. Examples of such situations were to:

- Inform oncoming drivers their lights are off;
- Inform drivers behind the reason for a car being stationary on the road (e.g. broken down or waiting for an animal to cross);
- Inform drivers in front they can go or cross;
- Inform inattentive drivers reversing in front of them of their presence;
- Inform drivers in front they are about to be robbed;
- Inform oncoming drivers of police checks ahead on the road;

- Inform oncoming drivers of animals, blocked road or accident ahead on the road;
- Inform drivers of an emergency situation;
- Try to communicate with another driver that you do not have a visual contact with, such as a lorry driver;
- Ask other drivers if they have just parked or if they are about to leave that parking bay;

5.4 Design recommendations

As long ago as 1976 Wilde mentioned that conflicts between drivers could be reduced and safety enhanced if drivers had a way to communicate with each other using a device similar to a walkie-talkie, a "drivie-talkie" (Wilde, 1976). This would reduce the ambiguity in sending and receiving of messages.

It is possible to utilise the issues raised by the interviewees in STUDY A to identify some preliminary design recommendations for a suitable DDCD.

- Firstly, it should not distract drivers from their main driving task. Therefore, the interaction should be basically by a voice-based interface with a button located on the steering wheel to activate it.
- Secondly, the device should allow its users to set up how they want to receive the messages. This could be either by audio or by text. Audio would be a preferred choice as it is less distracting (Green, 2008). Alternatively, the device could be integrated with the infotainment system (e.g. radio/CD player). For instance, in case the driver is listening to the radio the device could make just one audio alert (e.g. a beep) to inform that they have received a message.
- Thirdly, the device should provide easy access to a set of pre-defined messages. The driver could just select or say what the topic of the message is (e.g. "Deflated

tyre") and the device would send a pre-defined message (e.g. "You've got a deflated tyre"). As a free content message could lead to an inappropriate use, the device should be initially equipped only with this subset of messages, which could be expanded for future versions.

- Finally, the device should also provide some extra functionality such as informing the driver which vehicle (number plate, make and model) sent the message. The drivers could also add to the device their current status which would be available to other drivers. A particularly difficult task to implement would be to send a message to more than one vehicle and at the same time ensure that the message is only sent to relevant drivers.

5.5 Conclusions

Drivers use different ways of interacting with other motorists without the use of a DDCD, some of which are a combination of more than one form of communication. Participants reported they would use a DDCD to send messages in all scenarios, but they would avoid replying to the other driver if an aggressive message was sent. Most of them would not like to antagonise an angry driver and become involved in a road rage scenario. Moreover, similar to a mobile phone, participants would not like to get distracted from the main driving task by engaging in a prolonged conversation with the other driver through the device even if it is hands-free. A combination of traditional means of communication and an electronic device was suggested as a possible way of communication.

Passengers can have an effect on the driver (Dannefer, 1977). This study found that this could also equally apply to the use of the electronic device to exchange messages. Drivers can feel inhibited to use the device when they have a passenger with them, especially if

this passenger is a child or anyone who is easily offended and who might not react well to an aggressive or offensive message.

Drivers can share their status as part of the social interaction with other motorists. This information can have an effect on other drivers' behaviour such as the consideration of sending a message or not. This study found there are different ways that a vehicle that receives a message could be identified, such as by its licence plate. However, when talking about the identification of the sender of the message, results shows advantages and disadvantages in this identification being anonymous or not.

The specific task of receiving messages with the DDCD is the focus of the next chapter. The chapter presents the two studies (STUDY B and STUDY C) that were carried out in this research specifically related to this task. STUDY B aimed to elicit opinions from experts while STUDY C built on the results from STUDY B to collect regular drivers' opinions on the set of driving communication scenarios.

6 Receiving messages with a driver-to-driver communication device (STUDY B and STUDY C)

6.1 STUDY B – A workshop to elicit the opinion of experts

6.1.1 Introduction

The aim of this qualitative study was to capture the opinions of experts on a set of questions specifically related to the task of receiving messages using the DDCD. The questions were designed to accomplish the overall objectives of this research. The questions involved participants' feelings (OBJ 03) and opinions about the messages (OBJ 04). The set of questions addressed the best ways to present the messages not only in terms of content and format but also modality (OBJ 05). Based on the results of this study, relevant recommendations for the design of the DDCD were presented in section 6.1.3.2 (OBJ 06).

This study adopted a mix-method approach using workshops and driving scenarios to elicit knowledge from a group of experts. Workshops and scenarios can be used very effectively to encourage discussion and lead to the formation of ideas and concepts. Brainstorming methods in which experts are challenged to generate new ideas or designs are commonly used with a high rate of success (Hoffman, Shadbolt, Burton, & Klein, 1995). All of these methods are described separately and in detail in the methodology chapter of this document (see Chapter 03 page 66). This study was published in the proceedings of the 6th International Conference on Applied Human Factors and Ergonomics (Lamas et. al, 2015).

6.1.2 Method

6.1.2.1 Participants

Fifteen participants, all of them academic researchers, were involved in this study. They were recruited from the departments of Psychology, Computer Science and from the Faculty of Engineering at The University of Nottingham. Participants' positions varied from late stage PhD students, associate professors and research fellows. Participants were selected because of their knowledge and expertise in the areas of HF/E, HCI or psychology of driving. Participants were recruited by email with details about the workshop including date, time and venue.

6.1.2.2 Driving communication scenarios

A subset of five driving communication scenarios was presented to participants in this study. This subset is based on the set of driving communication scenarios designed for this research, which are described in detail in section 0. In STUDY A, the communication scenarios were presented only in textual form as this was an initial exploratory investigation. In this specific study, STUDY B, the scenarios were presented in both graphical and textual form in order to stimulate discussion from participants in the groups. A short description of the scenarios and their nature is presented below in Table 6.1.

Table 6.1. STUDY B - Driving scenarios

#	Nature	Description
01	Accident	Main driver receives a message sent to multiple vehicles from an oncoming vehicle informing them that an accident has just happened ahead of them on their side of the road.

02	Social	Main driver has a sticker on the back of their car from the football team they support. They receive a friendly message from the driver behind who supports the same football team.
03	Slow	Main driver is late for work / an appointment. The car in front of them is travelling very slowly. Main driver receives a message from the driver saying they are lost.
04	Manoeuvre	Main driver receives a message from the driver of a blue car leaving the car park just in front of them, asking if they can pull out in front of them as soon as the traffic lights turn green.
05	Apology	The traffic light is green for the main driver, but a blue car has blocked the junction. The main driver receives an apologetic message from the driver of the blue car.

6.1.2.3 Procedure

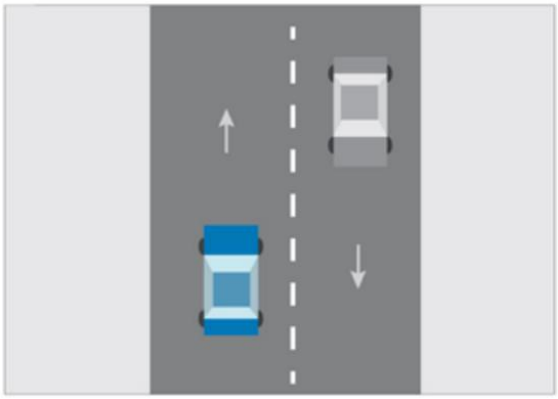
When participants arrived at the study venue, they first of all read the information sheet which contained details about the steps involved in the workshop and signed the consent form. Before they took their places, the researcher assigned participants to one of five possible groups. Each group was comprised of three participants. The groups were created in such a way that there was at least one member in each group with knowledge in automotive HF/E or the psychology of driving. Participants were invited to take their places at the table with the number of the group they were assigned to.

After all participants had arrived and were assigned a group, the researcher, who was also acting as workshop facilitator, gave a short 10-minute PowerPoint presentation explaining the planned activities to the participants. The presentation also contained details of the five driving scenarios. Before the workshop started, the researcher asked participants if they had any questions. The total duration of the workshop was 60 minutes.

The workshop took place in a university lecture room comprised of many long tables (240cm x 90cm) with three seats in each table. A set of items was placed on each of the five tables used for the study. The first item was a sheet of A3 paper in landscape mode with the communication scenario in both textual and graphical form. Figure 6.1 depicts the five scenarios used in this study. Each table contained a different scenario, which was placed on the centre of the table. The second item was a sheet of flip-chart paper with the number of the scenario at the top. This sheet of paper contained four questions, each one in a different quadrant of the paper. Finally, there were also coloured pens and coloured Post-it notes available for participants on each table. Each table contained a set of Post-it notes with different colours.

SCENARIO 01

You receive a message sent to multiple vehicles from an oncoming blue vehicle informing you that an accident has just happened ahead of you on your side of the road.



SCENARIO 02

You have a sticker on the back of your car from the football team you support. You receive a friendly message from the driver behind you who supports the same football team as you.



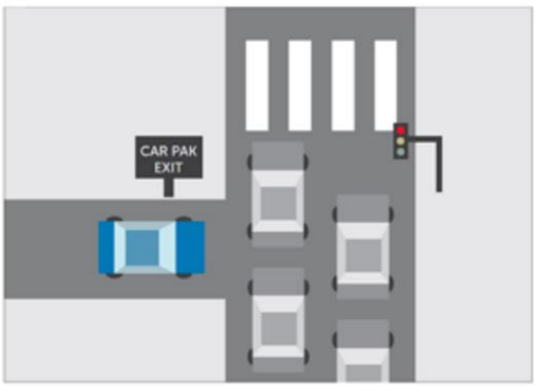
SCENARIO 03

You are late for work / an appointment. The blue car in front of you is travelling very slowly. You receive a message from the driver saying they are lost.



SCENARIO 04

You receive a message from the driver of the blue car leaving the car park just in front of you, asking if they can pull out in front of you as soon as the traffic lights turn green.



SCENARIO 05

The traffic light is green for you, but a blue car has blocked the junction. You receive an apologetic message from the driver of the blue car.

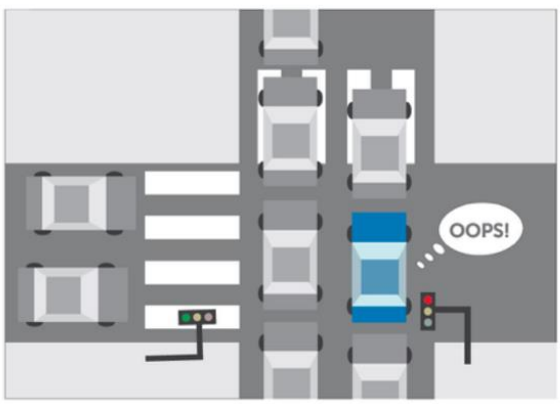


Figure 6.1. STUDY B - Driving scenarios

Each group had eight minutes to answer four questions related to each different communication scenario. The aims of the questions were to investigate participants' opinions about message content and modality and also to capture participants' feelings about receiving the message. The questions are presented in Table 6.2. Participants were required to answer the same set of four questions for all scenarios. The workshop facilitator placed a large countdown timer in the centre of the room in a location that was clearly visible to all participants. This helped the groups to effectively manage their time while answering the questions.

Table 6.2. STUDY B - Questions

#	Questions
01	What do you think about receiving this message?
02	How would you feel?
03	What should the message be?
04	How could the driver best receive the message?

Participants wrote their answers to each one of the questions on the Post-it notes and affixed them to the flip-chart paper below each question, as depicted in Figure 6.2. They were encouraged to use more than one Post-it note if possible to be able to explain their thoughts in detail. After eight minutes the countdown timer alerted participants that time was up. At this point, the workshop facilitator kindly asked the groups to change tables, moving to the next table where another communication scenario was presented. The first group moved to the table where scenario two was presented, the second group moved to the table where scenario three was presented and so on until all the groups had moved to another table. The groups were allowed to see the previous groups' answers.

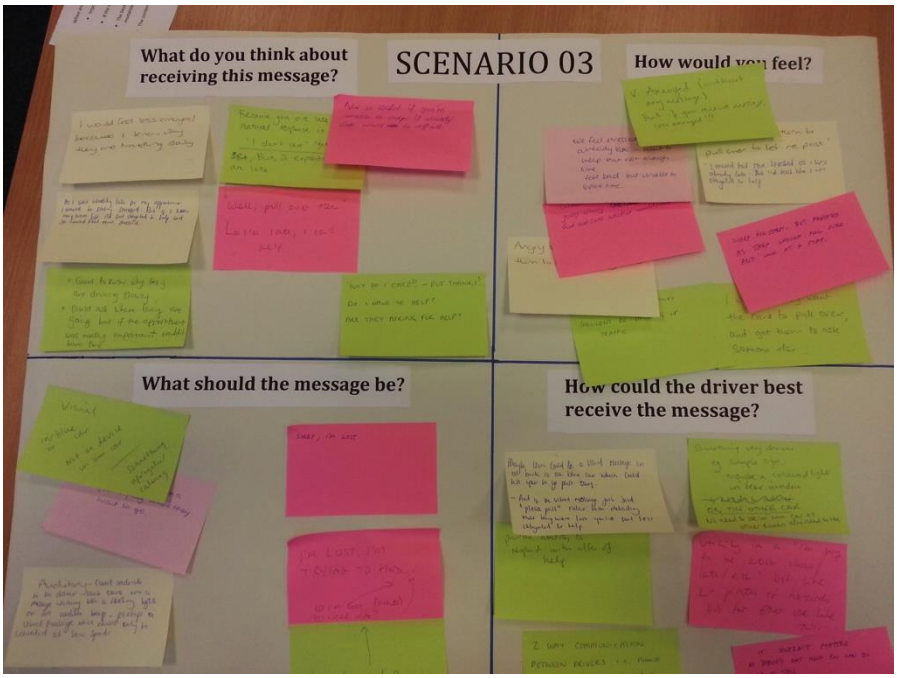


Figure 6.2. STUDY B - Flipchart paper

Each group used the same colour Post-it note throughout the study. For example, group one used the lime-green Post-it notes in all the scenarios, while group three used the pink ones. The groups took their blank Post-it notes with them when moving tables. The use of different colour Post-its for each group was designed to help the researcher to easily identify answers from each group when conducting the data analysis later.

On all the tables, there were sheets of paper containing general topics to consider when answering the four questions. Groups were prompted to think about these topics during the workshop. The topics included, for example, important automotive issues such as driving distraction and road safety, and factors related to driver-to-driver communication such as vehicle identification, anonymity, message content and message format.

6.1.2.4 Data analysis

This study adopted the same iterative thematic analysis method described in section 3.10. Textual information from the Post-it notes were transcribed to a text document and initially grouped by driving scenario and question. An extra piece of information related to the group number and colour (e.g. G01) was added at the end of each answer. The main themes compiled for this study varied from different emotions to the use of specific technology terms such as satnav and augmented reality. The final data was then reduced to a set of themes based on each question and communication scenario.

6.1.3 Results and discussion

6.1.3.1 Emotions

Participants were required to answer one question about how they would feel receiving messages from other drivers in each one of the specific scenarios presented to them. This question was asked because the DDCD may produce a significant effect on the emotions of the receiver of the message, which could then lead to a profound effect on the outcome of the communication between drivers. For example, the situation could be dealt with quickly and easily if the message received helps to clarify any misunderstanding, or the message could produce a negative outcome with the other driver becoming stressed or angry. Both negative and positive emotions can have a decisive effect on driver distraction similar to other distraction sources, such as information overload (Riener, 2012a).

Participants reported a mixture of positive and negative feelings regarding this question in most scenarios. On the positive side, some participants mentioned they would feel very grateful and pleased after receiving a message. Several participants also mentioned the messages would make them feel less annoyed with the whole situation. The DDCD was

described as very useful and as a device that would make drivers feel in control of the situation, thereby increasing their awareness. Drivers would have a clear understanding of the situation on the road, for example the reason for having a traffic jam, if they received messages alerting them about an accident ahead on the road. The importance of this has already been investigated using driver assistance systems to provide information about the environment, supporting drivers in difficult situations by increasing their awareness (Fuchs, Rass, Lamprecht, & Kyamakya, 2007).

Participants also expressed pleasant feelings associated with the shared interest message from the supporter of the same football team, presented in the social scenario. This message would make drivers feel connected to other drivers. The need for connectedness is one of the principles that underlies social behaviour (Mackie, Devos, & Smith, 2000; Rettie, 2003). A few participants also mentioned that this specific situation would make them feel part of something bigger. This feeling of belonging to a group was identified by (Christiansen & Maglaughlin, 2003) as a specific and important type of awareness which has been used in the CSCW literature.

The DDCD could also help relieve extreme negative emotional responses when the sender of the message apologises for having executed a bad manoeuvre. According to participants from three groups, in scenario five they would feel less angry, knowing that the other driver acknowledged their error by sending an apologetic message for having blocked a junction.

On the negative side, participants mentioned feeling stressed, angry and annoyed with some of the messages. In scenario number three, participants reported they would not know what to do if they received a message from a slow driver in front. Participants from one group suggested that the correct action of the lost driver should be to pull over and check a map and not to send a message. Moreover, participants commented that they

would not be willing to help a lost driver if they were in a hurry. This result is depicted in the driver-to-driver interaction model (see section 2.3.2.4) and the joint-action control model (see section 2.3.2.1) both of which state that the outcome of the process may differ according to how urgent their goal is.

Participants mentioned that some of the messages received contained no new information per se. According to these participants, they were not willing to receive such messages as they were viewed as useless and a waste of network resources that could be used to exchange other more important messages. Participants also expressed negative feelings if they were constantly receiving messages about a shared interest. An overload of these messages could make the receiver of the message feel really annoyed. A similar result was found in research carried out with a specific group of drivers who use the car as a calm place and do not want to be constantly receiving notifications about social interactions (Riener, 2014).

Messages with some sort of request in the social environment of the road can be categorised as an informal order (Renge, 2000) or according to the LMDI model as a directive act in which the receiver needs to take some action (see section 2.3.2.2). A few participants stated that they might feel obliged to obey this request in all the messages or even to reply to all messages. This is something that they might not always want to do, which would create a negative feeling and a decreased willingness to use the DDCD. This feeling of obligation is part of the social context of the road, as reviewed in section 2.3.1, in which drivers feel that they need to act politely to avoid moral judgements (Lennon & King, 2015).

6.1.3.2 DDCD design

Participants provided valuable comments regarding the design of the DDCD. The first comment was regarding the advantage of having the DDCD well integrated with other in-vehicle devices. Audio messages, for example, could be played using the sound system of the vehicle. This integration could also enhance the functionalities provided by the communication device. Participants mentioned that the DDCD could be closely integrated with the IVNS to present information about the specific location of an occurrence such as an accident on the road. In this particular scenario, for example, the IVNS could provide options to the driver of alternative routes to avoid going near the accident. This functionality could improve the communication between drivers by providing a better experience for the DDCD users, who could have their journey times reduced.

Participants clearly reported their lack of interest in some of the messages received, especially the ones with content not directly related to the driving context. Therefore, it was suggested that DDCD should allow drivers to block specific types of messages while receiving others. This functionality of content blocking is widely used in all sorts of technology-mediated communication, for example in order to prevent children from accessing specific content (Dickerson, 2009). Participants also commented on the possibility of completely switching off the DDCD at any time. In both situations, since the driver does not successfully receive the message, the DDCD should provide some sort of system notification to the motorist who sent that message. There is no cost in the grounding techniques reviewed in Table 2.2 which covers this situation. A new cost could be added which involves the effort required to produce feedback that the other part did not receive the message.

Trust is a very important aspect of any form of electronic-mediated communication, as presented in section 4.1.1.6. Trust is even more relevant in the automotive context where

it is very difficult to know how genuine the content of a message is in a very short period of interaction. During the study, a few participants raised the issue of trust concerning message content in scenario number one (Accident). Participants reported there is no way of knowing if a reliable source sent a message about an accident on the road only from its content. However, some suggestions were given which could help the receiver of the message decide on the reliability of the message. An extra piece of information could be added to the message to assure the driver that it is trustworthy. One way of assuring the driver that the message is trustworthy is by displaying the message to the driver only when the number of drivers who sent it reached a minimum number. In this case, the extra piece of information could be the number of drivers who sent the message. This would increase the cost in grounding technique associated with delaying message presentation (see Table 2.2) which could make the message irrelevant by the time the other driver receives it. One group suggested that the message could display an extra piece of information if it comes from a reliable source such as Highways England. Participants also reported trust issues in other communication scenarios, as there is no way of knowing if drivers really meant what they said, for example if they are genuinely sorry for performing a bad manoeuvre or if they are just using the DDCD to justify it. The main reason behind this is the lack of eye contact or facial expressions which makes it very difficult for drivers to express themselves appropriately in social interactions using non-verbal visual cues (Rakotonirainy et al., 2008).

Participants were asked what they felt the best way would be to present the message to drivers. This specific question focused on modality of presentation. Participants were experts in HCI and HF/E with vast knowledge of different forms of technology to present information. Overall, they reported that the most appropriate way to receive visual messages would be with the use of heads-up displays (HUDs), which display information

on the vehicle's windscreen. Participants mentioned that HUDs are less distracting when compared to other types of displays such as heads down displays, which is in accordance with the literature (Burnett, 2003; Gabbard, Fitch, & Kim, 2014). Participants also suggested that the messages could be received via audio means in most scenarios with a few reporting that multimodal displays could be the best solution. Multimodal displays distribute the information across different modality channels (i.e. auditory, visual and touch) and this is based in part on Wicken's Multiple Resource Theory. According to this theory, resource competition is reduced and performance is increased when tasks are presented in different modalities (Wickens, 2008).

Participants were also asked about the content of the messages in each scenario. Some reported that the content of the message should be succinct and displayed very briefly to avoid driver distraction as this would reduce the amount of time drivers would be engaged in a secondary task (Green, 2008). They also mentioned that a lot of effort must be made when designing the content of the messages. Similarly, extensive research has been conducted on how vehicle navigation systems should present content of information to drivers in the best possible ways (Burnett, 2000; May, Ross, & Bayer, 2003). One particular example in this study of how the content of the message should be carefully designed was presented in scenario four (Manoeuvre) where a vehicle is leaving a car park. According to participants, this message could be rephrased to show an indication of the direction of movement of the vehicle instead of a request to pull in front. Participants reported that an arrow pointing to the right, for example, would be less intimidating for the driver to agree to the request. Drivers would be able to make a clearer decision as to whether it would be appropriate or not to let the sender of the message pull in front them. This would also avoid a negative reaction.

6.1.4 Study limitations

In this particular study, expert participants were from academia. No study was made with industry experts in automotive HF/E and HCI. Research shows that, when modelling systems, professionals from different backgrounds and environments can have different mental models (Ford & Sterman, 1997). Academics may have extensive knowledge on theories relative to the automotive context and their practical applications, whereas experts from industry may have expertise on other practical aspects such as product development stages or market trends. Knowledge elicitation from experts in both industry and academia may have provided additional information.

Due to time constraints of the participants, it was not possible to run the workshop for more than one hour. With more time available, it would have been highly valuable to run a post-workshop focus group in which all participants could talk about their answers to each of the scenarios. More comprehensive data would come from this discussion with all participants.

6.1.5 Conclusion

This study found that in some scenarios a DDCD could have a positive effect on the outcome of drivers' interaction by promoting politeness, increasing their awareness and making the driver feel more appreciative. However, there were other situations in which communication between drivers was felt unnecessary or in which drivers felt obliged to reply. This could make drivers feel annoyed and angry, especially if there is an overload of these messages. The DDCD should be designed to allow drivers to block such undesired messages. It was also found in the study that the aspects of reliability, modality of presentation, message topic and content must also be addressed when designing a DDCD.

6.2 STUDY C – A video-based study to explore alternative HMI designs

6.2.1 Introduction

Contrary to STUDY B, which captured opinions from experts, STUDY C aimed to elicit opinions from regular drivers on several factors that may influence the task of receiving messages with a DDCD. More specifically, this study established four objectives, which address the overall objectives of this research:

1. To investigate participants' emotions experienced in each of the driving scenarios (OBJ 03);
2. To explore the overall acceptance of the device in each one of these scenarios (OBJ 04);
3. To capture participants' opinions about content and format of the messages presented to them in each of the driving scenarios (OBJ 05);
4. To provide design recommendations for message presentation (OBJ 06);

6.2.2 Method

6.2.2.1 Participants

A convenience sample of 48 drivers, 23 male and 25 female, participated in the study. Their ages ranged from 19 to 70 (mean= 35, SD = 12.7). Participants were recruited on the basis that they must have held a valid driving licence for at least two years (mean=15, SD=6.0). Participants also had to drive regularly, at least three times a week. Most of them (64%) reported that they regularly drove for at least 60 minutes a week on average.

6.2.2.2 Driving scenarios

Unlike the two previous studies, in which the driving communication scenarios were presented in textual form (text and image), for this study, the scenarios were presented

in a video format, each one about 1.5 minutes long (see Figure 6.3 for an example still image from a video). Video-based scenarios provide more detailed information with rich content and with more details about the HMI such as the use of audio and visual message presentation. The videos were designed using the STISIM version 3.0 driving simulator software.



Figure 6.3. STUDY C – Still image from an example of a video-based scenario

The messages presented in each video were both auditory and visual. In some of the scenarios, participants were able to easily identify who sent the message as a speech bubble was displayed accompanying the other driver's moving vehicle. The visual part of the message was always displayed on the right-hand side of the windscreen, close to the driver's field of vision, simulating a HUD. This simulation was video-based and the information displayed in black for clarity. The study was not concerned with the perceptual use of a HUD; it focussed on the implications of different information content. With real automotive HUDs, the information is shown as a transparent display on the windscreen (Gabbard, Swan, & Hix, 2006). Both auditory and visual parts of the message

were presented at the same time. In all scenarios, the messages were received while both vehicles were in movement.

Table 6.3 shows the subset of five scenarios used in this study with the main auditory and visual elements of each one. Throughout the rest of this chapter the scenarios will be referenced with their number and main descriptive word in order to help the reader to easily comprehend which scenario is being referenced, for example scenario 01_ACCIDENT or 02_SOCIAL.

Table 6.3. STUDY C - Driving scenarios

Scenario number	Nature of the scenario	Message topic	Visual	Auditory
01	Information	Accident ahead		"Accident ahead – 2 miles"
02	Social/Friendly	Shared interest – football team		♪♪ "You'll never walk alone!" ♪♪
03	Driving related	Slow vehicle in front		"Slow, elderly driver"
04	Driving related	Apology for bad manoeuvre		"Sorry!"
05	Information	Problem with participant's vehicle		"Your back-passenger door is not properly closed"

6.2.2.3 Procedure

Participants initially signed the consent form and read the information sheet that contained detailed information about the procedures of the experiment. After this, participants filled in a general questionnaire about their gender, age, driving experience and competency with technology (see Appendix iv page 371). Participants were presented with one detailed driving scenario at a time on a laptop.

After watching one of the video-scenarios twice, participants were able to ask the researcher any questions to make sure they had fully understood it. Participants then filled in three different questionnaires: a driver-to-driver communication questionnaire (see Appendix v page 372), a Van der Laan scale (Van Der Laan et al., 1997) to capture users' overall acceptance of a device (see Appendix vii page 375) and a scale to capture users' feelings (see Appendix vi page 374). Participants were also asked to write suggestions about what they thought the message should be like. All of these questionnaires were regarding the scenario they had just watched. After this, participants were presented with the next video-based scenario and the same process started again. All participants answered questions based on the same set of five scenarios. The scenarios were presented to each participant in a different, randomised order. At the end of the study, participants were told not to say anything about the experiment to any friends or family who might also take part in it later.

6.2.2.4 Data analysis

This study was mainly focused on the use of questionnaires to capture drivers' opinions on several factors, although subjective data was also collected at the end. For each scenario, participants reported their opinions with respect to the acceptability of the DDCD by means of the driver acceptance questionnaire designed by Van Der Laan et al.

(1997) described in section 2.4.2. The questionnaire consists of nine, 5-point rating scale items, ranging from -2 to 2. The results of this questionnaire show the scores on the two acceptance subscales, one denoting the perceived usefulness of the device and the other denoting the perceived satisfaction.

Participants also reported their emotions when receiving the messages in each driving scenario. This was measured with the Self-Assessment Manikin (SAM) questionnaire (Morris, 1995). Each of the three emotional dimensions depicted on this scale is represented by a graphic character displayed along a continuous nine-point Likert-scale. For the first dimension of 'pleasure', the scale ranges from a smiling, happy character to a frowning, unhappy one. The second dimension is 'arousal', and the SAM scale ranges from a sleepy character with eyes closed to an excited one with eyes open. The last dimension is of dominance and the scale ranges from a very small figure representing a feeling of being controlled to a very large figure representing a character in control (see Figure 6.4).

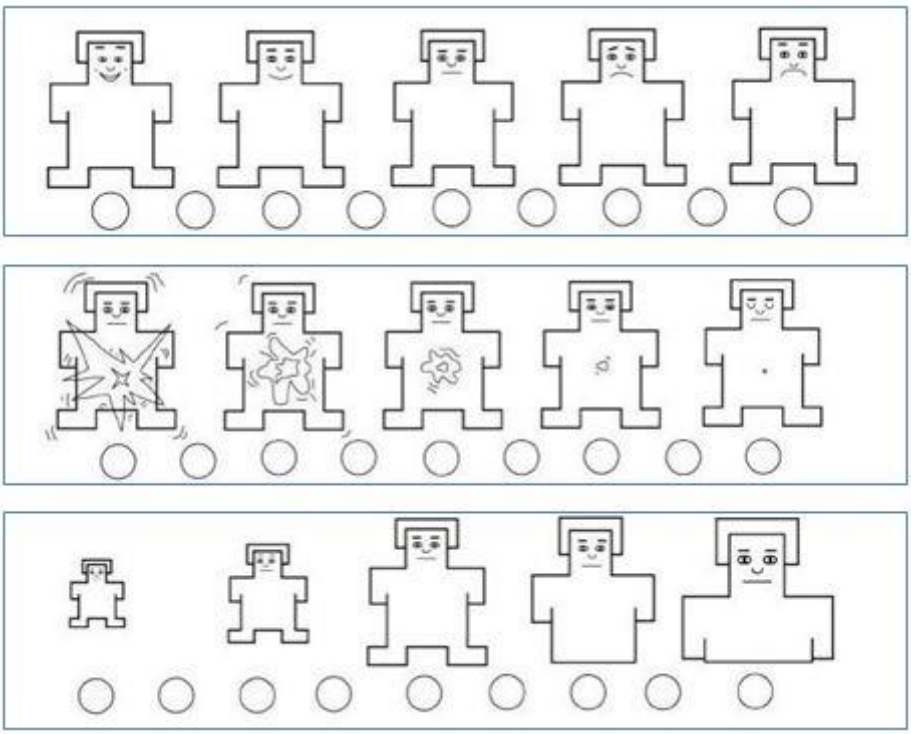


Figure 6.4. STUDY C – SAM questionnaire by Morris (1995)

A driver-to-driver communication questionnaire was designed specifically for this study to elicit opinions about several factors that may influence message presentation. This questionnaire was designed based on the results of the two previous studies and also on the diagram described in section 4.1. The questionnaire consisted of Likert-type questions with five alternative responses: strongly disagree (1), disagree (2), neutral (3), agree (4), strongly agree (5).

In the last part of the driver-to-driver communication questionnaire, participants were asked to write how they would like the content of the message to be for each specific scenario. The same iterative, thematic analysis method for qualitative data presented in section 3.10 was used for this. All the suggestions were initially grouped by driving scenario. A list of main codes was then produced with more codes being created during the analysis process.

6.2.3 Results and discussion

The results and discussion of this study are divided into three sections each one focusing on one of the questionnaires presented to participants. The first section describes the factors affecting the presentation of messages to motorists, which were investigated in the driver-to-driver communication questionnaire. The following two sections present the results and discussion from the overall driver acceptance of the DDCD and drivers' emotions felt when receiving messages.

6.2.3.1 Driver-to-driver communication questionnaire

This section shows the results of the driver-to-driver communication questionnaire presented to participants after each driving scenario. This questionnaire aims to capture opinions about message design (content and format), and also the effect of the message on drivers' intentions and driver distraction. All the results related to improvements in message design take into account the use of pre-defined messages which senders would be able to select from a list before sending them. Therefore, these results aim to discuss how these pre-defined messages should be designed to present clear information in the best possible way.

6.2.3.1.1 Drivers' intentions

Messages received via the DDCD can make drivers' intentions clearer when compared to traditional means of communication (e.g. flashing headlights, honking horn, and gestures). The message "Accident ahead", for example, can carry much more information and be less ambiguous than flashing headlights, which could have several different meanings (Renge, 2000).

Participants were asked if the message for each scenario made the intention of the other driver clearer. Results are presented in Figure 6.5. This result is in accordance with the

aims of this PhD research and indicates that the use of messages can make the intentions of other drivers clearer and avoid misunderstandings in communication.

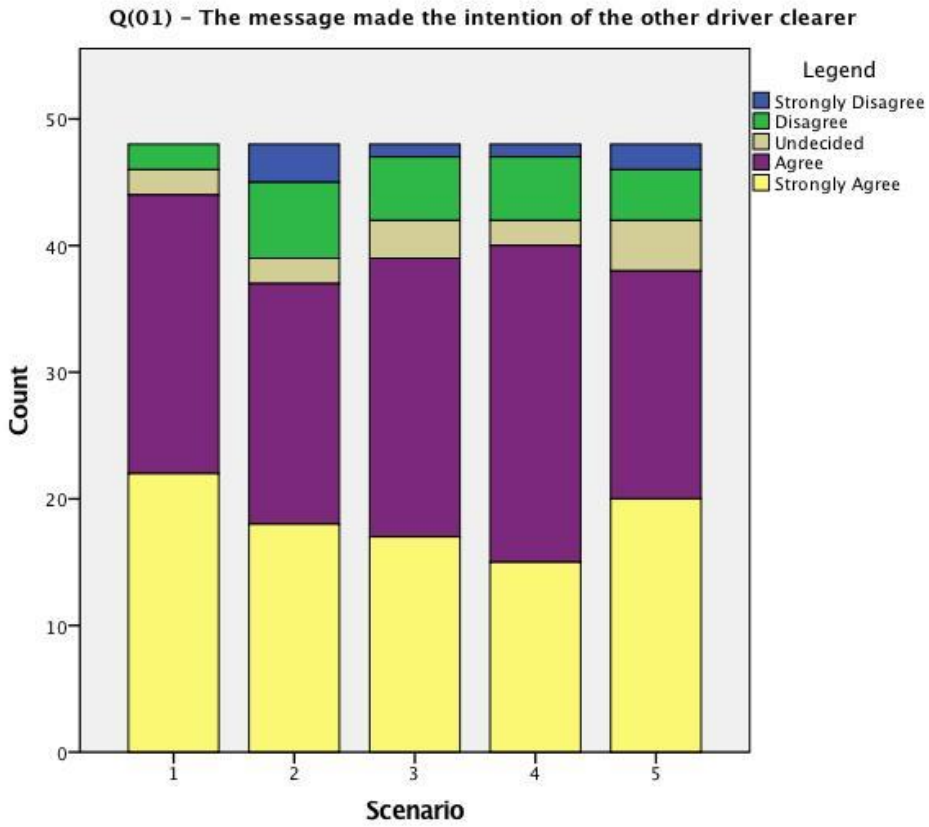


Figure 6.5. Driver-to-driver communication questionnaire – Drivers' intentions

Participants were also asked if they would have acted differently if they had not received the message. According to the results presented in Figure 6.6, for all scenarios except scenario 02_SOCIAL, participants agreed with this statement. This result was also found in STUDY B. The messages in the other scenarios provided the drivers with new information, which helped them to improve their situation awareness and make decisions, which could lead to positive changes in their driving behaviour. However, the message received in scenario 02_SOCIAL would not help drivers improve their awareness of the situation as it was not directly related to the road context.

Most of the driver-to-driver interaction models reviewed in Chapter 02 (see sections 2.3.2.1 and 2.3.2.3) state that drivers need to constantly monitor the environment in order to make a decision as to whether they would change their driving behaviour or not.

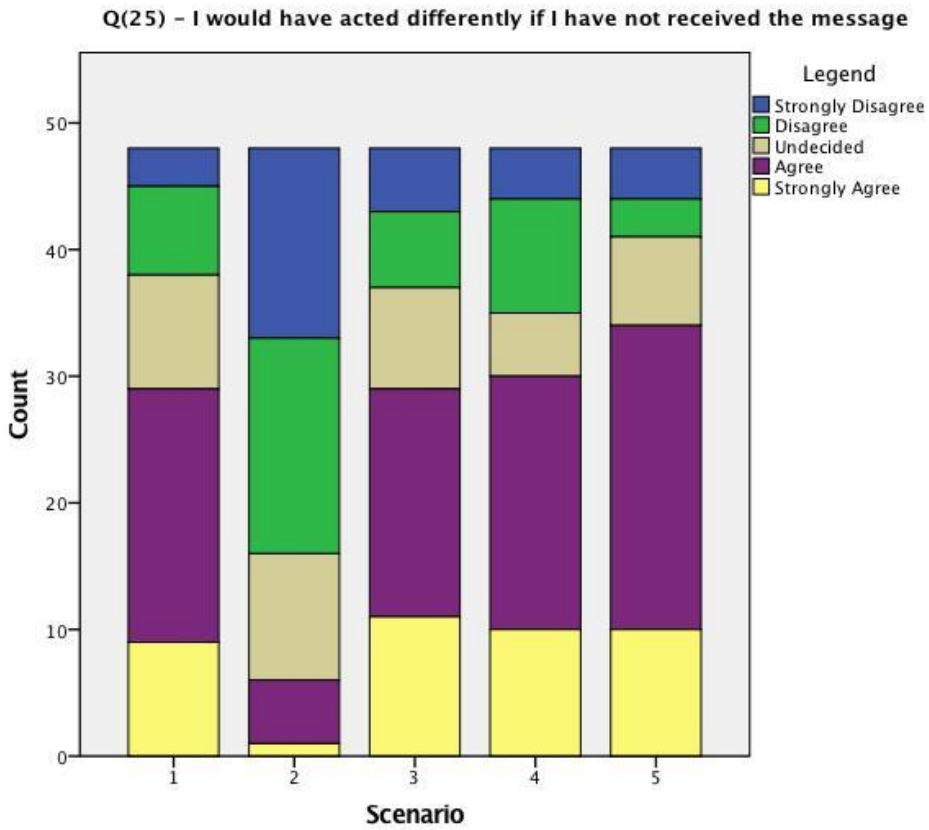


Figure 6.6. Driver-to-driver communication questionnaire – Different reactions

6.2.3.1.2 Willingness to receive/block messages

Although messages can make the intention of other drivers clearer, it is very important to understand if drivers would be willing to receive these messages under different circumstances. Results from STUDY B reported the importance of having a functionality that would allow the driver to block specific types of messages. This functionality is already available in different forms of CMC.

Participants were asked if they would have blocked the message and not receive it, if it was possible. Results are shown in Figure 6.7. This result confirms the importance of receiving messages particularly in scenarios 01_ACCIDENT and 05_PROBLEM, which could have a direct effect on driving behaviour and on the safety of their journey.

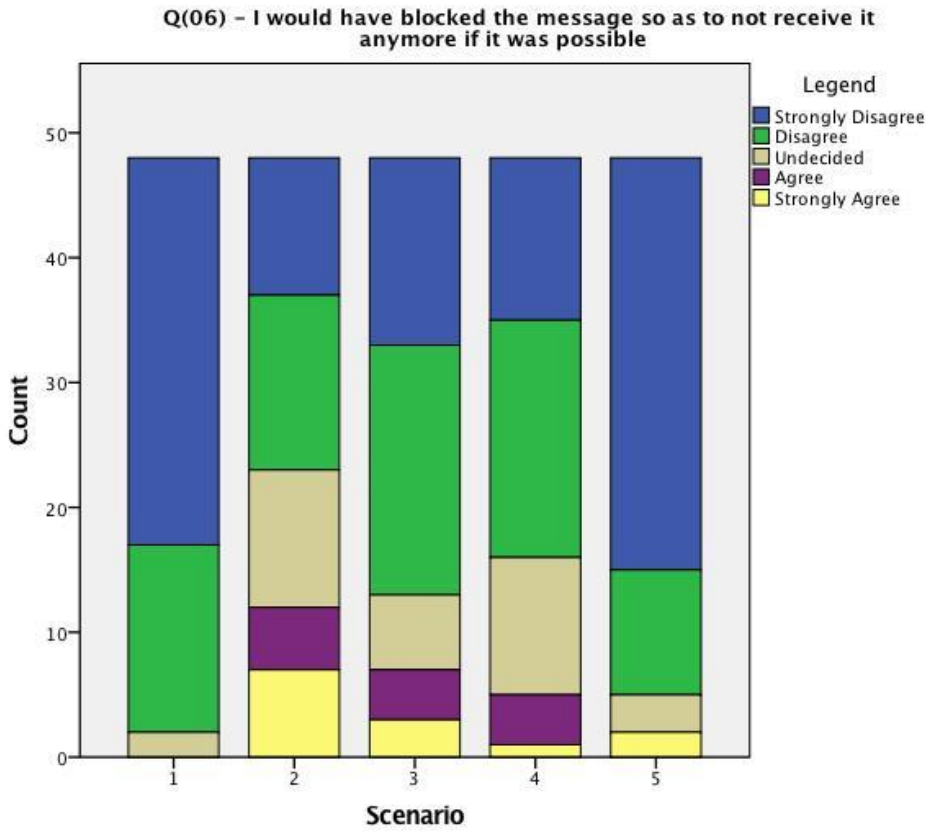


Figure 6.7. Driver-to-driver communication questionnaire – Message block

Participants were also asked if they would be willing to receive more messages of this same type. As expected, the results are almost the exact opposite of the ones found in the previous question (see Figure 6.8). This result is in accordance with STUDY B that showed that drivers are not willing to receive messages not related to the driving context. This result also is in accordance with the overall driver acceptance of the device presented in section 6.2.3.2, which showed lower acceptance values for scenario number 02_SOCIAL.

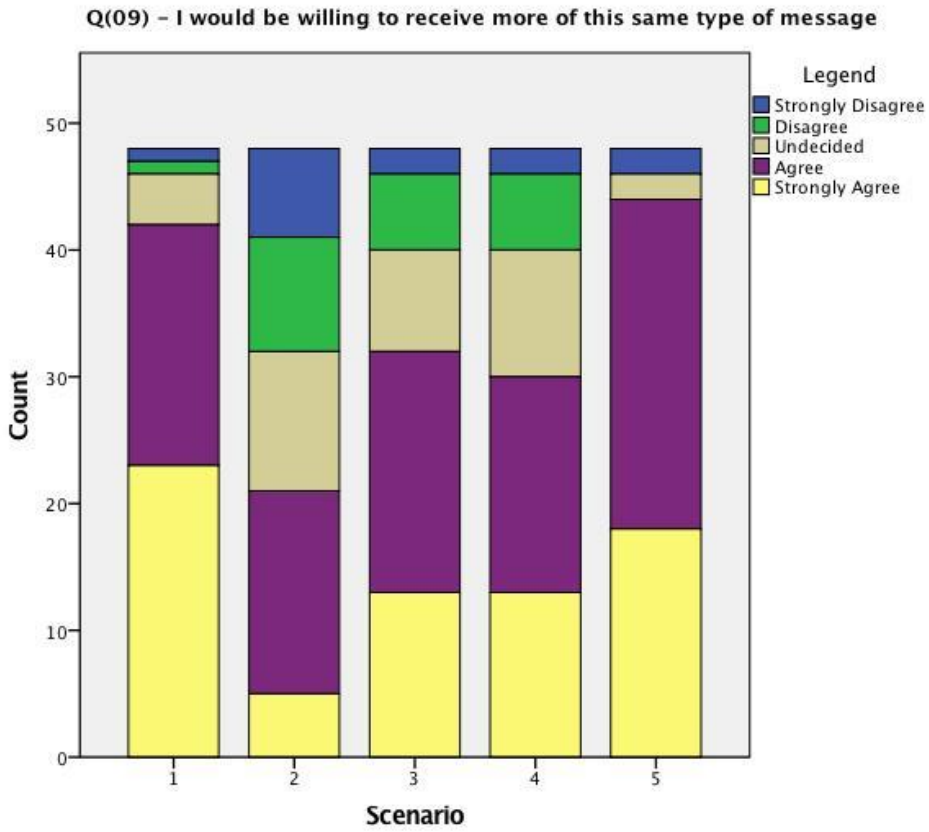


Figure 6.8. Driver-to-driver communication questionnaire – Willingness to receive message

Finally, participants were asked if they would prefer to use traditional methods of communication rather than the DDCD to communicate with the other drivers in each of the driving scenarios. The results are presented in Figure 6.9. Traditional communication includes the use of gestures, verbal utterances and what is already available in the vehicle such as indicators, headlights and horn.

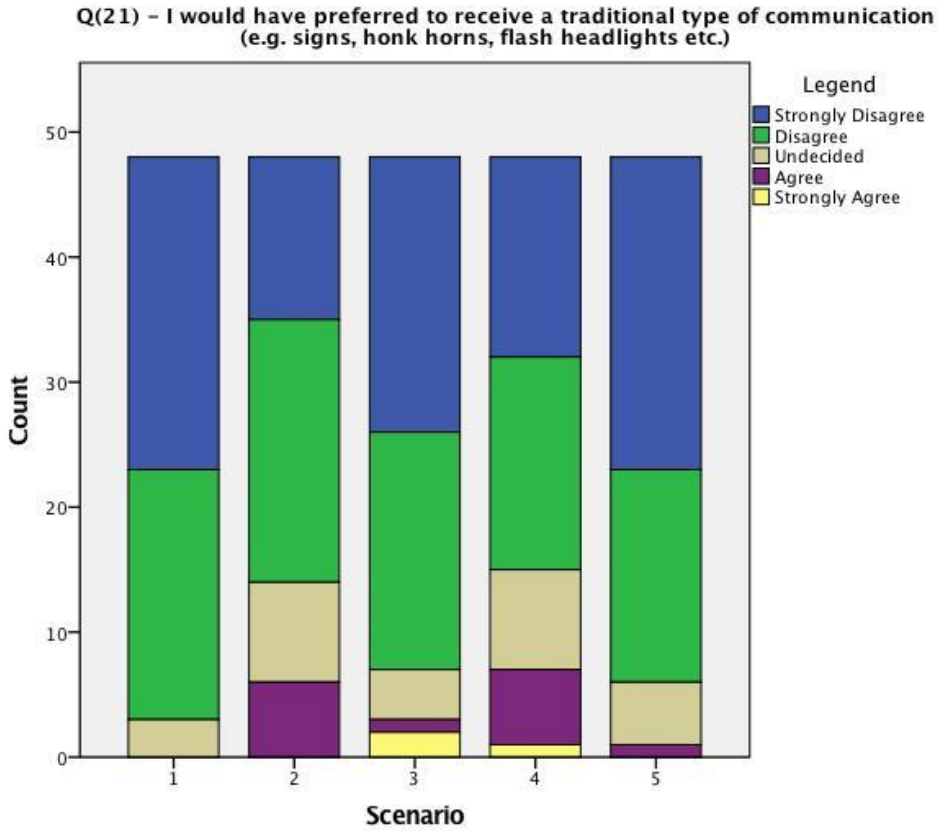


Figure 6.9. Driver-to-driver communication questionnaire – Traditional means of communication

6.2.3.1.3 Driver distraction

Driver distraction, which has been a major topic in driving research, is defined as any diversion of visual, cognitive, biomechanical, or auditory load from the driving task (Ranney, Mazzae, Garrott, & Goodman, 2000).

Participants were asked if the message received in each scenario could make them feel distracted from driving. Results from this question are shown in Figure 6.10. Results show that for scenarios 01_ACCIDENT, 03_SLOW and 04_APOLOGY participants would not feel that the message was distracting and disagree with this statement.

However, in scenario 02_SOCIAL, most participants would agree with this statement. Two reasons may explain this result; the specific nature of the scenario and the fact that the

message was musical and lasted longer. For scenario number 05_PROBLEM, it was found that participants were undecided about this statement. The message presented in this scenario also lasted longer than the other scenarios. Longer messages would increase the amount of time drivers would be engaged in a secondary task, therefore increasing their chance of being distracted (Green, 2008).

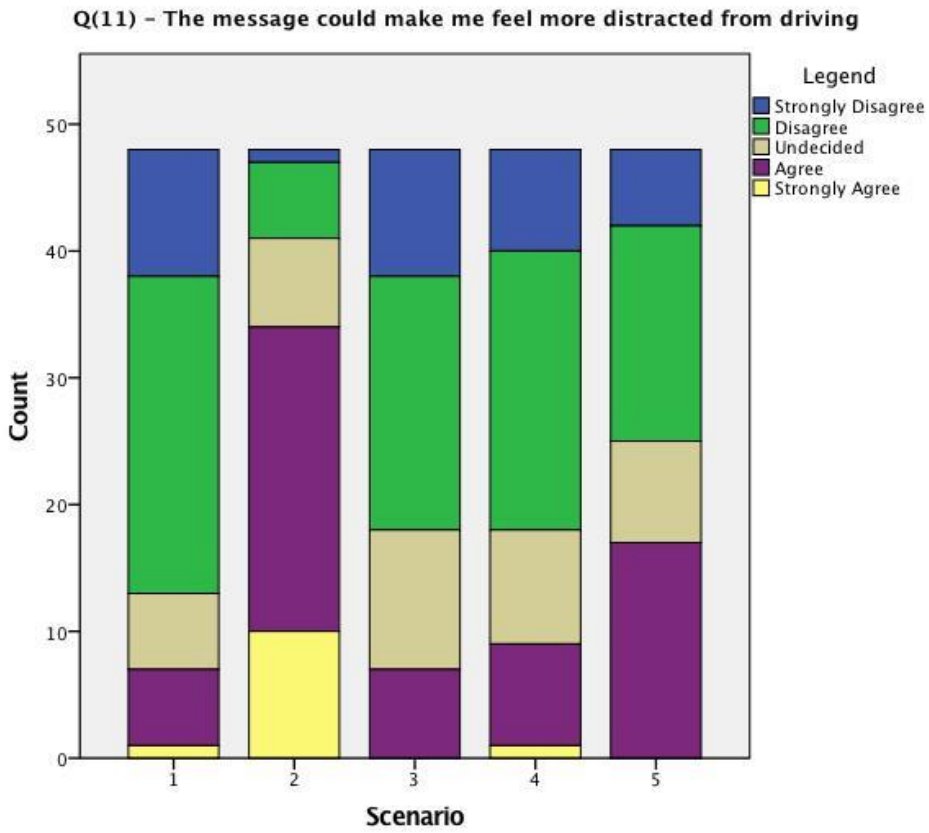


Figure 6.10. Driver-to-driver communication questionnaire – Driver distraction

6.2.3.1.4 Message content

According the results from STUDY B, some messages could be rephrased in order to become clearer and less intimidating for the other driver. Regarding the content of the message, in this study participants were initially asked if they would have rephrased the message in a different way. The results from STUDY C can be seen in Figure 6.11, which

shows that, overall, participants disagreed with this statement. However, at the end of the questionnaire, participants were asked to provide any suggestions about how the message could be improved. These suggestions are presented in section 6.2.3.1.9 and provide valuable information on how each specific message could be better phrased.

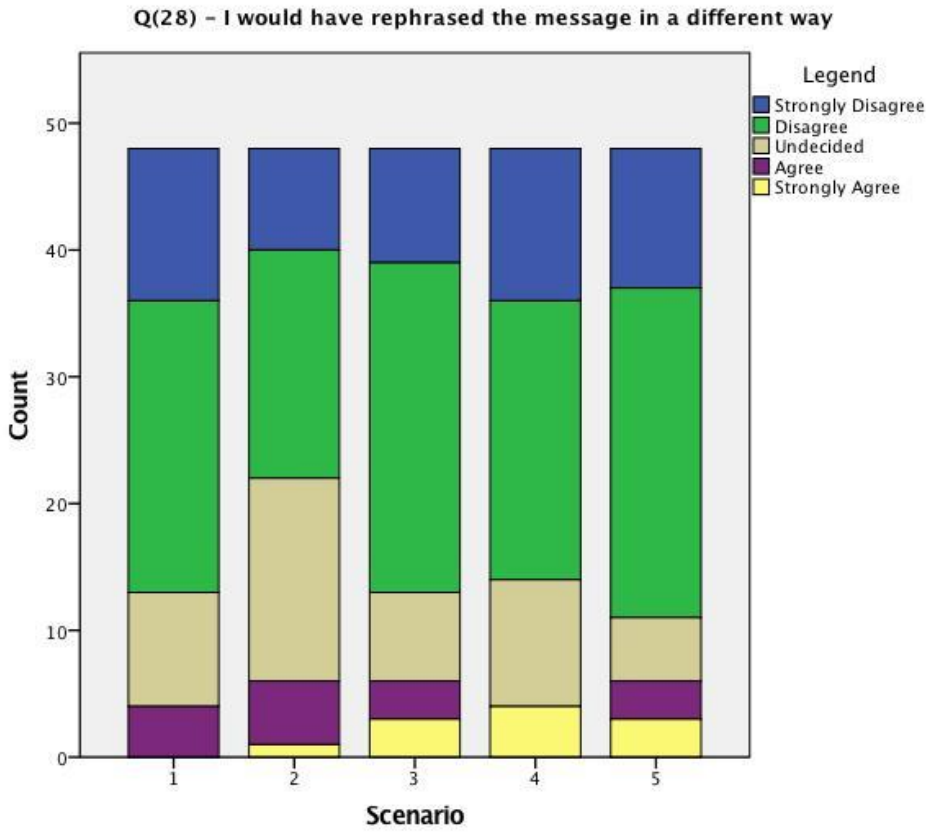


Figure 6.11. Driver-to-driver communication questionnaire – Rephrase message

The second question was regarding how complete the message seemed to be. Contrary to many other forms of electronic mediated communication reviewed in Chapter 02, driver communication can take place in a very short space of time with few opportunities to make a point (Goffman, 2009). Therefore, it is important that the message should be as simple as possible, but at the same time provide all the necessary information. There should be no back and forth of exchanging messages; one message should clearly and concisely say it all. The results are presented in Figure 6.12. Participants agreed that for

all driving scenarios the messages were complete and provided all the information they needed to fully understand the situation.

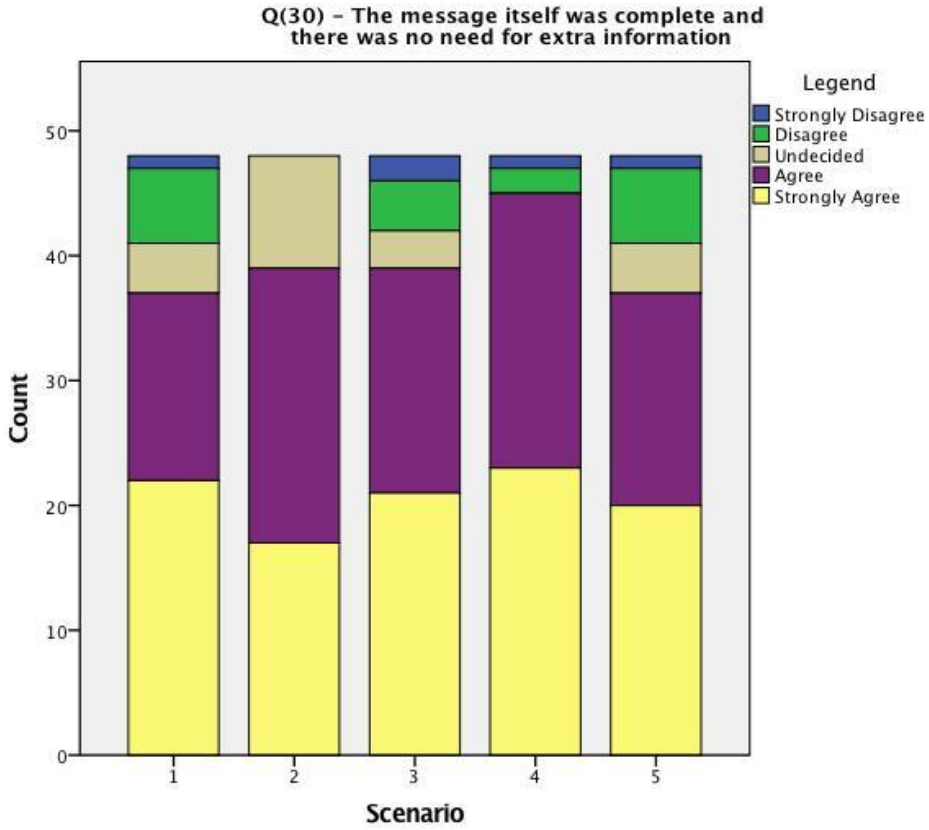


Figure 6.12. Driver-to-driver communication questionnaire – Message completeness

6.2.3.1.5 Visual design of messages

Participants were asked for each driving scenario if the visual representation of the message was clear to them. The results are presented in Figure 6.13. Scenarios 02_SOCIAL, 03_SLOW and 04_APOLOGY contained fewer visual elements than the other two scenarios and were self-explanatory without the auditory part of the message. This could explain why these scenarios had only a few disagreements regarding the statement that the message was clear. In contrast, scenario 01_ACCIDENT had many visual elements that required participants to comprehend in a short interval of time. The researcher

presented the visual part of the message to the participants on a piece of paper and explained to them after they had received the message what each one of these elements represented. Scenario 05_PROBLEM had just one visual element but it needed the auditory part of the message to be fully comprehended.

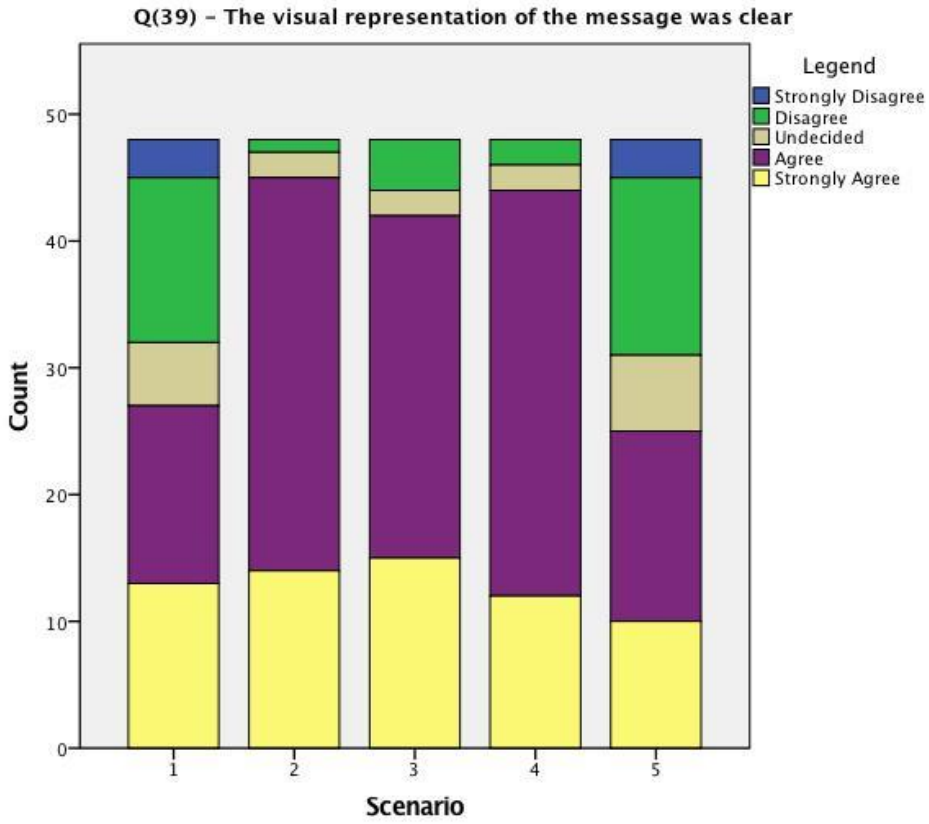


Figure 6.13. Driver-to-driver communication questionnaire – Visual representation of message

One important piece of information when receiving a message relates to sender identification. STUDY A showed the importance of identifying the driver who sent the message to avoid abusive use of the DDCD. However, there are some scenarios in which this information may not be relevant. In this study, both situations were explored. Sender identification could be either presented in visual and/or in auditory form. Based on the results of STUDY B, it was decided that the information of who sent the message would be presented in visual form only, making use of the graphical representation of a HUD.

The messages were presented to participants with or without the use of speech bubbles. Speech bubbles have been used extensively with different interfaces in the HCI context (Lucero, Holopainen, & Jokela, 2012; Piper & Hollan, 2008; Reeves et al., 2004). Speech bubbles were used in scenarios 02_SOCIAL, 03_SLOW and 04_APOLOGY and depicted situations in which it was possible to identify the driver who sent the message as shown in Figure 6.14. The speech bubble was displayed on the car that sent the message, similar to a comic book where speech bubbles are commonly used to show which character said something.



Figure 6.14. Message representation - use of speech bubble

In scenarios where no speech bubble was used, the messages were presented in a rectangular box (see Figure 6.15), indicating that it came from more than one driver such as in scenario 01_ACCIDENT, or that it was not possible to identify which driver sent the message for example in scenario 05_PROBLEM.



Figure 6.15. Rectangular representation of message

Participants were asked if they agreed with the statement that it was easy to identify the driver who sent the message. The results can be seen in Figure 6.16. For the scenarios where the speech bubble was used, participants overall agreed with this statement. Therefore, speech bubbles proved to be an effective way to quickly identify the driver if the DDCD has a visual component such as HUD. One of the strong points of using this approach is that sender identification and message content are presented simultaneously, therefore reducing the time it takes to present the message and the overall cost in establishing common ground as reviewed in Chapter 02. Moreover, drivers do not need to take their eyes off the road to see the message. However, there are some well-known challenges, described earlier in this chapter, when using HUDs to present information to drivers, such as the overuse of augmented reality content can make the real world view too cluttered with issues in contrast and depth perception (Gabbard et al., 2014). The use of HUD can also contribute to the decrease of drivers' attention resources to important real-world cues, which can increase driver distraction.

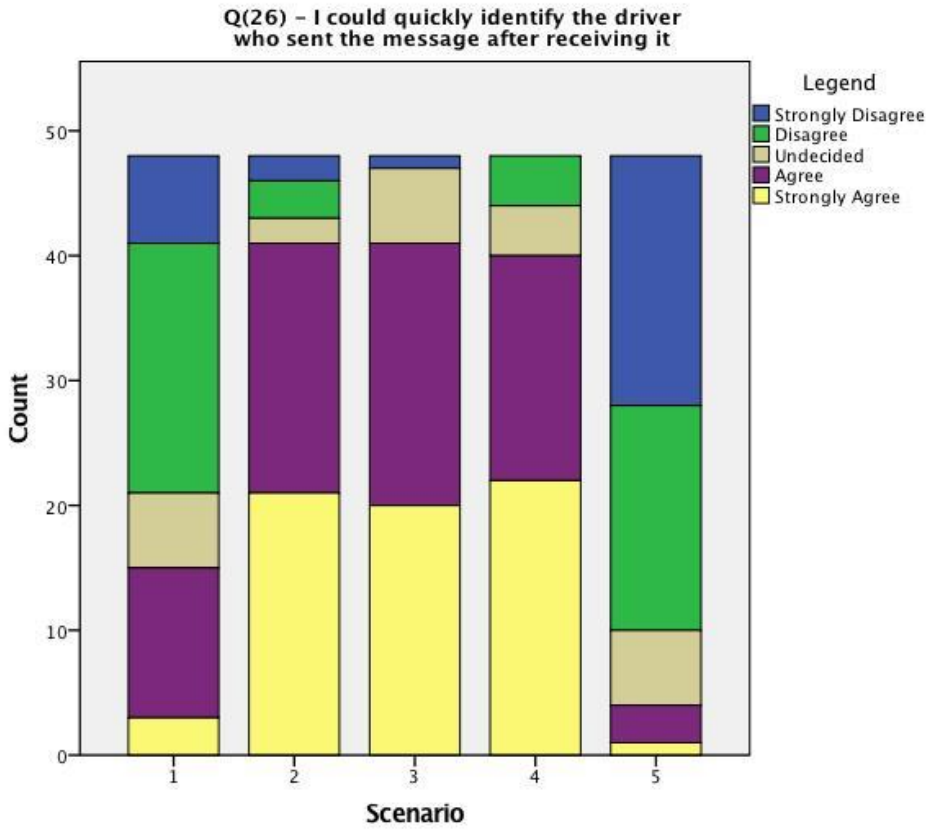


Figure 6.16. Driver-to-driver communication questionnaire – Driver identification

6.2.3.1.6 Auditory design of messages

All messages were presented in both visual and auditory forms. The auditory part of the messages was designed to provide clear information in a succinct way. The auditory part was also designed to provide complete information even if the visual counterpart was not available. Participants were asked if they could understand everything in the auditory part of the message. As can be seen in Figure 6.17, participants agreed in general with this statement for all scenarios. Participants fully understood the auditory content of the message.

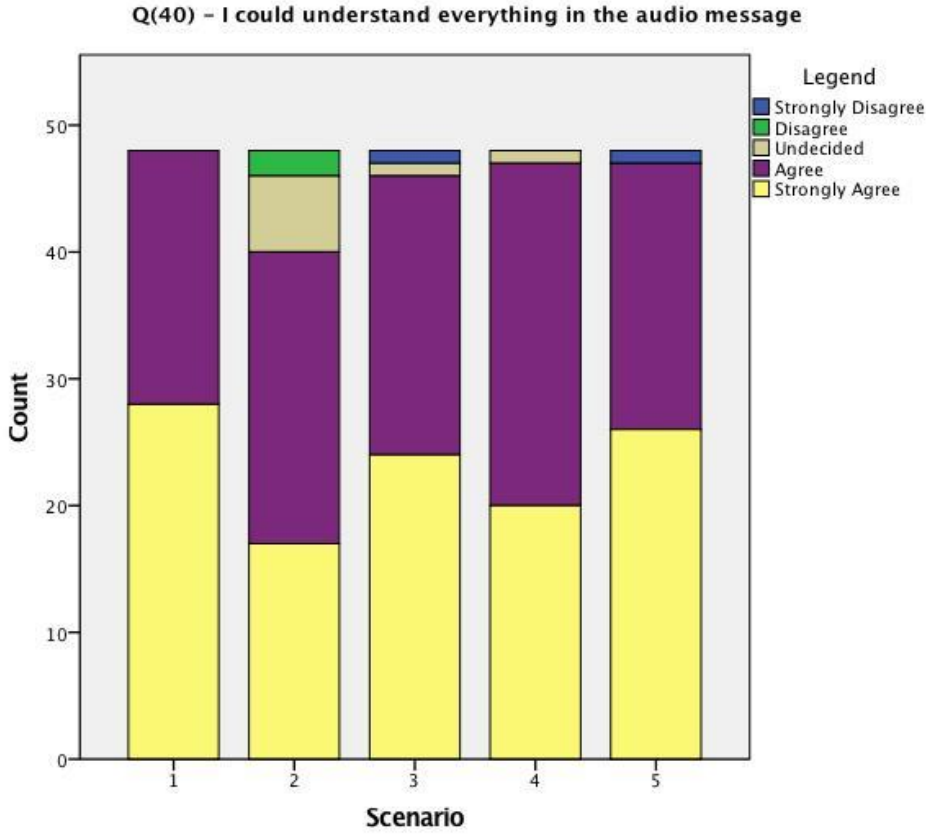


Figure 6.17. Driver-to-driver communication questionnaire – Message understanding

6.2.3.1.7 Duration of message

According to the results presented in Figure 6.18, participants also agreed that the messages were not too long. Messages should be succinct as some situations provide a very short window of interaction for drivers to communicate with each other. Scenarios 02_SOCIAL and 05_PROBLEM were the ones that the messages were longer in duration compared to the others. For these two scenarios, participants' opinions diverged more than the other scenarios. Although the auditory part was clear, a few participants mentioned that speed of speech in scenario 05_PROBLEM was a little slow. Participants also reported that the auditory messages in these two scenarios could be improved if they were shorter.

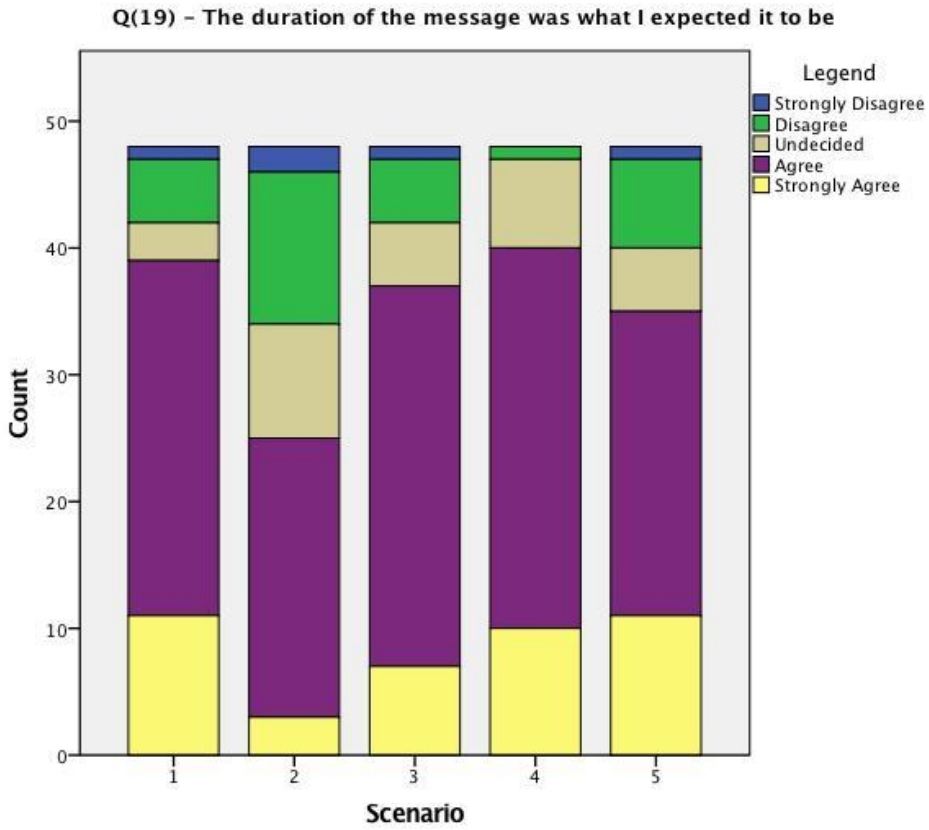


Figure 6.18. Driver-to-driver communication questionnaire – Duration of message

6.2.3.1.8 Voice representation

Results from previous studies described in sections 5.3.2.3.2 and 6.1.3.2 highlighted the significant effects of having the actual voice of the driver versus a pre-recorded voice such as a computer-generated voice. If the driver has the freedom to say anything they want (i.e. free content messages) and their actual voice is transmitted to other drivers, this could not only have an effect on the content of the message, but also the driver will be able to express their personality, emotions and a range of social cues (Large & Burnett, 2013). This can have either positive or negative effects on the outcome of the message and therefore may lead to aggressive driving behaviour.

Emotions can have a decisive effect on the interaction between drivers, as depicted in the driver-to-driver interaction model in section 2.3.2.4. For this study, participants were asked if they could feel the emotional feelings of the driver from the auditory part of the message. As can be seen in Figure 6.19, for scenarios 01_ACCIDENT, 03_SLOW and 05_PROBLEM participants disagreed with this statement reporting that they could not feel any emotional feeling whatsoever. This could be related to the content of these messages that was more informative. The content of these messages was not related to any kind of feelings in particular. In contrast, the content of the messages of scenarios 02_SOCIAL and 04_APOLOGY is more related to emotions. The messages provide a pleasant, social link in scenario 02_SOCIAL and an apologetic tone in scenario 04_APOLOGY. Even though the auditory part of the message in scenario 04_APOLOGY was explicitly designed to supress the driver's feelings, a few participants felt an emotional tone from the content of the message.

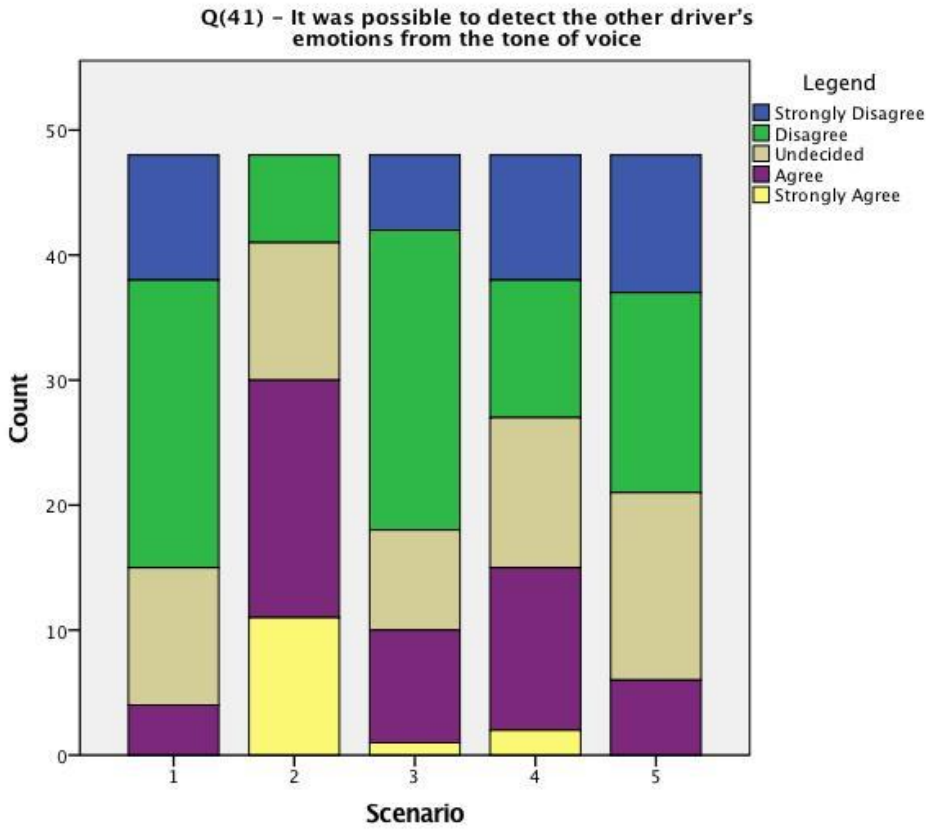


Figure 6.19. Driver-to-driver communication questionnaire – Other driver's emotions

Another topic related to speech systems concerns the type of voice used to present information. Vehicle navigation systems provide different types of voices for their users to choose from with different tone, pitch, gender, language and even personalised voices from special characters of movies. The first exploratory study confirmed the need for the DDCD to have this functionality (see section 5.3.2.3.3). Research has also been carried out on the effect of the type of voice presented in a vehicle navigation system on emotions and driving behaviour (Large & Burnett, 2013), with a mixture of positive and negative feelings, such as trustworthiness and annoyance, for a message presented in an IVNS with the same content, but with different voices.

Participants were asked if they would prefer a different voice to represent the driver's own voice. The results are presented in Figure 6.20. For this specific study, participants

accepted the voice presented to them and would not prefer to have a different voice, although a few male participants mentioned they would prefer to receive a message with a female voice.

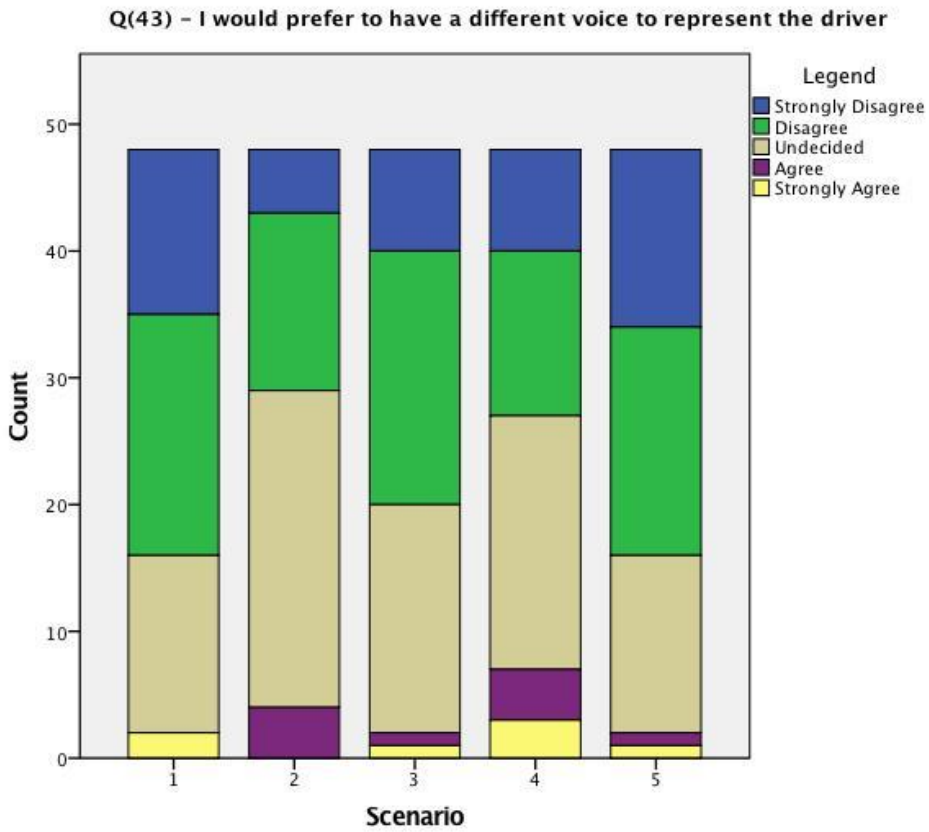


Figure 6.20. Driver-to-driver communication questionnaire – Different voice

6.2.3.1.9 Suggestions on message design

After each driving scenario, participants were asked to provide suggestions on how they would like the message to be. Results from this subjective data are presented in this section, divided according to each driving scenario.

General suggestions

Although some of these comments were made with regard to one specific scenario, they could equally be applied to all of them. Some of the visual symbols were not familiar to

the participants. Therefore, some participants suggested displaying words below each symbol (P30). For one of the participants the visual part of the messages could have been displayed only with words, as they found that the icons were more distracting (P25). The messages could have been flashed instead of displayed only once (P19), to capture the attention of the driver. The visual part of the message could have a humanoid figure to represent a more social interaction between drivers (P21). It was highlighted the importance of clearly designed symbols that drivers from all cultures would easily understand whether they are driving in their home country or abroad (P34).

Scenario 01_ACCIDENT

Some participants reported that the visual symbols presented in the message were unfamiliar and unclear to them (P18, P31, P32). The visual representation also included too many details (P08, P18, P29, P35), which resulted in some of the participants taking a while to understand the content of the message (P18, P23). One participant said that if they were already familiar with the symbols this would not be a problem, but for the first time the message was presented there was a lot to process (P18). Based on the volume of information presented to them, some participants suggested that the message should have been displayed for a longer period (P34, P41). Participants suggested the message should be only auditory (P39), with smaller visual signs (P36).

Results from the previous study with experts highlighted the need for the DDCD to be integrated with other in-vehicle devices such as IVNS and media system (e.g. radio, sound system). This same result was found in this study with regular drivers. Participants pointed out this integration with devices (P21) and suggested leaving all the information related to the accident to be presented by the navigation system. The IVNS could display

an alternative route to avoid the area of the accident. It could also display the speed limit near the accident (P06) and the estimated delay (P05, P24, and P33).

The queue ahead visual symbol (see Figure 6.21) was confusing for one of the participants (P18) and could be replaced by the word "QUEUE" instead (P08). This visual icon, instead of presenting a queue of vehicles could display what actually happened, in this case an accident. The accident could be presented visually by an icon displayed two cars crashing (P20, P26, P28, P31) or by the words "ACCIDENT AHEAD" (P09), which was not presented in visual but only in auditory form.



Figure 6.21. Message representation - Queue ahead

Participants also provided suggestions about the visual icon, which depicts the number of drivers that sent the message to them (see Figure 6.22). The visual icon could display the image of 10 cars instead of only one car with the number 10 inside it (P06). One participant suggested using sticky figures instead of cars (P25), since it was drivers who sent the message. This information was also considered unnecessary by a few participants. It was mentioned that if the message had already been verified by higher authority, there was no need to display the number of cars that sent it (P20, P34, and P39). This information could be presented with a smaller icon for the number of drivers

who sent the message and a bigger checking icon for the verified message (P46) as the verification by the higher authority can be considered more important than the number of drivers who sent the message. Participants also mentioned changing the checking icon (P04) to a similar icon used by another application (i.e. Waze), which they are more used to interacting with (P14).



Figure 6.22. Message representation - Number of drivers

This scenario is more important and crucial compared to the other scenarios as it has an impact on the drivers' journey and their behaviour. Due to this reason, the message should display a warning signal to inform them about the importance of the message (P15, P18, and P47). An example of such an alert could be the sentence "REDUCE SPEED, ATTENTION!".

Scenario 02_SOCIAL

This scenario was considered very distracting with unnecessary information by several participants (P04, P20, P21, P30, P37, and P39). Most participants would not like to socially interact with other road users about a shared interest not related to the driving context. One of them specifically mentioned that the situation would annoy rather than help them (P39). One participant, however, explicitly liked this idea and suggested the possibility of having one option in the DDCD to add the driver to a social network or communication app for later communication (P35).

The thumbs-up visual icon should be excluded, as it was considered unnecessary by some participants (P18, P24, and P26). The sign of the football team would be enough for them to understand that the other driver had a shared interest with them. Moreover, one participant thought that the thumbs-up icon could be misunderstood and indicate that they were connected to a social network (P24).

The auditory part of this message was different to the others as it presented a small part of the popular football team chant. Participants reported that this auditory part should be quieter and more subtle and softer rather than excited and loud (P08, P14, P19).

Scenario 03_SLOW

Most recommendations for this scenario were related to the auditory part of the message. A couple of participants did not see the need to mention that the driver in front was an elderly driver (P04, P26). According to them, the only auditory information needed would be that a slow motorist is driving the vehicle, which could be due to many reasons (e.g. elderly or novice driver, problem with vehicle etc.).

The auditory part was considered too slow (P44). Changes were suggested in the tone of the voice (P39) and also the gender of the speaker (P34). For one participant, it was not clear if the aim of the message was for the main driver (i.e. the participant) to slow down because there was an elderly driver in front or if the message was intended to simply inform them that there was a slow, elderly driver in front of the participant's vehicle (P06).

One participant reported that a stressed driver would overtake the slow vehicle whether the message was presented to them or not. The message could actually make the driver feel even more stressed. One possible solution to this could be to present the following message "Slow, please. Elderly driver. Thank you!" (P35).

Two participants did not like the use of the speech bubble to indicate which vehicle the message came from (P25, P36). Alternatively, a virtual sticker (P17) could be displayed on the back window of the vehicle. The visual sign of two elderly people (see Figure 6.23) should be changed as it represents the idea of pedestrians rather than drivers (P04, P21, P46). One difficult point would be how to display the information of an elderly driver visually. As mentioned before, the use of words such as "Elderly Driver" (P09) or "60+" (P47) alongside the image was encouraged. Another suggestion from a participant was to replace the elderly sign by a yield sign (P18).

Finally, this message could be presented sooner (P10, P35) to avoid accidents. The message was also seen as unnecessary and, according to one participant, should only be sent if there was a mechanical issue with the vehicle that prevents the vehicle from moving faster (P20).



Figure 6.23. Message representation - Elderly sign

Scenario 04_APOLOGY

In this scenario, most suggestions aimed to have a positive impact on the interaction between the two drivers, especially the one behind who would not be happy to have

another driver cutting in front of them. Participants reported that they felt the driver was not truly sorry by the tone of the voice in the auditory message. The tone of voice should be softer (P39), more apologetic (P08), more genuine (P28, P33) and not forced (P33) as it sounded condescending (P21). Similar to the previous scenario, this message could also make the driver more irritated and, according to a few participants, was not useful (P37) and should not have been sent (P20, P31).

The visual representation could be improved by showing a polite gesture with a hand raised next to the word "Sorry" (P10, P15). Any extra piece of information, such as if driver would need to stop the vehicle (P42), could also be presented visually. Finally, it was considered important by one participant to add to the message some sort cordial content (e.g. "It was my fault. Hope I didn't cause you problems") (P47).

Scenario 05_PROBLEM

In this scenario, the visual and auditory parts complemented each other. The auditory part was preferred (P39) as the visual was not clear (P39) and only raised attention to the audio (P35).

The message should display a visual blinking icon (P44) of the whole vehicle showing clearly which door was not closed properly (P14, P15, P17, P18, P20, P24, P30, P44, and P47). The warning symbol should be removed as it denotes something more urgent (P18, P31, P46) which requires a prompt action by the driver. One participant felt unnecessarily stressed by the warning sign (P18). The word "Warning" could be presented instead of the sign (P09).

The auditory part of the message was considered too long (P26, P37) and too slow (P23) by a few participants. This also caused distraction (P37). The auditory alert of the DDCD could mimic what a driver would do without the DDCD. One participant suggested having

the horn honking as an auditory alert (P45). However, the driver may become confused regarding the origin of the auditory alert (i.e. was it coming from the DDCD or the driver of another vehicle actually honking their horns?).

Finally, one participant raised the topic of privacy by stating that this message should not be anonymous (P25). Therefore, it should be displayed like the others with a speech bubble on the vehicle that sent the message.

6.2.3.2 Drivers' acceptance

Results show that scenarios 01_ACCIDENT and 05_PROBLEM have the highest rates of usefulness and satisfaction, while the use of the DDCD in scenario 02_SOCIAL was considered significantly less useful. This highest acceptance rate of the DDCD could be related to the nature of these two scenarios. The messages received in scenarios 01_ACCIDENT and 05_PROBLEM are closely related to the driving context and have a crucial effect on driving behaviour and safety. Figure 6.24 combines both subscales of usefulness and satisfaction for each one of the driving communication scenarios.

Scenario 01_ACCIDENT depicts the situation of an accident ahead where the driver might not be aware of it if the message had not been sent. The accident may have a significant effect on journey time and the route selected. After receiving the message, drivers could make a decision to change their route and avoid the accident. Alternatively, if it was not possible to avoid the accident, drivers would at least be aware that their journey time would take longer than initially expected. These reasons could explain why this scenario has high rates of acceptance of the DDCD.

The door of a vehicle not properly closed poses a significant threat to the safety of the occupants of the car. This can explain why scenario 05_PROBLEM has a higher rate for both usefulness and satisfaction of the DDCD. Drivers would be willing to use the device

in this scenario and would feel satisfied to receive such messages if they experienced these situations. After receiving the message, drivers could then stop in an appropriate place to close the door, and while not reaching this place, at least be aware that the door of the vehicle was not completely closed.

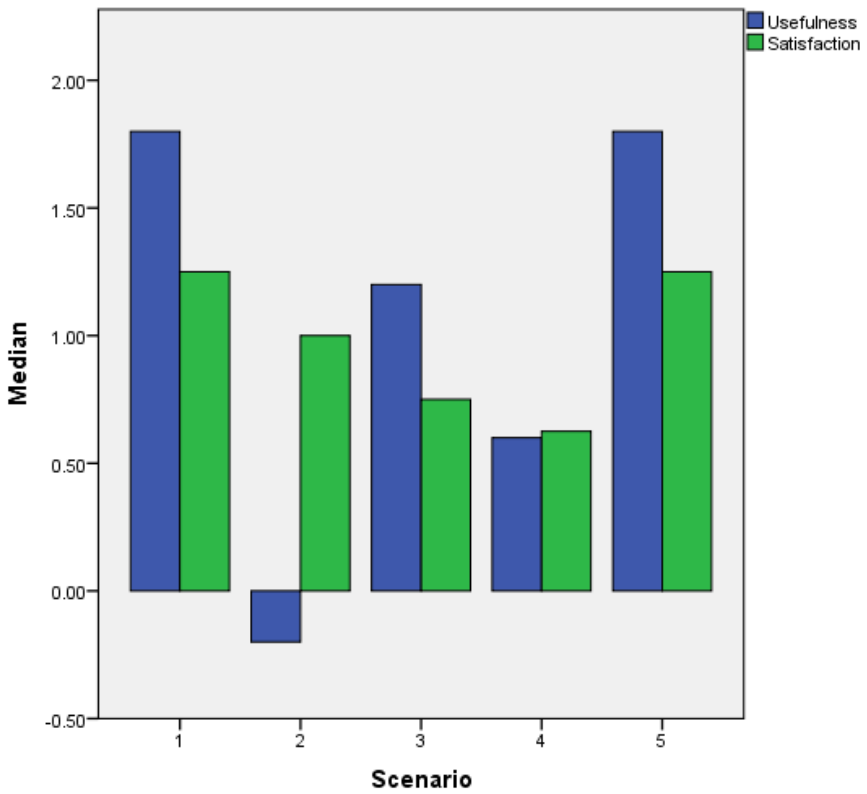


Figure 6.24. Usefulness and satisfaction ratings

Scenario 02_SOCIAL had the lowest rate of usefulness, significantly lower than the other scenarios. This result is in accordance with the previous studies and with participants' suggestions described in section 6.2.3.1.9. Drivers do not want to use the DDCD in scenarios not related to the driving context even if it is a friendly, social interaction with another driver who has a shared interest. Driver distraction was one of the reasons mentioned by participants. However, the satisfaction rating was not low, which could be

explained due to the fun, social aspect of this scenario. Participants felt good and found it fun to receive a friendly message from another driver, but also some of them reported having the possibility of turning it off, especially if other drivers start sending them the same message.

Although the message presented in scenario 04_APOLOGY is related to the driving context, participants had mixed opinions about the acceptance of the DDCD in this situation. While some participants liked receiving the message and the acknowledgement of the driver, others found it unnecessary, not genuine and condescending. Therefore, this scenario did not have higher acceptance ratings when compared to scenarios 01_ACCIDENT and 05_PROBLEM. This result can have an effect on whether apologetic messages should be available on a DDCD and if so, whether drivers would be willing to use them or prefer to have them disabled. Results from a previous study, which are described in section 6.1.3.2, reported that drivers could abuse the device in this situation by making a wrong manoeuvre on purpose and use the apologetic message just to justify their behaviour even though it is not their real intention to apologise.

Finally, yet importantly, results show that the DDCD has an overall positive usefulness rating for scenario 03_SLOW. Without receiving the message, the driver behind would not know why the vehicle in front was driving so slowly. Communicating this situation to the driver behind would be very difficult using traditional means of communication. A DDCD would therefore be useful in this scenario even though the driver behind would not be able to increase their speed after receiving the message.

6.2.3.3 Emotions

Drivers may experience different emotions when receiving messages from other drivers via the DDCD. These emotions could have either a positive or a negative effect on their

interaction with the other drivers and on their driving behaviour. Emotions are represented as a factor which may influence the interaction between drivers in one of the models reviewed in Chapter 02, section 2.3.2.4. It is therefore crucial to understand if these emotions could have an impact on the use of the DDCD in each of the different scenarios, which could discourage its use.

Overall, participants reported a mid-range value for this rating, which would seem to indicate that when they received the messages they did not feel controlled by or in control of the situation. Different results were found for the two dimensions of pleasure and arousal. These results can be better explained and visualized by a pleasure versus arousal space as depicted in Morris (1995). This form of representation showed in Figure 6.25 has been used extensively in the literature and the results can be analysed in terms of which quadrant of Pleasant, Unpleasant, Calm or Excited a situation may fit in.

Based on the graphs, it is possible to see that for scenarios 01_ACCIDENT, 03_SLOW and 04_APOLOGY most of the ratings are within the Calm/Pleasant quadrant. This result shows that the messages did not make participants have unpleasant feelings about receiving them or too excited, which could be a clear and obvious reason for adopting the DDCD in these situations. However, a few ratings for these three scenarios were also found within the Excited/Unpleasant quadrant. Different reasons can explain this for each one of these scenarios.

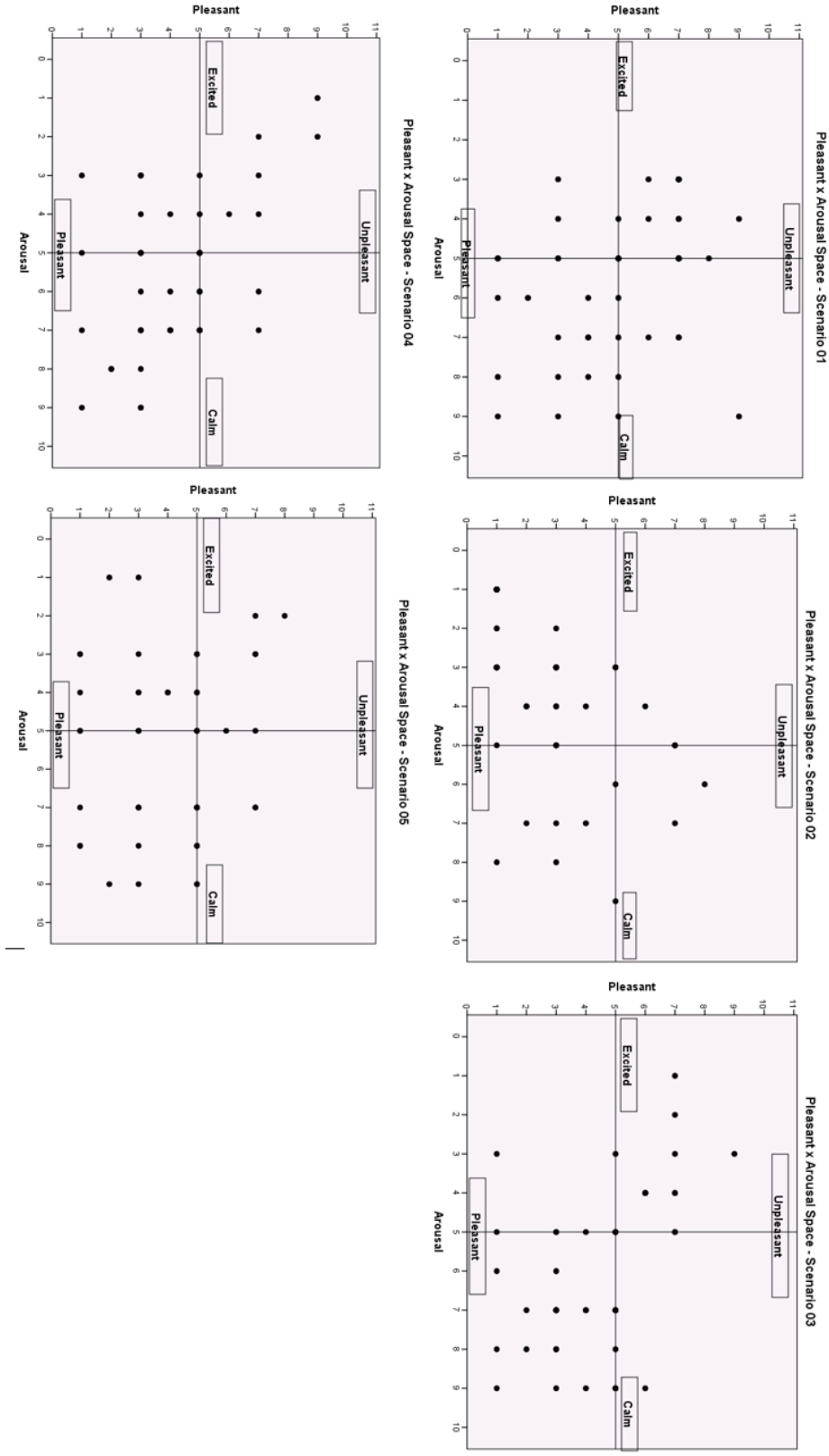


Figure 6.25. Pleasant versus arousal space

Firstly, participants might have rated scenario 01_ACCIDENT in terms of the content of the message and not how the message might have made them more aware and be helpful. This explains why some participants rated their emotion as unpleasant and excited. The information that an accident happened ahead on the road could make drivers feel sad about it and worried about the seriousness of the accident, if it had many causalities etc.

Secondly, the feeling of powerlessness when receiving a message from a slow, elderly driver in front could explain why some participants rated scenario 03_SLOW in the Unpleasant/Excited quadrant. Drivers could do nothing about this situation, as they were unable to overtake the vehicle in front, which was moving too slowly. This unpleasant feeling could make drivers feel more excited in a negative way by trying to overtake the vehicle as soon as it was safe to do so.

Thirdly, other results for the scenario 04_APOLOGY clearly show that participants had mixed feelings and opinions about receiving an apologetic message due to dangerous driving behaviour. A few participants mentioned that they felt the driver was not truly sorry by the tone of the voice in the auditory message. Moreover, participants might have had unpleasant reactions to the action of the other driver (i.e. cutting in front) combined with this apologetic message.

A different result was found in scenario number 02_SOCIAL, in which participants' ratings fit in the Pleasant/Excited quadrants. This is in accordance with what was expected from the nature of this scenario, which is more socially engaged and friendly. A friendly interaction based on a shared interest could have a positive effect on drivers' emotions even though it may cause other issues such as driving distraction.

Most ratings for scenario 05_PROBLEM fall within the lower part of the graph, on the Pleasant scale. However, they are equally divided between the calm and excited spectrum. When receiving a message that the passenger door is not properly closed this

could lead to a feeling of negative excitement as there is imminent danger of the door opening. This could be why some participants felt more excited than others.

6.2.4 Design recommendations

This section describes a set of the design recommendations created based on the results of STUDY C.

Users should be able to block specific types of messages

The results of this user-elicitation study confirmed the previous results of STUDY B that drivers are not interested in sending messages to other drivers with topics outside the driving context. This study confirmed that a social/friendly message had a very low level of acceptability by drivers. Drivers should therefore be able to block specific types of messages either temporarily or permanently. While some drivers might find one category useful or relevant and be willing to receive more of one type of message, others may find it unpleasant with a negative effect on their driving behaviour. Therefore, this functionality is deemed important in a DDCD.

Messages should be designed to minimize workload and driver distraction

Messages with too much visual information are considered to be too distracting, especially if the visual information is new to drivers. Moreover, one unique message should be able to have all the information the driver needs to understand the situation. A balance is therefore needed between the amount of information presented and the need to convey the meaning of the message in the clearest and most succinct way. This also depends on how the visual information is presented, e.g. HUD, integrated with SATNAV system or in an instrument cluster.

Messages should be designed with symbols, which are familiar, immediately recognizable and clear

This study found that some drivers did not know some of the visual representation symbols used in the messages, such as the queue ahead sign. Results show the need to provide textual information below these unfamiliar visual symbols. When designing the messages, it is important to use visual representation that is widely known, especially taking into consideration that the message is not going to be displayed for a long period. The driver needs to interpret the message quickly and without negatively affecting the driving task.

Users should be able to choose the format of message presentation

Clearly, some participants preferred one type of presentation (auditory/visual) to the other for some of the scenarios. The DDCD should be able to allow the driver to choose which mode of presentation they would prefer. This configuration could also be applied temporarily or permanently. Drivers may not be willing to receive the message in an auditory format for one specific journey during which, for example, they are talking to the passengers or listening to music.

Drivers should be able to understand both the visual and auditory part of the message separately. These two parts should be independent of each other and not complement each other. Otherwise, drivers would not be able to capture the full content of the message if they have chosen to disable one of the input modalities.

Audio messages should be clear and customisable

The auditory part of the message should be designed clearly so to avoid any misunderstandings of the message. Auditory information should be limited in length and content. The auditory part of the message should be straight to the point and provide all the information needed without being too long or too verbose.

Drivers should be able to choose which voice is used when receiving messages, similar to route guidance alerts on an IVNS. Different voices with different tone, pitch, language and gender should be available to choose from.

The owner of the vehicle could set up if the messages sent by them should carry out information about the driver gender or not. Further research could be undertaken in the future to determine the effect of the gender of the driver on the outcome of the message. If a vehicle is driven by more than one person (e.g. husband and wife) this functionality would ideally offer a choice of voice gender.

The DDCD should be integrated with other in-vehicle devices

Similar to the previous study, this study confirmed the fact that the DDCD should be integrated with other devices in the vehicle such as IVNS and media systems. The DDCD should be designed in such a way that it makes use of the capabilities of these other devices. For example, information related to alternative route to avoid an accident with the delay time in traffic could be presented on the IVNS, while all the auditory messages could make use of the sound system available in the vehicle.

Information about the message sender should be presented

One important issue to be considered when receiving a message is if the message should display information about the driver who sent it, by providing an indication of the vehicle where the message came from. This could prevent abusive use of the device, if the driver

knows that they will be identified when sending a message. Speech bubbles were used as a visual form of identification of vehicles. This study has not used any kind of auditory form of identification of the vehicle. If the driver opts to receive only auditory messages some sort of indication needs to be presented to them. This could be either the licence plate or physical characteristics of the vehicle.

6.2.5 Conclusion

An electronic message received with a DDCD can make the intentions of the other driver crystal clear. However, before a message is presented to users, it is very important to consider issues such as driver distraction and the willingness of the drivers to receive these categories of messages. Also, the DDCD should be designed in such a way that there is no overload of unnecessary messages, and that no important messages are skipped.

In addition, the messages should be designed in such a way that their content is complete without being too long. Due to the very rapid nature of the communication, while driving, it is important that both auditory and visual contents should not be too long or distracting. Drivers should be able to choose if they want to receive specific types of messages and should be able to choose the best form of representation for this message.

The next chapter describes an exploratory on-road study (STUDY D), designed to understand how drivers naturally identify any single vehicle around them. According to the task analysis designed earlier in this research, vehicle identification is a very important task required by drivers when sending a message using the DDCD.

7 The task of vehicle identification (STUDY D)

7.1 Introduction

Driver-to-driver communication comprises of an exchange of messages. Drivers, using a hypothetical device, send messages, which will be received by other motorists. However, before completing the process of sending a message, the driver needs to clearly identify which vehicle will receive the message. The task analysis presented in Chapter 04 showed that identifying the vehicle to send a message to is one of the main tasks required by users when interacting with the DDCD.

> Passenger: "Wow, I wish I had a car like that!"
>
> Driver: "Which car do you mean?"
>
> Passenger: "A car like that red Ferrari [point to car] that has just overtaken us."

According to the theory of communication grounding, some human conversations aim to establish referential identity with a mutual belief that the parties involved have correctly identified the same referent (Clark & Brennan, 1991). Several techniques are available for this type of content. The most relevant for driver-to-driver communication are employing indicative gestures (Clark et al., 1983) and providing descriptions that would match the referent in question (Isaacs & Clark, 1987). An example of these two techniques can be seen in the dialogue box below, which depicts a conversation between a driver and a passenger:

Similar to this type of communication between a driver and a passenger, the interaction between the driver and the vehicle identification system (VIS) could use a similar approach. The driver would initially inform the system of their intention to start the

process of sending a message. The system would ask which specific vehicle/s the driver would like to send a message to. The driver would then use one of the two techniques suggested by (Clark & Brennan, 1991) to inform the system of the chosen vehicle.

> Driver: "I would like to send a message [to that vehicle]"
>
> System: "Which vehicle would you like to send a message to?"
>
> **Driver: [identify the vehicle to the system]**

This chapter focuses on how the driver can identify a single vehicle to the system. Drivers could identify the vehicle to the VIS in several ways. Based on the theory of communication grounding, it is hypothesized that drivers could identify vehicles to the VIS more naturally by interacting with speech recognition systems and/or finger pointing gesture recognition systems.

Finger pointing gestures have several applications for the driving context. One previous research study explored different scenarios where pointing could be used in a vehicle, working as part of the navigation system, performing tasks such as to narrow down points of interests(POIs), to get more information about a specific POI, to mark a POI with a tag or to share this POI with social network (Rümelin, Marouane, & Butz, 2013). Finger-pointing has also been previously used to operate controls in vehicles (Cairnie, Ricketts, McKenna, & McAllister, 2000) and to select menus (Alpern & Minardo, 2003).

Speech interfaces have also been incorporated by the automotive industry in recent years. The most common applications supported include navigation, music selection and mobile communication (Lo & Green, 2013).

This study only focuses on the identification of a single vehicle. Drivers provided descriptions, which most of the time were applicable to only one vehicle. Therefore, in this case the cardinality of drivers' interaction presented in the communication

framework is one-to-one. The identification of multiple vehicles at the same time may require a different approach and this was not covered in this study. Further research would be required to investigate possible ways for drivers to identify more than one vehicle at the same time. An unpublished academic paper on this study was submitted to the 2017 University Transport Studies Group Annual Conference (Lamas, 2017).

7.1.1 Study aims

An on-road exploratory study was designed to investigate how drivers would naturally and instinctively identify any vehicle nearby to a hypothetical VIS. The study had two overall aims. The first aim of the study is to provide a list of design recommendations for a VIS, which addresses the same overall aim of this research. The second aim of the study is to produce a vehicle identification taxonomy based on the results. These recommendations and taxonomy would be particularly useful to developers and designers of vehicle HMIs and to industry manufacturers who could make use of these guidelines to provide cars with VIS.

In order to achieve both aims, four objectives were established for this study. The first objective is to find the most natural way to identify a vehicle. Based on the review of the literature on communication grounding, vehicle identification via speech, indicative gestures or a combination of both would appear to be the most natural means of identification. The second objective of this study is to identify the most commonly used descriptors or vehicle characteristics used by drivers. The number of descriptors used in a unique identification and their sequence are also investigated. The third objective of the study is to capture the types of gestures most used and the frequency of use. The last objective of this study is to understand the types of identification issues that could occur and how these issues can be addressed. These four objectives are closely related to how

drivers might interact with a VIS and therefore contribute to fulfilling one of the aims of this research, which is to explore alternative HMIs for the electronic device (OBJ 05).

7.2 Method

7.2.1 Participants

A convenience sample of ten participants (six female, four male) took part in the study. Participants were recruited on the basis that they must hold a valid UK driving license and be a native English speaker or have a very high level of proficiency in English. Their ages ranged from 21 to 53 (mean= 37, SD = 12.5) with an average of 15 years' driving experience. Participants reported that they drove regularly on average for at least 60 minutes a week, with an average annual mileage of 7000 miles. The whole study lasted no longer than 45 minutes and took place in an instrumented vehicle authorised by the university.

7.2.2 Procedure

Firstly, after reading the information sheet, participants were asked to read and sign a consent form. Participants were also asked to fill in a short general demographic questionnaire (see Appendix viii page 376). Participants then had a short practice session, with the vehicle still stationary, during which they were asked to identify some vehicles. The vehicles identified for this training session were the ones parked nearby. Participants were told to feel free to ask any questions before the actual study began.

In the main study, participants were seated in the passenger seat of a car, which was driven along a route through Nottingham, near to the University campus. The PhD researcher sat in the back seat of the vehicle taking notes. Another researcher from the University of Nottingham drove the vehicle, always following the same route (see Figure 7.1). The route comprised a variety of areas and road types, such as dual carriageways,

single carriageways, roundabouts, urban roads, roads in 20mph zones, etc. This route was shown to the participants prior to the study. Participants were allowed to ask the researcher in the back seat, and not the driver, for further instructions if they were unsure about any aspect of the study.

Participants were informed that they had to assume that there was a system in the vehicle, which they would be able to communicate with during the journey. The purpose of the system is to send messages to other vehicles in the vicinity. Participants had to identify these vehicles to enable the system to know where to direct the communication.

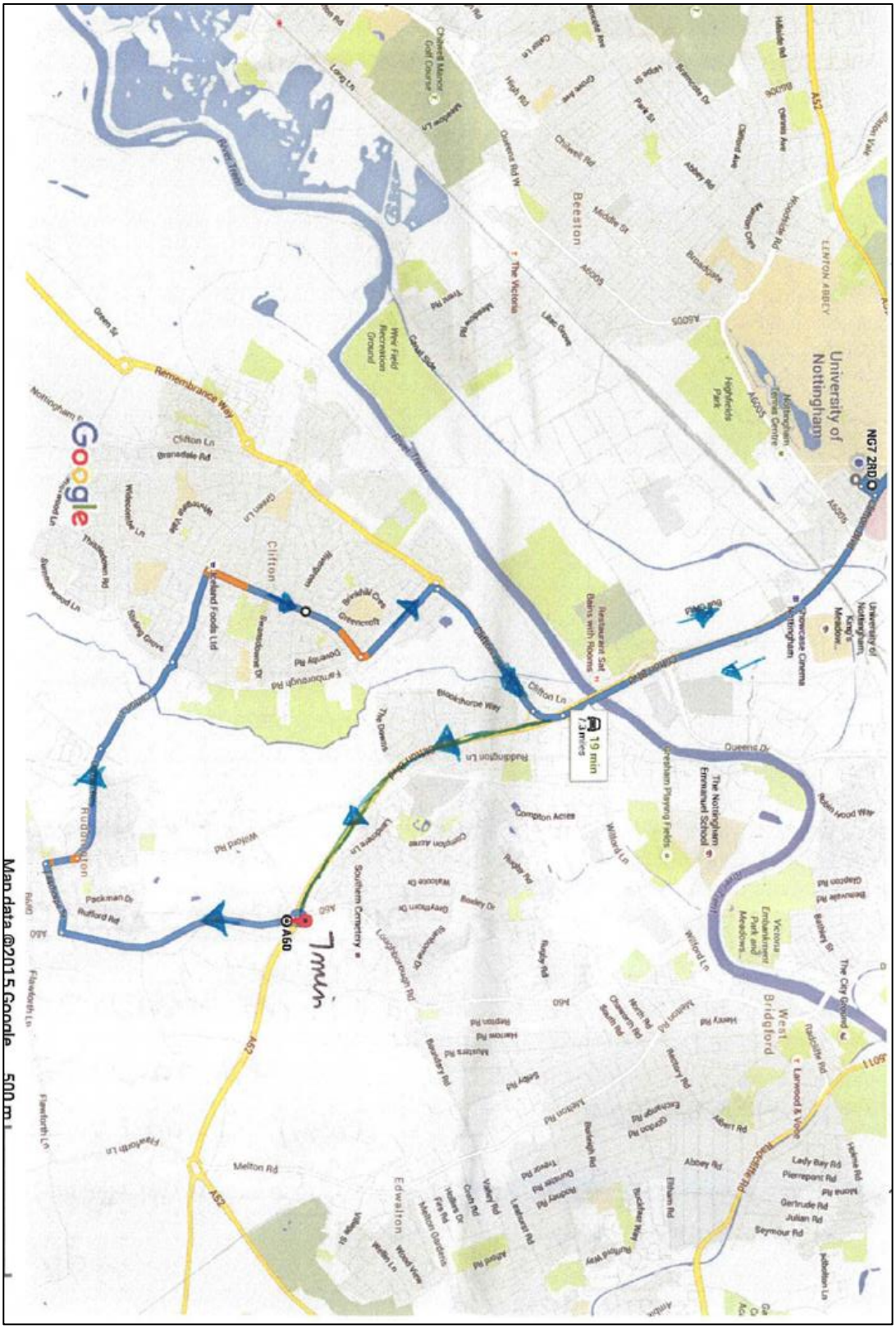


Figure 7.1. On-road study route

During the session, participants were prompted by an auditory alert (a beep) at random time intervals. The researcher in the back seat controlled the beeps. At the sound of the beep, participants chose a single vehicle close by and demonstrated how they would identify that vehicle to the system quickly, and in a natural and instinctive way. The researcher only played the beep when he was sure there was at least one vehicle nearby that the participants could identify. The vehicle they chose to identify was located anywhere around them in the road environment – i.e. it could be in front, behind, on same side of road or opposite, moving or parked, etc. Participants were asked, if possible, to identify a different vehicle each time and only one vehicle per beep. They were asked to do this in what they believe was the most instinctive way in each instance. Participants were also asked to identify only motorised vehicles (not pedestrians or cyclists).

An extra rear-view mirror was placed on the windscreen in front of the participants, so they could identify any vehicles behind the car. They were asked to adjust this rear-view mirror before the study started. During the study, participants were audio- and video-recorded. They wore eye-tracking glasses to capture eye movements. The eye tracking glasses were used in this study only as a video camera to record where participants were looking all the time. A video camera was also placed in front of the participant on the dashboard to capture possible gestures (see Figure 7.2). The whole journey took approximately 30 minutes and ended when they arrived back at the starting point on campus. At the end of the study, participants were asked some questions about the way they identified some of the vehicles and if they would have done anything differently in retrospect.

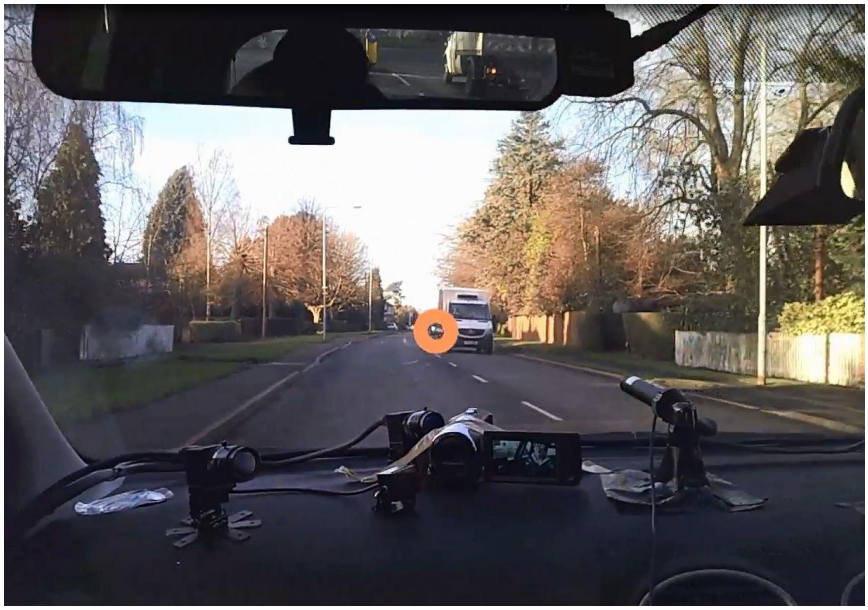


Figure 7.2. Study setup including eye tracking trace

Participants were free to stop participating in the study at any time for any reason, without penalty. If they wished to stop, they would be driven back to the pickup point at the university campus. They were paid £10 in shopping vouchers for their participation.

7.3 Analysis

According to the Oxford English Dictionary (1989), a descriptor is: "a word or expression used to describe or identify something". Although this definition implies only identifications using language, the word descriptor is used extensively in this document to explain all types of descriptions used by participants to identify a vehicle, whether it was a verbal description or identification with a gesture.

A formal iterative analysis technique for qualitative data, described in section 3.10, was used, which is based on the demarcation of words/short sentences (i.e. codes) linked back to the research aims (Hignett, 2010). Before starting the analysis, a list of main codes was produced based on the expected descriptors that were going to be used by the participants, including "vehicle colour", "vehicle location", "vehicle classification" and "vehicle number plate". The researcher then analysed the transcripts for each participant.

More codes related to unexpected descriptors were created during this process. The coding process continued in order to find common themes. The final data was reduced to a set of codes based not only on all descriptors used, but also on issues that arose during the identification process such as visual limitation and errors in identification.

7.3.1 Inter-observer agreement

Inter-observer agreement can be defined as the extent to which two or more observers obtain the same results when they independently code the same part of data (Robson, 2002). Having a good inter-observer agreement is a confirmation that the list of codes is clear and has not been applied in an unusual or unconventional way. For this study, another researcher coded the videos of two participants (around 20% of the data).

There are two ways to measure the inter-observer agreement, with some debate about the merits of each approach in the literature. This involves either the calculation of the degree of correlation between the two sets of measurements or the calculation of agreement between them (Robson, 2002). For this study, a concordance measure using Cohen's Kappa coefficient was used. This method is used extensively in the literature and according to Bakeman and Gottman (1997) it is particularly valuable in sequential analysis involving coding over time. This method also corrects for chance agreement. The software package *NVivo 10* was used in the analysis including the inter-observer agreement and the calculation of the Kappa coefficient. The following 'rules of thumb' presented in Table 7.1 regarding the value of the Kappa coefficient was suggested by Fleiss, Levin, and Paik (2013):

Table 7.1. Kappa coefficient values

Kappa value	Interpretation
Below 0.40	Poor agreement
Between 0.40 and 0.60	Fair agreement
Between 0.60 and 0.75	Good agreement
Above 0.75	Excellent agreement

The Kappa coefficient for this study was 0.75, which can be considered an excellent agreement. This value was based on an average for all codes and transcription sizes, and it was weighted by transcription size. A Kappa coefficient of 0.89 was found for all codes and transcription size unweighted.

7.4 Results

7.4.1 Frequency of descriptors

The main measure used in the analysis was frequency count. Initially, a list of descriptors was created based on all the words, expressions or gestures used in all 411 unique vehicle identifications (average of 41 identifications per participant). The descriptors were then coded for each of their occurrences in the transcript. classification of the vehicle.

Table 7.2 shows the number of occurrences of each descriptor by descending order and examples of each one of them. As can be seen, the three most common descriptors used were colour, location and classification of the vehicle.

Table 7.2. Frequency and examples of descriptors

Descriptor	Example	Frequency
Vehicle colour	Yellow, red, greenish, bright blue	319
Vehicle location	In front, at traffic lights, in left lane	316
Vehicle classification	Car, lorry, bus, van, people-carrier, saloon	230
Vehicle make	Toyota, VW, Renault	148
Vehicle action	Approaching, overtaking, passing	92
Vehicle model	Auris, Golf, Scenic	58
Vehicle exterior	Boots lorry, … with a crane on top, 4-door, lights on	43
Vehicle direction of movement	Oncoming, same direction	37
Time of identification	Just now	31
Vehicle number plate	RV13 RXW, R reg., 2013 plate, plate ends with VO	30
Vehicle size	Big, small, single-decker	28
Vehicle no movement	Stopped, parked	26
Specific type of vehicle or vehicle with specific function	Taxi, ambulance, construction van	18
Previous identification of same vehicle	Still following, the same car	11
Vehicle age	Old, new	3
Comparison to other well-known vehicles	Royal mail type, jeep-type	2
Driver or passenger identification	Three old people in it	2

7.4.2 Number of descriptors

An analysis was also done on the number of distinct descriptors used in each unique vehicle identification. This was important to understand how many descriptors participants felt were needed to clearly identify a vehicle to send a message. An example of identification that used three descriptors is "Blue Toyota in front", which used one colour descriptor, one make descriptor and one location descriptor. Figure 7.3 shows a graph with the number of descriptors used. Descriptive statistics are presented in Table 7.3.

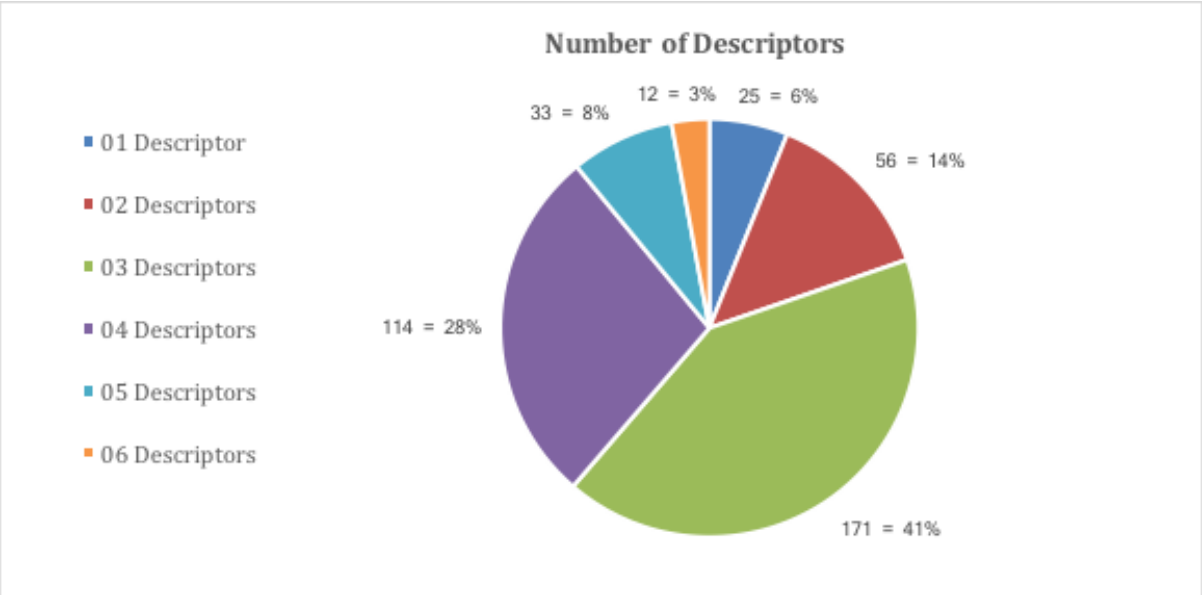


Figure 7.3. Frequency of number of descriptors

Table 7.3. Descriptive statistics - Number of descriptors

Mean	Variance	SD	CV
3.27	1.17	1.08	33%

In 171 distinct and unique vehicle identifications, three descriptors were used. This was the most frequent number of different descriptors used. The seven most used descriptors

also had more occurrences in three-descriptor identification as Table 7.4 and Figure 7.4 show.

Table 7.4. Number of descriptors by type

DESCRIPTOR	NUMBER OF DESCRIPTORS						TOTAL
	01	02	03	04	05	06	
Vehicle colour	0	37	143	97	33	9	319
Vehicle location	25	19	109	101	35	15	304
Vehicle classification	0	25	116	66	18	5	230
Vehicle make	0	13	53	53	19	10	148
Vehicle action	0	9	42	26	12	3	92
Vehicle model	0	4	12	23	13	6	58
Vehicle exterior	0	3	14	18	6	2	43

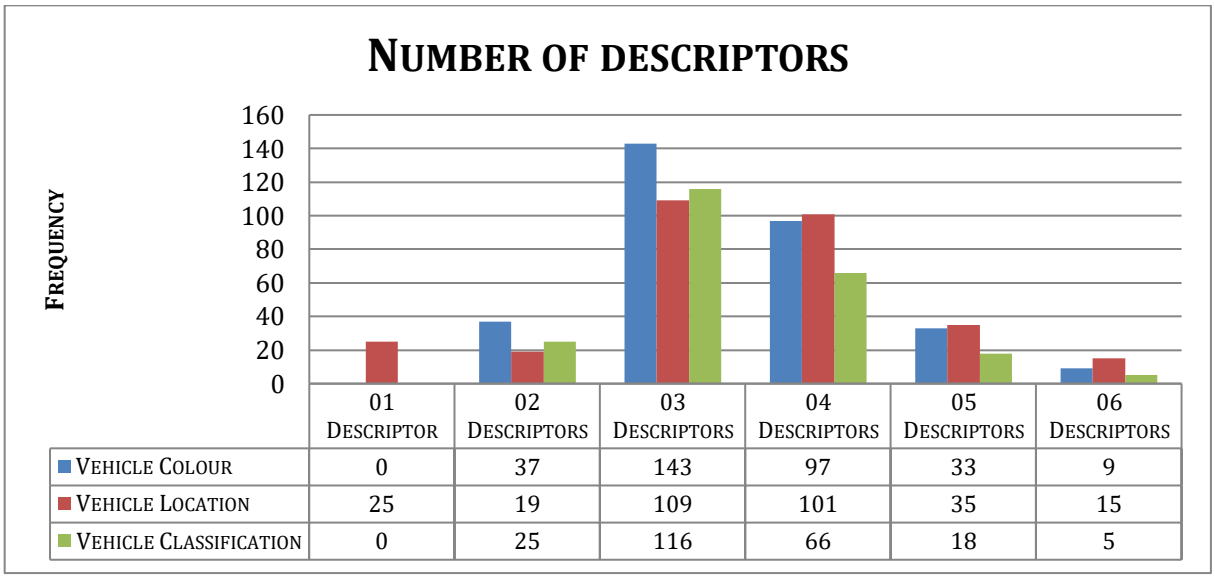


Figure 7.4. Number of descriptors

7.4.3 Sequence of descriptors

One important piece of information when identifying a vehicle is related to the sequence in which descriptors were used. Table 7.5 shows the sequence of descriptors for the seven most frequently used descriptors.

Table 7.5. Frequency of sequence of descriptors

DESCRIPTORS	SEQUENCE OF DESCRIPTORS						TOTAL
	1st	2nd	3rd	4th	5th	6th	
Vehicle colour	218	59	28	10	4	0	319
Vehicle location	57	25	126	76	23	9	316
Vehicle classification	30	134	58	6	2	0	230
Vehicle make	46	81	16	4	1	0	148
Vehicle action	15	19	42	14	2	0	92
Vehicle model	3	32	18	4	1	0	58
Vehicle exterior	15	8	5	13	2	0	43

Based on the results presented so far, it is possible to identify a pattern of identification which comprises of the triad COLOUR + CLASSIFICATION + LOCATION in this order as the most frequent form of identification of a vehicle as presented in Figure 7.5.

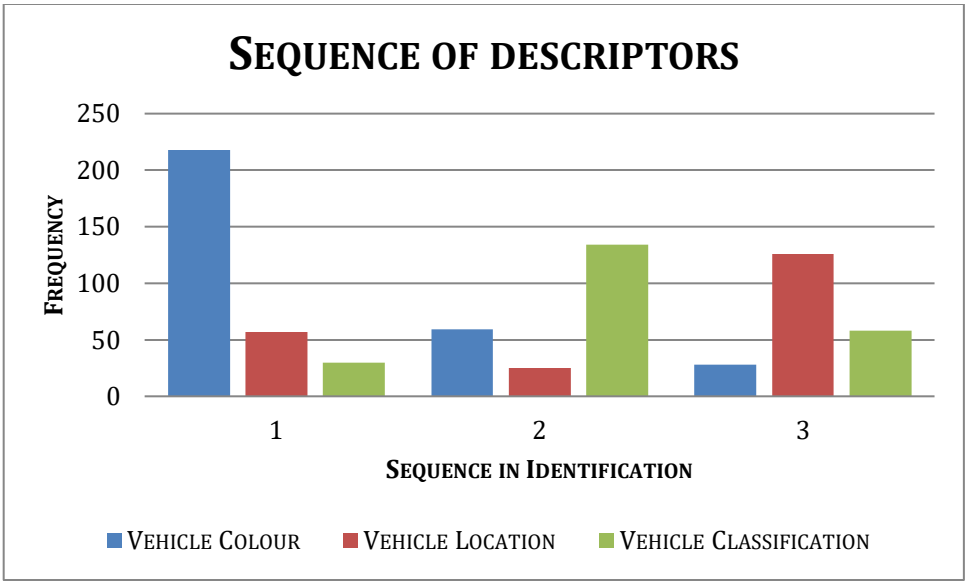


Figure 7.5. Sequence of descriptors

7.4.4 Connections between descriptors

Cluster Analysis is a form of data visualisation, usually represented as a diagram that clusters selected data together if they are similar on selected characteristics. Cluster analysis was applied to check the relationship between descriptors for all participants. The seven most commonly used descriptors all have strong connections between themselves with a value of 1 for Jaccard's coefficient (see Figure 7.6). This value indicates that occurrences for all seven descriptors were found with same relevance in all participants' transcripts.

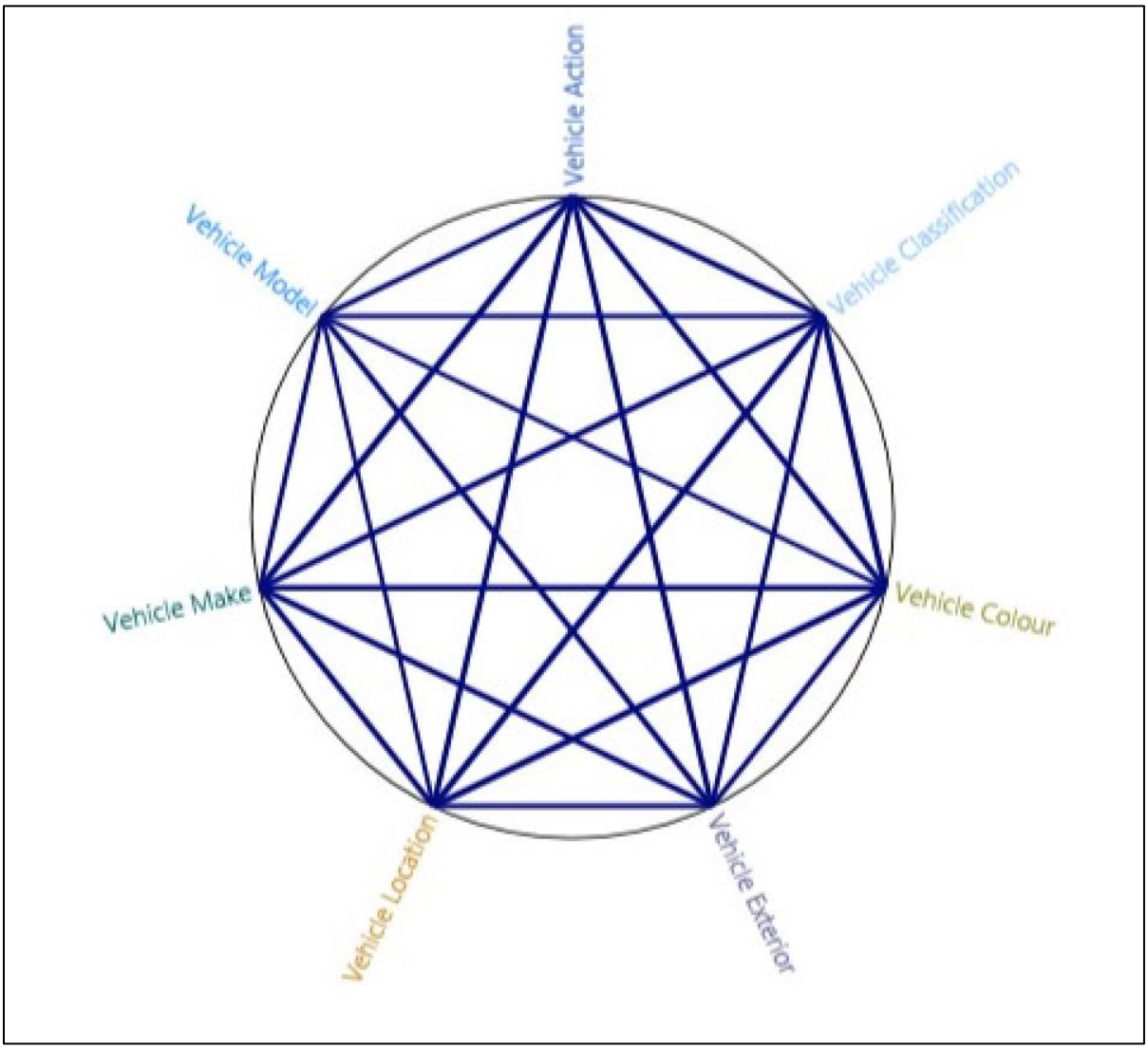


Figure 7.6. Cluster analysis - 7 descriptors

The cluster analysis of all the descriptors coded shows that some of these descriptors did not have strong connections with others (see Figure 7.7). Some of these descriptors, such as driver/passenger identification and comparison to other well-known vehicles, have no connection whatsoever to any other descriptor, which may indicate that they were used sparingly by only a few participants.

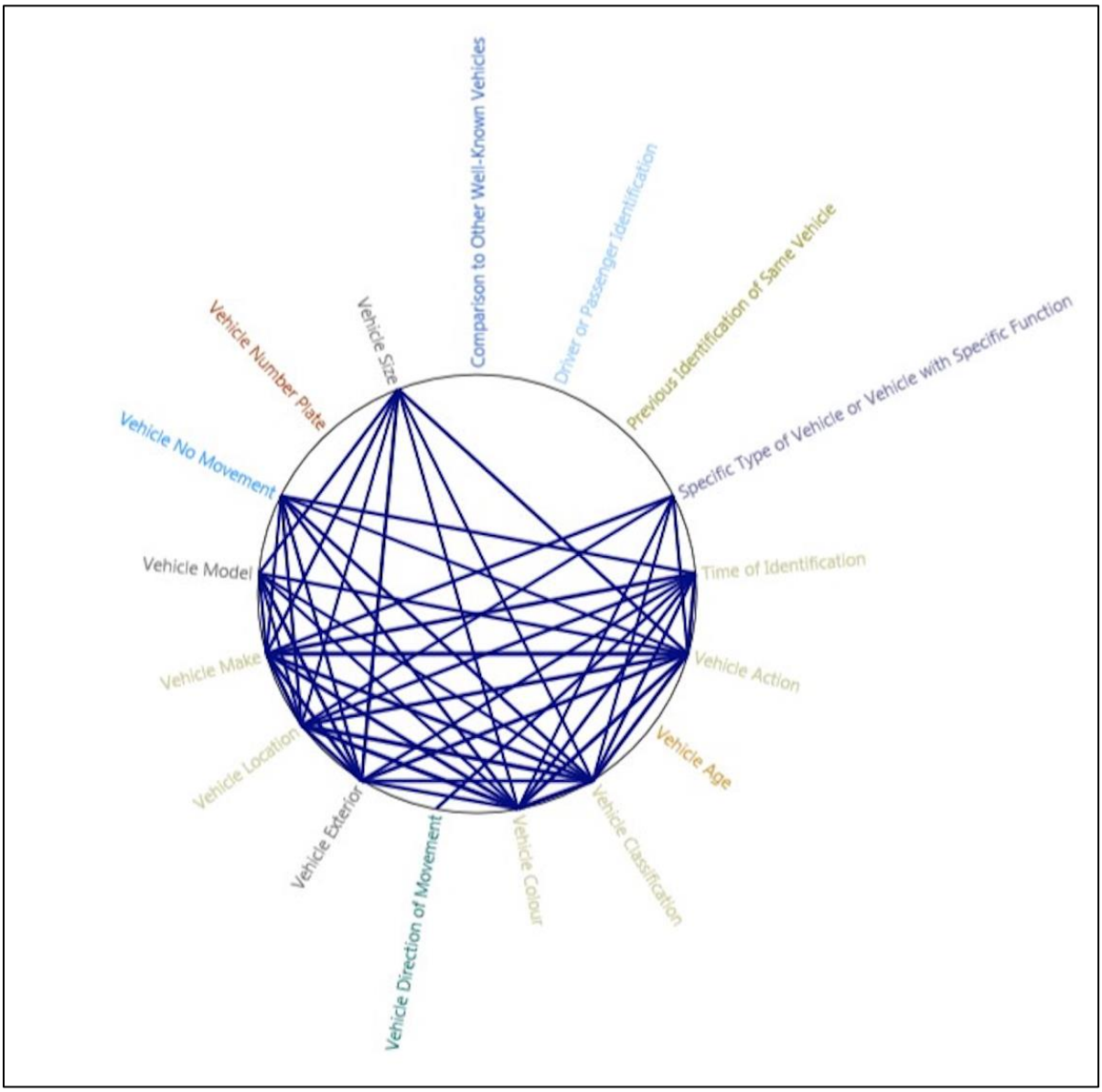


Figure 7.7. Cluster analysis - All descriptors

7.4.5 Gestural descriptors

Fifty-six gestures were used to identify vehicles. These gestures were all classified as location descriptors. Contrary to some verbal descriptors like vehicle colour and classification, which were equally used by all participants, gestures were frequently used by only two participants. Two other participants also used gestures, but only once in their identification. Gestures could be grouped in different ways. Gestures were initially grouped by body part (see Table 7.6), with most of the gestures being hand gestures, while only three of them involved the use of the head.

Table 7.6. Gestures - Body part

Body part	Frequency
Hand	53
Head	3
Total	56

Hand gestures could also be represented in different ways. Most of the gestures used by participants were a pointing gesture with one finger, either the index finger to point to a vehicle in front or the thumb to point to a vehicle behind (see Figure 7.8)

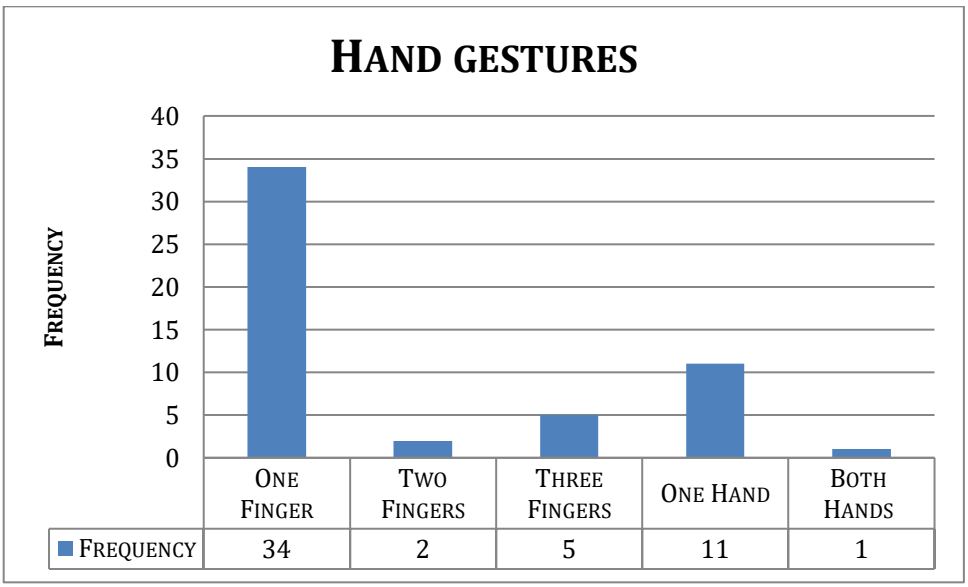


Figure 7.8. Hand gestures

Gestures were also classified according to whether they involved movement or if they were still. Based on this classification Table 7.7 shows how many gestures of each of these categories were made.

Table 7.7. Gestures - Movement

Type of gesture	Frequency
Movement	12
No movement	44
Total	56

7.4.6 Issues in identification

Some key major issues were found when participants tried to identify a vehicle. These issues are described in more details in the subsections below with their frequency of occurrence.

7.4.6.1 Errors in identification

The first and most important issue found when identifying a vehicle relates to errors in one or more descriptors used in the identification. These errors were either corrected by the participant immediately afterwards or not. Careful analysis of the video footage was subsequently made to identify and code the errors. If there was any doubt about any identification provided, this was not coded as an error. Figure 7.9 shows the number of errors made for each descriptor category. This result clearly shows that participants made more errors when they were trying to use the make of the vehicle as one descriptor. One participant even gave a personal comment regarding this: *"I am not so good at Japanese cars" (P03).*

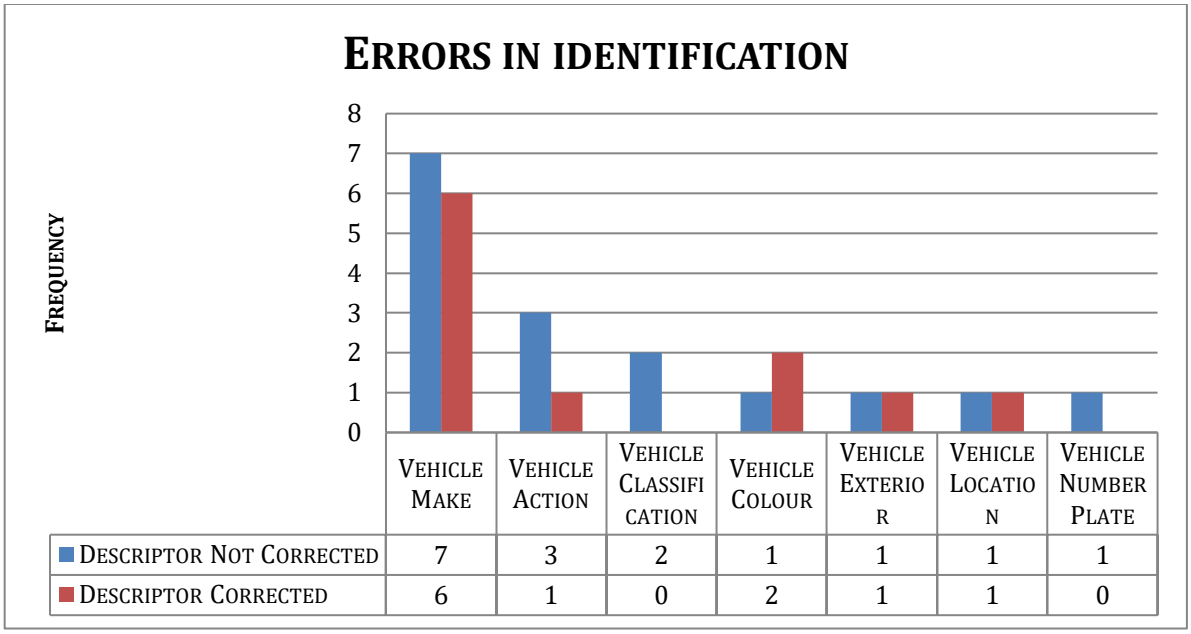


Figure 7.9. Errors in vehicle identification

7.4.6.2 Uncertainty in identification

Sometimes participants were not sure if the content of the descriptors they were using was correct or not. They also used vague words such as "something" or "thing" when they did not know exactly the content of the descriptor. Figure 7.10 shows for which categories of descriptors this uncertainty of identification happened more often.

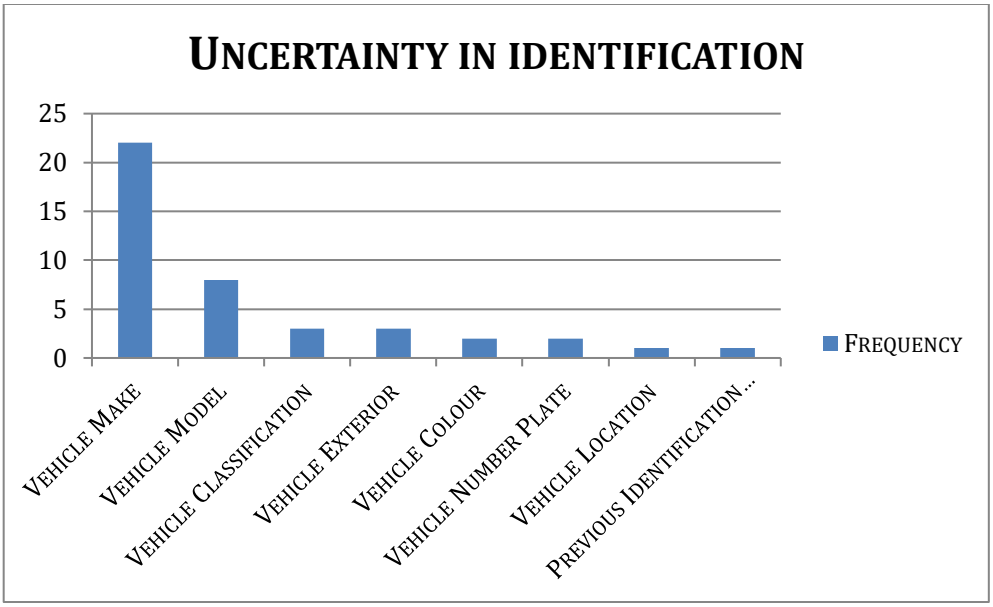


Figure 7.10. Uncertainty in vehicle identification

7.4.6.3 Repetition of descriptors

Another issue found when participants tried to identify vehicles relates to the repetition of descriptors. This repetition mainly occurred when participants added an extra descriptor after verbalising other descriptors before (e.g. "Jaguar, the maroon-coloured jaguar", "Truck on the right, blue truck", "Juke, Nissan Juke"). One participant also made use of repetition when they corrected erroneous information they had given (e.g. "Nissan gold…oh no Vauxhall gold"). Figure 7.11 shows the total number of instances in which this repetition occurred and with which categories of descriptors.

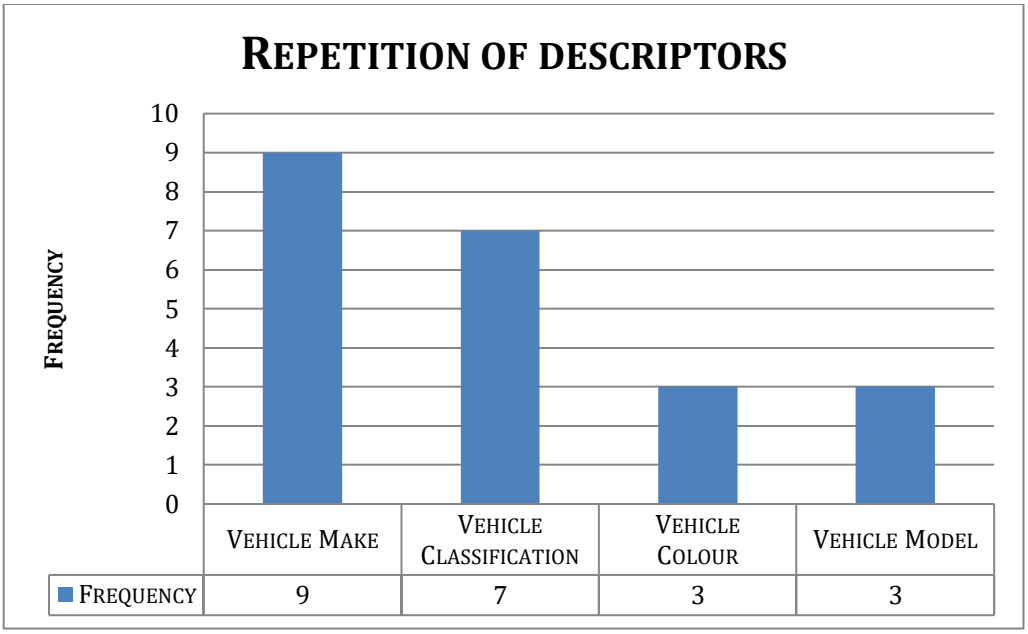


Figure 7.11. Repetition of descriptors

7.4.6.4 Non-unique identification

One important aspect to consider when identifying a vehicle to send a message is that the description provided to the system makes a unique identification; otherwise, the system may not be able to target the message to one vehicle only as there could be more than one vehicle nearby with the same characteristics provided.

A non-unique identification of the vehicle, which can be considered a type of an error in the identification process, occurred 35 times during the study, even though participants were clearly informed that they should identify a single and unique vehicle nearby. These identifications varied widely from the number of descriptors used, from either only one gestural descriptor (e.g. pointing in front) to four descriptors (e.g. "grey car parked on the left") as Figure 7.12 shows.

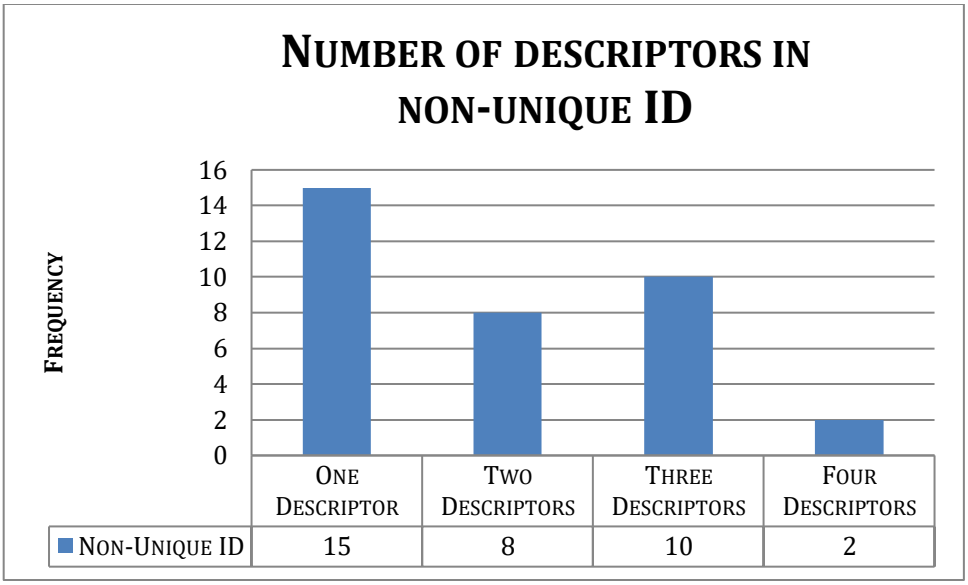


Figure 7.12. Number of descriptors in non-unique ID

7.5 Discussion

This chapter presents a study which aimed to investigate how drivers identify any single vehicle nearby and how this could lead to HMI requirements for a vehicle identification system. The most commonly used descriptors to identify vehicles were discovered as well as some issues in this process of identification. The next subsections focus on the discussion of some of these issues and also on different interaction mechanisms for the VIS, using gestures and natural language.

7.5.1 Visual limitations

Participants found it difficult to provide any descriptions of a vehicle in situations with poor visibility. This condition happened mostly due to the increased distance to the vehicle in front, which made it difficult for the participants to read the information about the make and model of the vehicle or its licence plate. In addition, in a few cases, the bright sunlight had a negative effect on one participant; they mentioned, "I can't see properly because of the sun" (P10). The effects of bright sun or darkness at night have a negative effect on clear identification of objects according to Wickens et al. (1998).

Even though the researcher made sure that there was always a vehicle to be identified nearby at the moment he played the beep, a few participants surprisingly also had difficulties sometimes finding a vehicle to be identified. This limitation happened in situations where there was apparently no external visual limitation at all such as poor weather conditions or barriers on a dual carriageway that could have prevented participants from seeing oncoming vehicles.

7.5.2 Natural language

Speech recognition systems have become more technologically advanced each year. However, the language between a human being and the speech recognition system is still quite different from a natural language between two human beings (Lo & Green, 2013). This difference between a more natural language and a slower, synthesised language used to communicate with a speech-recognition system was also mentioned by one of the participants in the post-study interview session. This participant mentioned they would describe the same vehicle in different ways depending on whether it was to a friend or to a machine.

All participants were clearly instructed to provide their identification to a hypothetical and imaginary device available in the vehicle. Even so, most of them made use of long verbal sentences with articles and prepositions with more natural language as they would if they trying to identify the vehicle to another human being instead of to a computer system (e.g." The blue Ford on the other side of the road", versus "Blue Ford other side"). Participants also added personal comments in the form of adjectives in some situations (e.g. "That horrible green van", "the nice silver Bentley").

7.5.3 Oncoming vehicles

Most vehicles identified were the ones following the same route as the participants. Out of a total of 316 identifications that used the location descriptor, only 34 referred to oncoming vehicles. Oncoming vehicles are very difficult to identify especially on motorways and dual carriageways with a space or barrier separating the lanes. The speed of the vehicle and this spatial barrier make it quite difficult to clearly identify a vehicle and to finish the whole process of sending a message in a reasonable amount of time. This difficulty was also mentioned by one of the participants during a post-interview. This complex situation to deal with imposes a restriction of possible use case scenarios for the communication device.

7.5.4 Gestures

Most gestures involved no movement whatsoever during the continuation stage. Interestingly, however, with some of the gestures which involved movement, the participants used their fingers to follow the vehicle (see Figure 7.13). This novel gesture expands the descriptor, not only with a more precise location of the vehicle but also with its action (vehicle movement). This natural gesture is more precise because it combines both the vehicle location and its current speed. However, the system would need to be able to track the movement of all vehicles nearby in order for this action to be accomplished successfully.

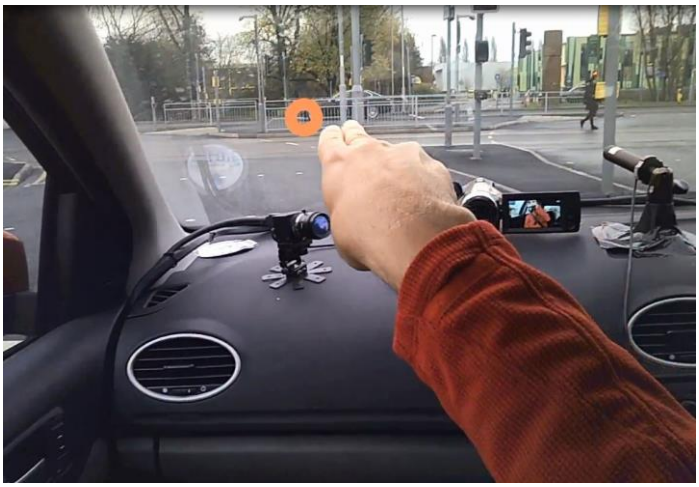


Figure 7.13. Gesture - Pointing in front moving

Another gesture, which involved movement, was used to identify vehicles in the distance. The participant performed a pointing gesture with the index finger, which was moved back and forth four times to make it clear that it was not the first vehicle in front, but four vehicles ahead. A head-rotating gesture was also used. Gestures using the head might be more appropriate to the driving context, as drivers do not need to remove their hands from the steering wheel.

Contrary to what was expected, not many participants used gestures to identify vehicles. Only two out of ten consistently used gestures throughout their identifications. At the end of the study, the other participants were asked if they could have used gestures as a form of identification and the reason for not using them in the study. According to one participant (P08), even though gestures, specifically a pointing gesture, could be considered a more natural way to identify a vehicle, it can only be used to describe the location of the vehicle, whereas with a verbal description, the driver could use many more descriptors. Another participant (P10) said they would only use gestures if the vehicles were very close to their own, otherwise, a verbal description would be preferred. Two

participants (P04, P07) mentioned that, for safety reasons, they would prefer not to take their hands off the steering wheel if they were driving.

Even though it was made clear to all participants that they were supposed to identify the vehicle to a hypothetical device available in the car, most of them mentioned that they avoided using gestures as it might have had a negative effect on the researcher who was driving the vehicle. According to them, the gesture could have obstructed the view of the driver (P06) and distracted the driver from the main task of driving (P01). One participant, presuming wrongly that they had to give the message to the driver, avoided using gestures, since the main driver had a different frame of reference and might not have been able to see where they were pointing at (P03).

7.5.5 Vehicle location

According to the results of the study, location is one important and frequently used descriptor to identify vehicles together with vehicle colour and vehicle classification. Two participants provided creative and innovative ideas, which could be implemented by a vehicle identification system.

One participant (P03) mentioned during the post-study interview the possibility of the system having imaginary position markers on the windscreen that would make a location of the vehicle more precise (see Figure 7.14). Drivers would use this location marker alongside other descriptors (e.g. colour, make/model) when identifying a vehicle. One example of such identification would be "Red Toyota P3". The system would then perform a scan for vehicles only in the field of vision of the driver within the area of P3 at the moment of the identification. The location markers would be the same for both left- and right-hand drive vehicles.

Although an interesting idea, drivers would have to learn the exact location of each of these markers and memorise their positions. In addition, if a vehicle is located on the border of two position markers, drivers would have difficulties determining which exact position the vehicle is in, unless the position markers are presented to them in an HUD where they could easily see inside which exact position marker the vehicle was. However, this implementation would not work if the vehicle to be identified was behind the main vehicle or on either side at the moment of interaction.

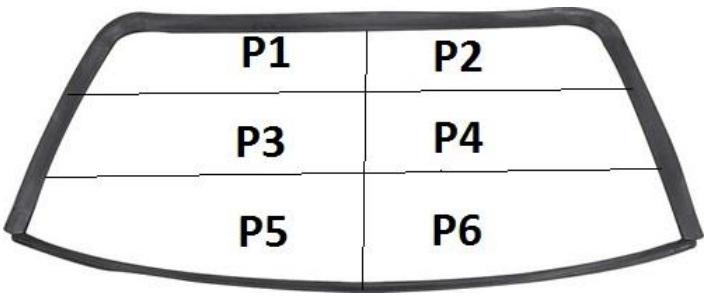


Figure 7.14. Windscreen location markers

Another participant (P04) suggested a way that vehicles anywhere around the driver could be identified precisely, not only in front but also behind and on either side. The driver would report the location of the vehicle using the analogy of a 12-hour clock, as frequently used in aviation (Crane & Crane, 2012; Kumar & Marshall, 2005) and military (United States of America: Department of Defense, 1994). A vehicle exactly in front of the driver would be at the twelve o'clock position whereas a vehicle exactly behind the driver would be at the six o'clock position. Although this concept could precisely identify the location of a vehicle, it would definitely impose an extra mental task on the driver, who would need to spatially calculate the location of the other vehicle in terms of the hands of an analogue watch.

This highly demanding task could be too much of a mental effort, taking into consideration the cognitive resources already used when driving a vehicle. Alternatively,

the same participant mentioned that the use of gestures may be enhanced if the system was able to clearly identify position markers on the top of the drivers' fingers and identify exactly where the driver is pointing.

7.5.6 Changes in identification

During the post-study interview, participants were also asked if they would do anything differently in retrospect about the identification of vehicles. Participants said they would try to be clearer in terms of the location of the vehicle (P07) and more consistent in the terms they used to provide vehicle location (P03). Another participant also mentioned using more descriptors related to the make and model of the vehicle even though they are not familiar with many different vehicle manufacturers (P01). Finally, P03 also mentioned trying to identify the vehicle more quickly.

7.6 Design recommendations and issues

Based on participants' responses, the study highlighted some key initial design recommendations, which would aid designers and developers of a specific vehicle identification sub-system of a DDCD. Even though participants were passengers in this study, the recommendations presented in this section can still be applied to drivers.

7.6.1 Descriptors

Based on the sequence and number of descriptors, the most frequently used were: VEHICLE COLOUR + VEHICLE CLASSIFICATION + VEHICLE LOCATION. The design of the system should therefore prioritise these three categories. The overall process of vehicle identification should be for the system to match the descriptors provided by the user with the information captured from vehicles around and, if there is a unique match, highlight this vehicle to the driver.

The system should be able to capture the basic descriptors from all vehicles around. This information could be transmitted using the infrastructure provided by V2V communication. Each vehicle should be able to share a set of basic information which does not change such as vehicle colour, make, model and classification. The location of the vehicle is constantly changing and therefore should be captured by sensors located on the main vehicle. This information would then be transmitted to the system which would complete the process of identification.

The system should expect from humans not only verbal identifications, but also a combination of both verbal and gestural descriptions. The system should have a large vocabulary for each descriptor type and be able to identify exact descriptions or descriptions that are more general. Participants reported different forms of description for the same basic colour such as blue, dark blue, bright blue and blueish.

The system could also be flexible and provide different ways for the drivers to describe the location of the vehicle, as this is one of the most important descriptors used. Different approaches could be implemented such as a wide range of gestures, a rich location vocabulary for verbal descriptions, and either one of the concepts previously mentioned in section 7.5.5 (windscreen markers or analogue watch). This location vocabulary must include words or expressions used not only to describe positions relative to the main vehicle (e.g. in front, on the left, in the distance) but also to describe a specific location (e.g. at traffic lights), a lane position (e.g. left lane, fast lane), and the road where the other vehicle is coming from (e.g. slip road).

7.6.2 Visual limitation

Although there were no participants with any severe visual limitations in this study, it is critically important to consider all types of drivers when designing the DDCD. Drivers

with colour-blindness may have difficulties describing the precise colour of a vehicle (Wickens et al., 1998), and the system should be able to aid the drivers in such situations. A dark red car at night could be easily misidentified as a brown one. Rain, snow and fog also contribute to poor visibility. Some makes and models of cars can be quite similar, and participants may easily misidentify one make for another, as happened relatively often in this study.

The system should, therefore, be designed in such a way that it can either provide clear and effective feedback when there was no result in the identification or, in case of similar descriptors, provide extra information about possible similar values (e.g. dark red could be identified as brown as well) and take this into account when performing a search.

7.6.3 Natural language

The speech recognition functionality of the DDCD should be able to accept more natural language as other mobile systems nowadays offer (e.g. Siri, Cortana, Google Voice), to make it easier for the drivers to use it with a low curve of learnability and a better user experience. The system should provide clear instructions and help users with which kinds of descriptors are easily accepted with a wide range of examples.

The system should also provide examples of descriptors, which are not accepted. An interesting descriptor, which was rarely used in the study, involves the description of the driver or passengers of the vehicle being identified. This descriptor could make it very difficult to be implemented by a system, and drivers should be aware that this sort of description, although highly applicable, may not be used. Users would need to undergo a training period to understand how the whole process of sending a message works, which includes the identification of a vehicle.

Based on the results of this study, the system should initially expect the three most commonly used descriptors, i.e. colour, location and classification. Future versions of the system could be improved to allow other categories of descriptors to also be incorporated.

7.6.4 Non-unique identification

The system could be designed in such a way that it provides prompt feedback when the driver gives a description which leads to non-unique identification. Ideally, the system could narrow down the option of vehicles nearby with the same characteristics and provide information to the driver about a description that differentiates these vehicles.

For example, if there were two black 4x4s in front of the driver with only one of them with a spare wheel on the back. If the driver provided the following information to the system "Black 4x4 in front", the system could provide feedback to the driver, either in speech or visually through HUD, and allow users to select which one specifically they were trying to identify.

Due to the nature of the process of sending a message, this feedback should be quick and help the driver to narrow down the selection to one vehicle only. Otherwise, the vehicle to be identified may have moved far away from the main driver, which would probably not make the nature of the message relevant anymore. In addition, this feedback should be provided only for vehicles in front or behind the driver on the same route. It would be difficult for the driver to remember specific characteristics of oncoming vehicles if they had already quickly passed by.

7.6.5 Design of gestures

According to Wigdor and Wixon (2011), a gesture consists of three stages: registration, continuation and termination. The first one, registration, is the moment that the type of

action is set. In the second stage, continuation, any parameters for the gesture are adjusted. Finally, the termination stage consists of the moment when the gesture ends.

The authors also present some guidelines when designing gestures:

- The number of steps before the registration stage should be minimal;
- There should be no ambiguity between the first two stages (registration and continuation);
- The same small subset of gestures should be consistently used as the first action for all gestures;
- There should be minimal mental and physical workload between each stage transition;
- The system should provide clear feedback for the user after each stage;

The use of gestures should also promote safety by reducing visual demand and should be easy enough to allow drivers to carry out the task (Riener, 2012b). Based on the gestural anatomy presented by Wigdor and Wixon, and the results of the study, a list of possible gestures, their related actions and anatomy were designed by the researcher and are presented in Table 7.8. Some of these gestures were actually made by two participants in the study, while others were added to cover the most common locations of vehicles. The system should be able to accept gestures performed with either the left or right hand to allow drivers to perform the gestures with the hand that is more comfortable for them.

Table 7.8. Gesture anatomy

Gesture name	Logical action	Registration	Continuation	Termination
ID First Vehicle in Front	Identify the first vehicle located in front of the main one in the same trajectory	Point index finger to vehicle in front being identified	None	Take the finger out of the ranging area of device, moving it back to the steering wheel
ID First Vehicle Behind	Identify the first vehicle behind the main one	Point thumb backwards	None	Take the thumb out of the ranging area of device, moving it back to the steering wheel
ID Moving Vehicle	Identify any moving vehicle in front but in a different trajectory	Point index and middle finger together in front of vehicle being identified	Move both fingers following the movement of the vehicle to be identified	Take both fingers out of the ranging area of device, moving them back to the steering wheel
ID Second Vehicle in Front	Identify the second vehicle in front of the main one in the same trajectory	Point index finger in front	Move index finger back and forth two times	Take the finger out of the ranging area of device, moving it back to the steering wheel
ID Vehicle at (Far) Distance	Identify a vehicle located far away from the main one	Point whole hand, palm down in front	Raise hand to top near the head	Take the hand out of the ranging area of device, moving it back to the steering wheel
ID Vehicle on Right	Identify a vehicle located on the right-hand side of the main one	Point thumb to the right	None	Take the thumb out of the ranging area of device, moving it back to the steering wheel

Gesture name	Logical action	Registration	Continuation	Termination
ID Vehicle on Left	Identify a vehicle located on the left-hand side of the main one	Point thumb to the left	None	Take the thumb out of the ranging area of device, moving it back to the steering wheel

7.6.6 Design issues

Based on the results of this study, some design issues and limitations of the device were also found. Firstly, it proved to be quite difficult to clearly identify oncoming vehicles, especially when travelling at higher speeds on a motorway or dual-carriageway where there is a physical barrier separating lanes. Secondly, poor visibility conditions may restrict clear identification of some descriptors such as vehicle colour and vehicle make. A mixed approach could be the solution for capturing gestures under different light conditions, with cameras working in brighter conditions (e.g. during the day) and infrared light detectors during darker periods.

7.7 Taxonomy

Based on the results of this study, a taxonomy of vehicle identification was designed. This taxonomy would be of considerable value to designers of a driver-to-driver communication device. This taxonomy, presented in Table 7.9, contains all descriptors found in this study, highlighted in bold and many others that could be used to identify vehicles. A database of these descriptors with a wide vocabulary for each of them could be incorporated into the system.

Table 7.9. Taxonomy - Vehicle Identification

TAXONOMY – VEHICLE IDENTIFICATION	
1.0	Number of vehicles to send message to
1.1	One
1.2	More than one
2.0	Location of other vehicle(s)
2.1	Single vehicle
2.1.1	**Location**
2.1.1.1	**Relative to main vehicle**
2.1.1.1.1	**In front of main vehicle / ahead / far ahead**
2.1.1.1.2	**Behind main vehicle**
2.1.1.1.3	**On the left of main vehicle**
2.1.1.1.4	**On the right of main vehicle**
2.1.1.2	**Specific location**
2.1.1.2.1	**At traffic lights**
2.1.1.3	**Lane position**
2.1.1.3.1	**Lane location (left lane)**
2.1.1.3.2	**Lane characteristic (e.g. fast lane)**
2.1.1.4	**Road coming from (e.g. slip road, oncoming traffic)**
2.1.1.5	**Position of other vehicle (e.g. first car in front of the queue)**
2.1.1.6	**Main driver's field of vision**
2.1.1.6.1	**Blind spot**
2.2	Multiple vehicles

2.2.1	In a specific circular range (e.g. 20-meter radius)
2.2.2	In a specific linear range (e.g. 100 meters in front/behind)
3.0	Direction of movement of vehicle
3.1	Vehicle
3.1.1	Main vehicle
3.1.2	Other vehicle
3.2	Direction of movement
3.2.1	Moving forward
3.2.2	Moving backward
3.2.3	No movement
4.0	Angle of other vehicle(s)
4.1	Same direction as main vehicle (i.e. zero degrees)
4.2	Opposite direction - coming towards main vehicle (i.e. 180 degrees)
4.3	Perpendicular direction (e.g. on an intersection – 90 degrees)
4.4	Any other angular direction
5.0	Speed of vehicle at moment of interaction
5.1	Vehicle
5.1.1	Main vehicle
5.1.2	Other vehicle
5.2	Stationary
5.2.1	**Parked**

5.2.2	**Not parked**
5.3	In movement
5.3.1	Low speed (i.e. below 30mph)
5.3.2	Medium speed (i.e. between 30mph and 60mph)
5.3.3	High speed (i.e. more than 60mph)
6.0	**Action of vehicle at moment of interaction**
6.1	**Own vehicle (e.g. we're following…)**
6.2	**Other vehicle (e.g. overtaking, delivering at pub, signalling to turn right, braking…)**
7.0	Visual limitation
7.1	No visual limitation – i.e. clear identification/visualization of other vehicle and driver
7.2	Partial visual limitation – i.e. no driver identification, but clear identification/visualization of other vehicle
7.3	**Visual limitation** – no identification of other driver and vehicle
7.3.1	Physical separation
7.3.1.1	Road characteristics
7.3.1.1.1.	Central reservation (e.g. motorway)
7.3.1.1.2	Road infrastructure (e.g. buildings, road works)
7.3.1.1.3	Road inclination (e.g. hills, slopes)
7.3.1.1.4	Bend on the road
7.3.1.2	Other vehicle(s) blocking

7.3.2	Limitation due to weather
7.3.2.1	Dense fog
7.3.2.2	Heavy rain
7.3.2.3	Heavy snow
7.3.2.4	**Bright sunlight**
7.3.3	Limitation due to insufficient light (e.g. nightfall, dusk – no road illumination)
8.0	Vehicle Identification
8.1	**Make**
8.2	**Model**
8.3	Size
8.3.1	**Big**
8.3.2	**Small**
8.3.3	Tiny
8.4	Colour
8.4.1	**Detailed description (e.g. dark navy blue)**
8.4.2	**Single description (e.g. blue)**
8.4.3	**Approximate description (e.g. blueish)**
8.5	Classification
8.5.1	**Lorry / HGV**
8.5.2	Bus
8.5.2.1	**Double-Decker**
8.5.2.2	**Single-Decker**

8.5.3	**Van**
8.5.4	**Minivan/ people carrier**
8.5.5	**SUV**
8.5.6	**Saloon**
8.5.7	**State car**
8.5.8	**Medium size car**
8.9	Motorbike
8.10	**Road sweeper**
8.6	Number plate
8.6.1	**Personalised number plate**
8.6.2	**Description**
8.6.2.1	**Full number plate**
8.6.2.2	**Partial number plate**
8.6.2.2.1	**Year**
8.6.2.2.2	**Starting / ending with**
8.7	Type of vehicle
8.7.1	**Regular vehicle**
8.7.2	Emergency service (e.g. ambulance, police, fire engine)
8.7.3	Delivery service
8.7.4	Other special vehicles (e.g. ice cream van, funeral car etc.)
8.8	Specific characteristic of other vehicles
8.8.1	**Vehicle Design**
8.8.1.1	**Words on vehicle (e.g. name of company, advertisement etc.)**
8.8.1.2	Sticker on window

8.8.1.3	**Different visual representation (e.g. lady bird spots on bonnet, stripes on bonnet and checks on sides)**
8.8.2	**Use of lights**
8.8.2.1	**Headlights**
8.8.2.2	**Fog lights**
8.8.2.3	**Brake lights**
8.8.3	**External attachment (e.g. ladder / bicycle on top, spare wheel on the back)**
8.8.4	Exterior cleanliness
8.8.5	**Number of doors**
8.8.6	**Age of car**
8.8.7	Problem with vehicle (e.g. deflated tyre, door open …)
8.8.8	Car customization (e.g. different alloy wheels, bigger exhaust pipe, etc.)
8.9	**Time of identification (e.g. just now)**
8.10	**Comparison to other well-known vehicles (e.g. Royal mail type van)**
8.11	**Vehicle previously identified (e.g. same vehicle as before, the one I saw earlier)**
9.0	**Issues in Identification**
9.1	**Uncertainty of identification**
9.2	**Repetition of description ("blue car, small blue car")**
9.3	**Error in identification**
9.3.1	**Corrected identification**
9.3.2	**Non-corrected identification**

9.4	**Non-unique identification**
10.0	Driver/passenger identification
10.1	Gender
10.2	**Age range**
10.2.1	Young adult
10.2.2	Adult
10.2.3	Senior
10.2.4	Very elderly
10.3	Physical characteristics
10.3.1	Hair
10.3.1.1	Style
10.3.1.2	Colour
10.3.2	Skin colour
10.3.3	Other drivers' clothing
10.3.3.1	Clothes
10.3.3.2	Hats
10.3.3.3	Glasses / sunglasses

7.8 Limitations

This study was an initial exploratory study. Therefore, ten participants were considered a reasonable figure. After analysis, more participants would be beneficial and would provide more data that are valid.

A dashcam is an on-board video camera that continuously records the view through a vehicle's windscreen. It may be attached to the interior windscreen or the top of the dashboard, by a suction cup or adhesive tape mount. It is mainly used to record traffic in front and behind the vehicle. Errors in vehicle identification would be more precise if a dashcam had been available throughout all the data collection phase. The eye-tracking monitor provided an appropriate front view camera to record where participants were looking all the time. However, there were some situations, especially when a vehicle behind was identified, that it was not possible to thoroughly check which vehicles were behind the car at the time and to confirm if it was a unique identification or if there were any errors. Therefore, for these situations, no error was recorded.

Although the beeps were controlled by the main researcher and were not played at specific intervals of times, some vehicle identifications could not be considered totally instinctive, as participants were looking for vehicles beforehand. They knew they were going to hear the beep frequently and then start looking for vehicles to identify nearby. Therefore, for this particular study, a time to complete task measure was not evaluated.

7.9 Conclusion and future work

Drivers encounter different situations on the road, which require them to communicate with other drivers. A driver-to-driver communication device could make drivers' intentions clearer. One essential task before sending a message to another driver is to identify which vehicle to send the message to. Designers and developers of a vehicle

identification system could take into consideration important aspects such as the sequence of descriptors used and a combination of both verbal and gestural descriptors with a rich vocabulary when designing a vehicle identification system to provide a better user-experience for drivers. The system should also be able to deal with different kinds of errors in the identification process. Some design issues with the system might be difficult to deal with, which could limit the use case scenarios of the device.

The study was only run during the daytime, from 10 am to 3 pm. Different situations might have occurred if the study had also been run during the night-time when there is a reduction in visibility. Then vehicle colour, make and model would possibly not be listed as frequently used descriptors. A future study, mainly running during periods of reduced visibility, would be considered important.

Different results might also have been found if the participants had actually been driving the vehicle and not sitting in the passenger seat. The number of descriptors might be different, as the participants would need to negotiate between the main task of driving their vehicle and the secondary task of identifying other vehicles nearby.

A future study could also focus on the time to complete the task of identifying vehicles and the workload involved. Participants sometimes took longer to identify a vehicle in different situations, and it would be important to know how long each person takes to identify a vehicle and the demands involved, in different situations and road environments, especially when they are driving.

The next chapter presents in detail a driving simulator study, which aims to investigate the task of sending messages using two different HMIs in two different time criticality conditions.

8 Sending messages with a driver-to-driver communication device (STUDY E)

8.1 Introduction

Driver-to-driver communication comprises of an exchange of messages. Drivers send messages to other drivers and receive messages from them. The task of receiving messages through the DDCD was investigated in two studies presented in Chapter 06. The task of sending messages, according to the task analysis presented in Chapter 04, can be divided into two main sub-tasks; vehicle identification and message composition. Vehicle identification was investigated in an on-road study presented in Chapter 07. The main aim of the study presented in this chapter is to investigate the task of message composition with the DDCD. However, in order to capture the whole process of sending a message, the task of vehicle identification was also investigated in the study.

Drivers can compose messages to other vehicles in different ways. Two distinct HMIs were chosen in this study, which are based on STUDY A, the exploratory study presented in Chapter 05. Results from STUDY A, show that drivers are prepared to send either free content messages or messages chosen from a pre-defined list. It was also found in STUDY A that both free content and pre-defined messages have their own advantages and disadvantages. Therefore, for the study presented in this chapter, it was decided that one HMI would be based on free-content messages in which drivers would mainly interact via speech interface. The other HMI was based on a selection of predefined messages grouped inside a menu structure that could be interacted with a touchscreen device.

Driving communication scenarios can be grouped into different categories, whereas messages can be grouped according to their content. Two examples are: if the message is related to the drivers themselves or the environment and if the message is related to a driving manoeuvre or a social interaction. However, driving communication scenarios could also be grouped based on the time criticality at the moment of communication. There are some time-critical situations in which drivers may not have enough time to send a message. One example of such a situation is highlighted in STUDY D (see section 7.6.6), where drivers may need to send a message to an oncoming vehicle travelling at high speed on a motorway. Sending a message to a slow vehicle in front, for instance, is a less-time critical scenario. The study presented in this chapter investigates the process of sending messages in both time critical and less-time critical scenarios.

8.1.1 Study aims

The main aim of the study was to explore the effects of HMI and time criticality on the task of sending messages to other drivers. Two distinct HMIs to send a message were explored in this study. Several objectives were defined to achieve this specific aim. One objective of the study was to establish the impact of the two different HMIs on driving performance by measuring speed deviation in a driving simulator. The effect of the HMI on task performance was also explored by measuring the time to complete the task of sending the message and the frequency of errors. Another objective was to investigate if there was any significant effect of HMI on workload. Workload was measured both with the NASA-TLX questionnaire (Hart & Staveland, 1988) and with a tactile detection task (Ranney, Baldwin, Smith, Mazzae & Pierce, 2014). Driver acceptance of the DDCD was also investigated with a version of the CTAM questionnaire. The effect of the HMI on driver distraction was investigated by measuring the total number of off-road glances,

long glances (> 2 seconds) and glance duration. The last objective of this aim was to capture drivers' subjective HMI preferences generally and specifically in time critical and less-time critical conditions.

The study also aimed to investigate the task of identifying vehicles. Similar to STUDY D, the analysis of the verbal content of the identification was explored by measuring the number of unique descriptors used to identify a vehicle and their sequence. When involved in the same communication scenario, drivers can compose different messages. Therefore, the third and final aim of the study was to investigate message composition by exploring the content of open messages and the selection of pre-defined messages. The aims and measures of this specific study are presented in Figure 8.1.

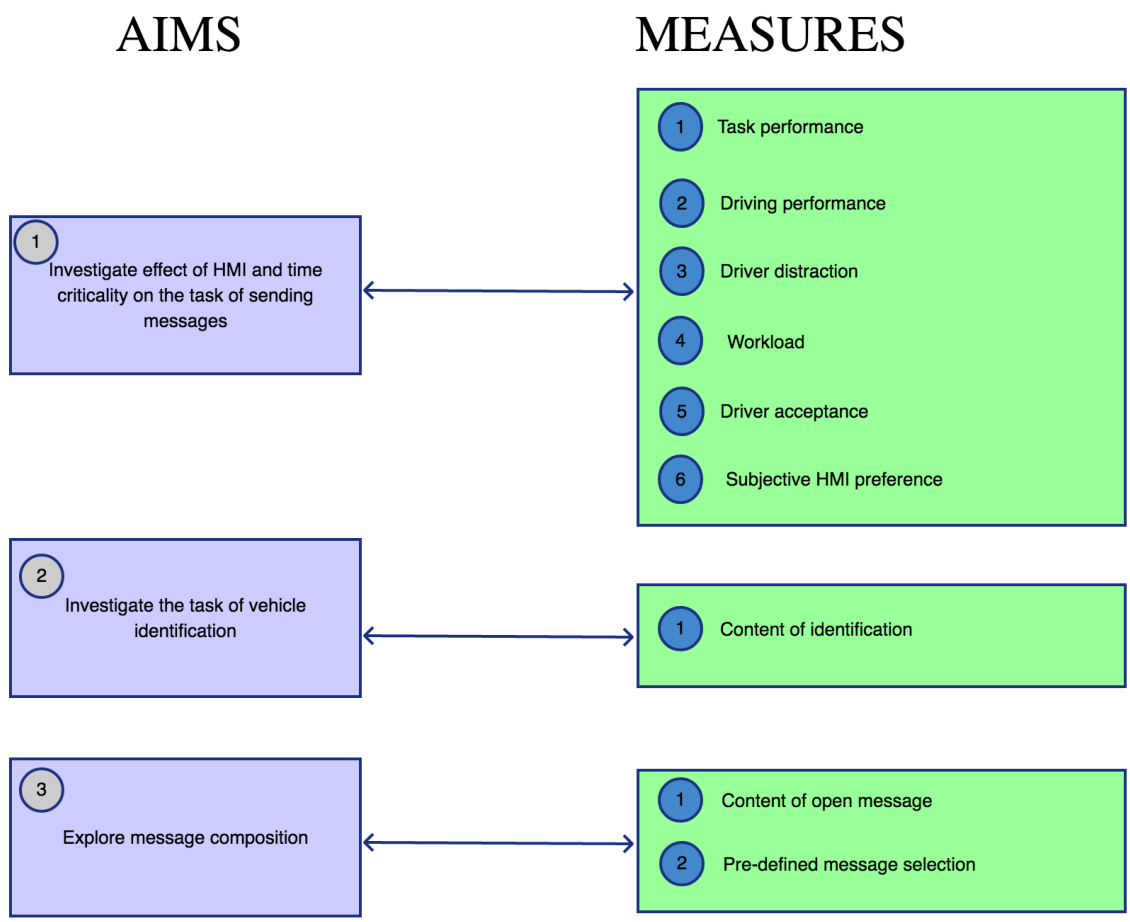


Figure 8.1. Study aims and measures

8.2 Method

8.2.1 Participants

Participants were volunteers who responded to advertisements posted online (i.e. email and social networks), and fixed on bulletin boards around the campus at the University of Nottingham, UK. Participants were recruited on the basis that they must have held a valid UK driving licence for at least one year and drive regularly. Further requirements were that they must not be pregnant and not suffer from severe motion sickness, epilepsy, migraines, dizziness, sleep disorders and blurred vision.

Twenty-one drivers were recruited for this study (11 male and 10 female; Age: Mean=37.5, SD=14.7, Range=21-65 years). Participants were experienced drivers (Number of years driving: Mean = 17, SD=13.6, Range= 1-40 years). Participants were also regular drivers (Current annual mileage: Mean=6667, SD=4396, Range=1000-15000).

All participants gave written informed consent before taking part in the study. At the end of the study, participants were reimbursed with £10 in shopping vouchers for their time and effort.

8.2.2 Study design

A within-subject design was adopted with time criticality and HMI as independent variables. Participants were asked to drive under two different scenarios, one with two time-critical (TC) situations and another with two less-time critical (LTC) situations. Two different HMIs to send a message to other vehicle/s were used in this study, both of which were presented on a touchscreen tablet. In one HMI, participants used free speech-based commands to send messages while in the other HMI participants selected the message based on pre-defined categories. Dependent variables were task completion time,

number of task errors, mean and standard deviation of speed, number of off-road glances (short and long glances), workload and acceptance of the technology.

Data was collected in the vehicle identification process, as type of descriptors used and their frequency. The messages sent using the speech interface were also analysed in terms of their content. Finally, subjective data was also collected regarding participants' preferences for HMI in the form of a semi-structured interview at the end of the study.

8.2.3 Apparatus and stimuli

8.2.3.1 Driving simulator

The study took place in a fixed-based, medium-fidelity driving simulator (see Figure 8.2). The simulator comprises of a right-hand drive Audi TT car positioned in front of a curved screen with an angle of 270°. Three overhead projectors were used to display the driving scenario on the screen. A 46" LCD display was placed behind the car to simulate the rear view, which could be seen by the driver using an existing rear-view mirror inside the vehicle. The side mirrors were two small LCD displays located on each side of the car.

Drivers interacted with the vehicle and the simulator software by using an authentic steering wheel with force feedback, accelerator, brake and clutch pedals, manual gearshift and indicator controls located inside the vehicle. The simulated driving scenario and driving experience were created using the software STISIM drive (version 3). A bespoke JAVA application was used by the STISIM software to calculate road speed, which was then presented on an 8" LCD display fitted into the instrumented panel.



Figure 8.2. Driving simulator with motorway scenario

8.2.3.2 Driving scenarios

The driving scenario initially presented a UK motorway with three lanes on each side separated by a central reservation area. Participants drove on this road setup for around 2 minutes. This road was then changed to a dual carriageway with the reduction of one lane down to two lanes. The reason for this reduction is the nature of one of the communication situations, which requires a vehicle to cut in front of the driver. All the other communication situations required a single carriageway. Therefore, after a few miles, another lane reduction down to one lane took place. Overall, the road was fairly straight with no sharp bends. The traffic was moderated on both sides of the road. The scenery was rural with trees and mountains to avoid presenting any other element, which could be too visually distracting. The maximum speed in all four scenarios was set at 70mph. The four driving communication scenarios designed for this study are described in detail in Table 8.1, with the main driver being the participant:

Table 8.1. STUDY E - Driving scenarios

Condition	Task #	Communication scenario	
TC	01	A vehicle in the outer lane of a dual carriageway cuts in front of the main driver and suddenly brakes to slow down. Main driver needs to send a message to the motorist of this vehicle to alert them about their aberrant and dangerous driving.	
TC	02	On the other side of a single carriageway, there is an overturned lorry on a bend with boxes spread across the road. A few yards ahead, main driver needs to send a message to alert an oncoming driver who is about to reach this accident.	
LTC	01	A really slow driver, travelling at well below the speed limit, on a single carriageway with steady oncoming traffic. Main driver unable to overtake the vehicle and therefore needs to send a message to this driver to speed up.	

LTC	02	On a single carriageway, the main driver's vehicle slowly has its speed decreased by the software to simulate a problem with the car. Another vehicle behind approaches and starts tailgating the main driver's vehicle. The main driver then needs to send a message to this vehicle behind about the problem with their car.	

8.2.3.3 Touchscreen

Participants sent messages to other vehicles on a 12.3-inch Microsoft Surface Pro 4 tablet computer running Windows 10. The touchscreen was placed on the dashboard near the steering wheel (see Figure 8.3). A low-fidelity prototype of the interface of the sub-task of sending a message via the DDCD was created with PowerPoint. Participants were asked to press the touchscreen with their left hand using one finger to start the task of sending the message.



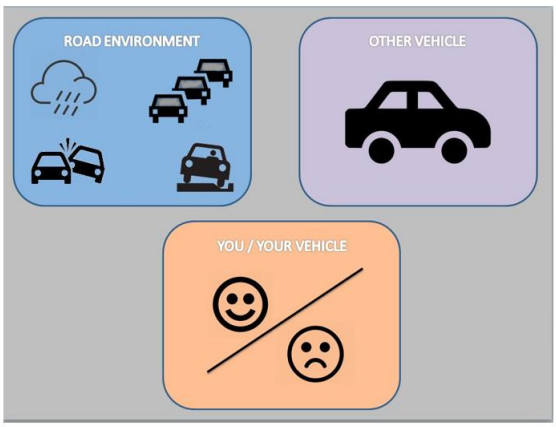


Figure 8.3. Touchscreen display with prototype

8.2.3.4 Eye tracking

During the study, participants used eye-tracking glasses from SensoMotoric Instruments (SMI) to capture their eye movements and fixation. The eye-tracking glasses were connected to a laptop computer with a USB cable. Before each driving session, the glasses were calibrated to make sure that no errors were encountered during data recording. The glasses consist of three small video cameras, one facing each participant's eye and the third camera facing the participant's field of vision. All videos were recorded at the frequency of 30 hertz.

8.2.3.5 Video cameras

Participants were video- and audio-recorded to enable the researcher to subsequently analyse in detail their facial expressions and interactions with the different HMIs. Three miniature cameras were strategically positioned for non-obtrusive data capture. These cameras were positioned on the dashboard of the car facing the participant, and on the back seat of the vehicle facing the road in front and the touchscreen display.

8.2.3.6 Vibro-tactile sensor

A small sensor was used in this study to allow a secondary task measure of workload to be captured. An ISO-standard process was followed to setup the sensor (Ranney et al., 2014). Participants wore a small buzzer attached to the left part of their neck, just above the collarbone. This small vibro-tactile motor makes a brief, low intensity pulse (<1 sec). The buzzer was connected by cable to a button, which was placed around the participants' right index finger. Participants were instructed to press the button as quickly as possible when they noticed the pulse (i.e. tactile detection task). The researcher provided instructions to the participants on how to fit the motor themselves using medical tape.

The sensor was connected to a laptop via a USB cable. This laptop contained bespoke software used to capture workload data. At the end of each driving session, the researcher had to close the application and disconnect the sensor to complete the process of collecting data. Data collected consisted of the participants' reaction time taken to press the button (in milliseconds) for each pulse.

8.2.3.7 Task

The task of sending a message consisted of two parts – the identification of the vehicle to receive the message and the composition/selection of the message. The first part was the same for both HMIs. Participants were instructed to speak out loud to the system, giving a short description of the target vehicle, e.g. "blue car in front", and then press anywhere on the touchscreen when they finished this step. The second part was different from one HMI to the other. In the speech-based HMI, participants were instructed to just say the message they were going to send out loud and then press anywhere on the touchscreen to send the message. In the pre-defined menu HMI, participants were instructed to navigate through different levels of a graphical menu-based system, by pressing the touchscreen until they found the topic of the message they were planning to send, and then press the YES button to send the message. Research has been carried out on investigating visual demand on structured touchscreen menus with various depths and breadths with the lowest acceptable demand associated with menus of no more than 3 levels of depth (Burnett, Lawson, Donkor, & Kuriyagawa, 2013). A detailed description of the interaction process for sending an apologetic message on both HMIs is presented in Table 8.2 and Figure 8.4.

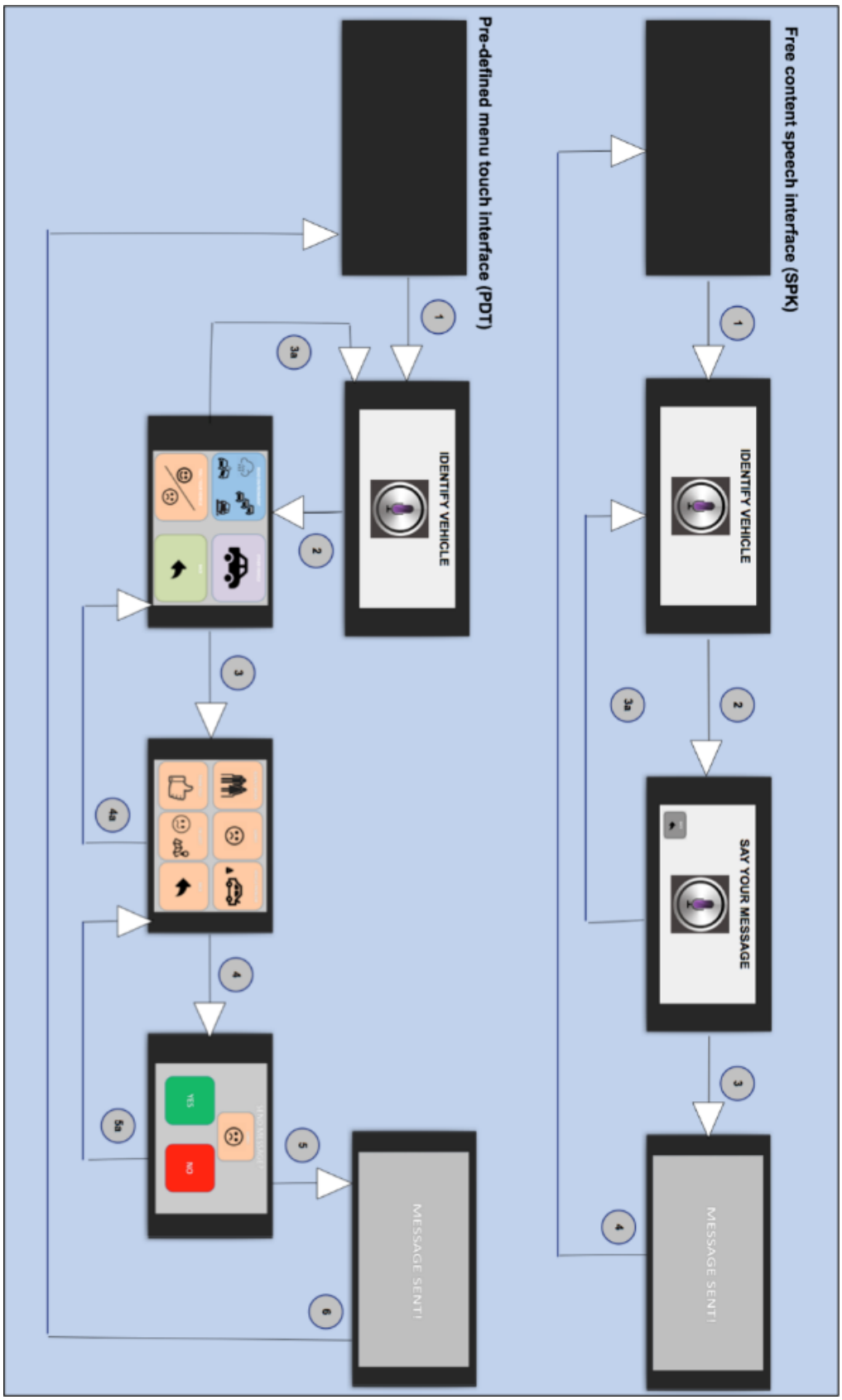


Figure 8.4. Interaction design

Table 8.2. Interaction design description

Number	Free content speech (SPK)	Pre-defined menu touch (PDT)
1	Before sending messages, the touchscreen display was blank. Participants touched anywhere on the screen to start the process of sending the message.	
2	The first part is to identify the vehicle to send the message to. An auditory notification was played on this screen with the following command "Identify the vehicle". Participants said the description of the vehicle out loud and pressed anywhere on the touchscreen. The system then confirmed the action and redirected the participant to the next screen.	
3	An auditory notification was played with the following command "Say your message". Participants said the message out loud and pressed on the central part of the screen to confirm the message.	Participants pressed on the first menu level containing the general categories of messages. These categories depicted messages related to the environment (road, weather), to the other vehicle or to their own vehicle.
3a	By pressing the BACK button on the bottom left corner of the screen the participant was redirected to the previous screen (2) and the message and the identification previously established was cancelled.	By pressing the BACK button on the bottom right corner of the screen the participant was redirected to the previous screen (2) and the identification previously established was cancelled.
4	If a successful message was sent, a notification was displayed. This notification was both visual and auditory. After 5 seconds, the message disappeared and the screen turned blank again.	After choosing which general category of the message to send (first level menu), a second level was displayed. Participants would then need to select from these options, which one was more related to the message they wanted to send.
4a	N/A	If no options seemed suitable, participants would press the back button, which redirected them to the previous screen (3) containing the first level menu.
5	N/A	If the participant was confident that this was the message to send, they could just press the YES button, which would then send the message.

Number	Free content speech (SPK)	Pre-defined menu touch (PDT)
5a	N/A	If the participant did not want to send that message, they needed to press the NO button, which would redirect them to the previous screen (4).
6	N/A	If a successful message was sent, a notification was displayed. This notification was both visual and auditory. After 5 seconds, the message disappeared and the screen turned blank again.

8.2.3.8 Questionnaires

Participants were asked to fill in three questionnaires at the end of each driving session. The first questionnaire was used to detect if participants were feeling any simulator sickness symptoms (see Appendix xii page 381). The second questionnaire was a standard version of the NASA Task Load Index (TLX) questionnaire to measure workload on five 7-point scales (see Appendix xi page 380). The last one was a driver acceptance questionnaire based on the car technology acceptance model (CTAM), described in section 2.4.1, with 10 Likert-type questions with five options ranging from 'totally disagree' to 'totally agree' (see Appendix ix page 377).

8.2.4 Procedure

Before the study began, participants signed a consent form and read an information sheet, which contained detailed information about the procedures of the study. After this, participants filled in a general demographic questionnaire with questions about their gender, age, driving experience and annual mileage.

Participants were then given 5-10 minutes to test the driving simulator to become familiarised with the controls of the vehicle and the driving scenario. Participants were

asked to drive as they normally would in a real driving environment and were reminded that their primary task was the driving task. Participants were also asked to stay in the inside lane the whole time to reduce variability in results due to overtaking.

Participants then had a short practice session, without driving, on how to send a message using both HMIs they were going to interact with throughout the study. At this moment, participants were allowed to ask the researcher any questions to confirm that they had fully understood this task and the study.

After these practice sessions, each participant completed four driving sessions representing each of the four conditions – a combination of a different HMI (i.e. speech-based and pre-defined menu) and criticality (i.e. time critical and less-time critical). The order of the driving sessions was counterbalanced. In each driving session, participants encountered two events (T1/T2), which required them to send a message to the other driver. A few seconds before each event occurred, participants heard an auditory notification saying, "Situation near". This notification was to inform the participants that a situation that required them to send a message was about to happen. As soon as the event unfolded, participants heard a second auditory notification saying, "Send message". At this moment, they had to start the task of sending the message to the other vehicle by pressing the blank touchscreen. The same situations were presented for each HMI at slightly different points in the driving scenario, with different vehicles, so that participants were not expecting them to happen at that point.

At the end of each driving session, participants filled in the workload, driver acceptance and simulator sickness questionnaires. At the end of the study, participants signed a post-trial consent form, stating they were not going to drive for at least 30 minutes after the study. Participants were also interviewed on their HMI preferences in each situation. The whole study took approximately 60 minutes to complete for each participant.

8.3 Results and analysis

8.3.1 Task times

Task times were analysed using t-tests (within) for each message task (T1/T2) with HMI as the independent variable. Unfortunately, four participants had to be excluded from the task time analysis only, due to technical problems capturing the data. The Table 8.3 shows mean time (in seconds) and standard error for each task and condition. Results from the t-tests are displayed in Table 8.4. There was a significant difference in time to complete the task of sending a message using the speech interface when compared to the pre-defined menu in all tasks, except one. This was the time to complete the second task of the less-time critical condition (LTC_T2), which was not significant (NS).

Table 8.3. Task time statistics

		LTC		TC	
		T1	T2	T1	T2
SPK	Mean time (s)	10.69	10.89	10.53	9.28
	Std. Error	.92	**1.19**	.82	.73
PDT	Mean time (s)	19.06	15.11	14.84	15.33
	Std. Error	**2.13**	2.84	1.29	1.79
Time difference (s)		8.37	4.22	4.31	6.05

Table 8.4. T-test results comparing two interfaces (speech and pre-defined menu) on time to complete task for each sub-task according to their level of time-criticality

		t	p	d
LTC	T1	-3.94	.001	-.98
	T2	-1.41	NS	-.32
TC	T1	-3.60	.002	-.83
	T2	-3.44	.003	-.81

8.3.2 Task errors

Participants made errors when interacting with HMIs. Figure 8.5 shows the total number of errors for each HMI and task. These errors were analysed using T-tests for each message task (T1/T2) with HMI as the independent variable. As can be seen in Table 8.5, there was no significant difference in the number of errors in all conditions except the second task of the less-time critical condition (LTC_T2) where the number of errors for the speech interface was significantly lower.

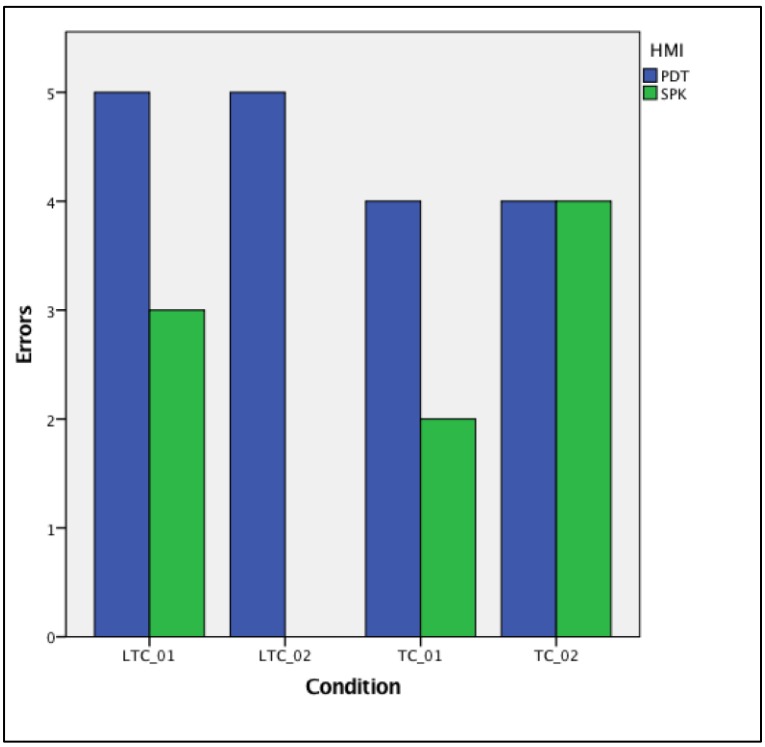


Figure 8.5. Frequency of errors

Table 8.5. T-test results comparing two interfaces (speech and pre-defined menu) on total number of task errors for each sub-task according to their level of time-criticality

		t	p	d
LTC	T1	-.81	NS	-0.18
	T2	-2.5	.02	-0.54
TC	T1	-.81	NS	-0.18
	T2	0	NS	0

Participants committed different types of errors when sending messages to other vehicles. The type of error with its frequency count is listed in Table 8.6.

Table 8.6. Types of errors

Type of error	**Frequency**
Wrong message sent	11
No vehicle identification	8
Wrong vehicle identification	3
No message sent	3
Premature start to sending message	2
Total	27

8.3.3 Driving performance

Mean speed and standard deviation of speed were calculated for each participant during three of the four tasks (LTC_T1, TC_T1, and TC_T2). This measure was not calculated on the LTC_T2 condition due to the nature of the scenario, which involved the speed of the main vehicle being automatically reduced by the software to simulate a mechanical fault with the vehicle. Mean speed and speed variation were analysed using t-tests (within) for

each message task (T1/T2) with HMI as the independent variable. Unfortunately, four participants had to be excluded from these measures due to technical problems collecting the data. Table 8.7 shows mean speed (in miles per hour) and speed variation (in miles per hour) with their standard errors for each task and condition.

Table 8.7. Driving performance statistics

		LTC	TC	
		T1	T1	T2
SPK	Mean speed (mph)	32.34	36.76	65.48
	Std. Error	8.62	13.11	9.04
	Speed variation (mph)	17.71	18.42	1.21
	Std. Error	10.44	9.02	2.41
PDT	Mean speed (mph)	37	34.30	64.95
	Std. Error	9.5	12.92	7.14
	Speed variation (mph)	24.62	23.82	2.15
	Std. Error	14.45	15.86	4.25

Results from the t-tests are displayed in Table 8.8, which shows that there were no significant effects of the HMI on mean speed and speed variation for all conditions.

Table 8.8. T-test results comparing two interfaces (speech and pre-defined menu) on mean speed and speed variation for each sub-task according to their level of time-criticality

		t	p	d
LTC	Mean speed T1	-2.03	NS	-.49
	Speed variation T1	-1.95	NS	-.42
TC	Mean speed T1	.60	NS	.15

		t	p	d
	Speed variation T1	-1.11	NS	-.69
	Mean speed T2	.20	NS	.05
	Speed variation T2	-.76	NS	-.18

8.3.4 Off-road glances

Complex in-vehicle displays may result in an increased number of eye glances made towards the displays while driving. Therefore, it is important to measure the number of off-road glances in order to evaluate driver visual distraction. The total number of glances, and more specifically long glances (>2 seconds), was measured together with mean glance duration for each condition (TC/LTC) with HMI as independent variable (see Figure 8.6). Two participants had to be excluded from this measure due to technical problems collecting the data with the eye tracking glasses.

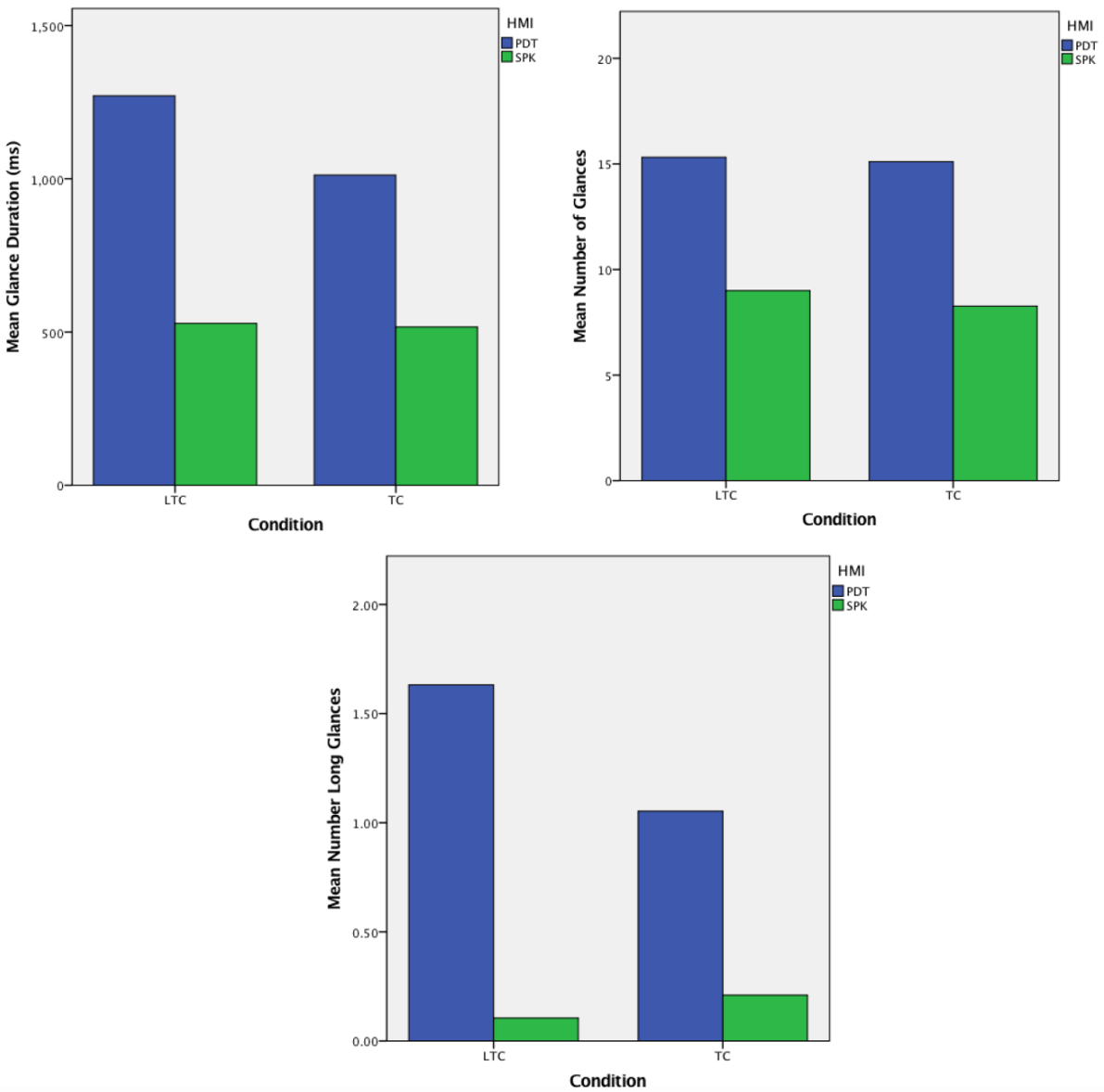


Figure 8.6. Eye-tracking measures

The three measures were analysed using t-tests (within) for each condition (LTC/TC) with HMI as the independent variable. The results from the t-tests are displayed in Table 8.9, which shows that there were significant effects of the HMI on the number of off-road glances (all glances and long glances) and glance duration.

Heat maps were also generated to visualize the degree to which participants attended to different areas of interest (AOI) during each one of the tasks (see Figure 8.7). The AOIs used in this study were the road ahead, the rear-view mirror, the other vehicle (i.e. receiver of the message), the touchscreen display and the speedometer. These were chosen because they were the areas which participants most looked at during the communication process. Larger areas in red indicate high fixation intensity. Results from the heat maps shows higher fixation intensity for the predefined menu HMI when compared to the speech-based HMI for the same task and condition.

Table 8.9. T-test results comparing two interfaces (speech and pre-defined menu) on number of off-road glances for each level of time-criticality

		t	p	d
LTC	Total glances	-4.26	.00	.98
	Long glances	-6.20	.00	1.42
	Glance duration	-6.16	.00	1.41
TC	Total glances	-4.49	.00	1.03
	Long glances	-3.83	.00	.88
	Glance duration	-5.76	.01	1.32

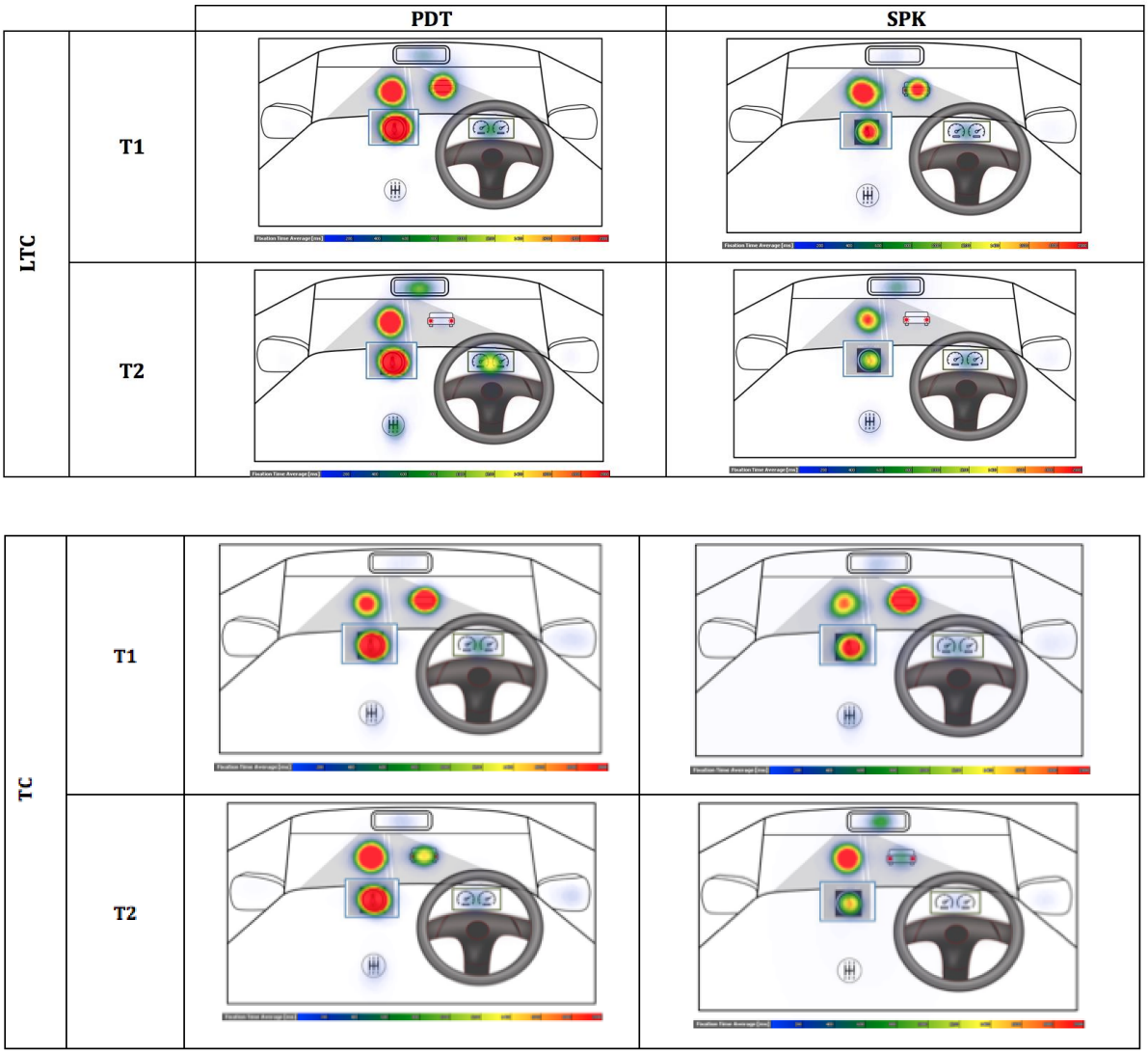


Figure 8.7. Heat maps highlighting different AOIs

8.3.5 Workload

Workload was measured at the end of each driving session in two different ways, objectively by a tactile detection task (TDT), and subjectively with a NASA-TLX questionnaire, comprised of seven sub-ratings.

The seven sub-ratings were analysed using a Wilcoxon signed rank test for each criticality condition separately (TC, LTC) with HMI as independent variable. This data was collected for all participants in the study. Figure 8.8 shows the values for each sub-rating and condition.

There were no significant effects of the HMI on all sub-ratings for both critical and less-time critical conditions. Results from all Wilcoxon tests can be found in Table 8.10.

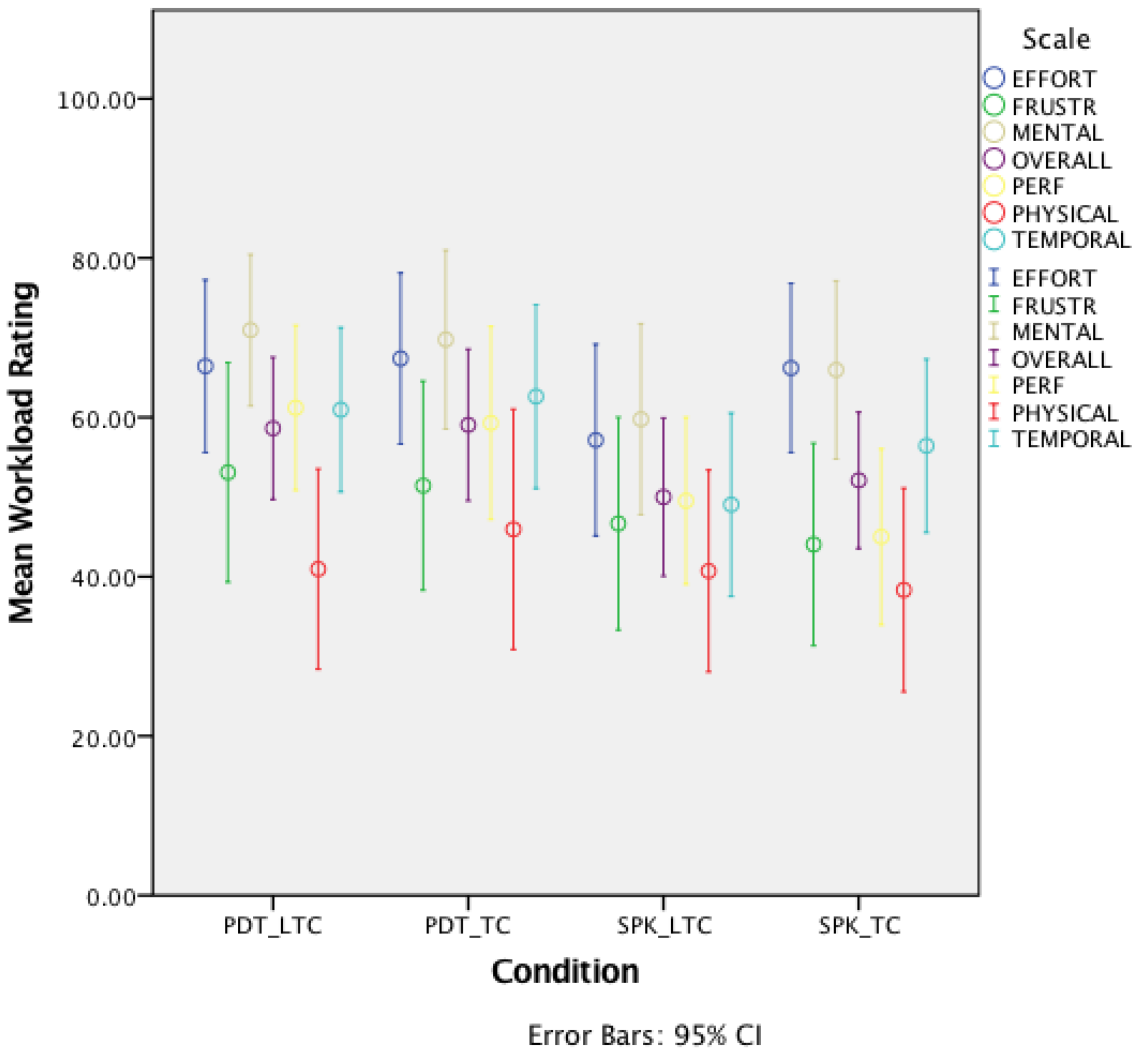


Figure 8.8. NASA-TLX sub-ratings scales

Table 8.10. Wilcoxon test results comparing two interfaces (speech and pre-defined menu) on NASA-TLX seven sub-ratings of workload for each level of time-criticality

		T	z	p	r
LTC	EFFORT	123.5	1.15	NS	.25
	FRUSTRATION	119.5	.546	NS	.12
	MENTAL DEMAND	131.5	1.47	NS	.32
	PHYSICAL DEMAND	87	-.325	NS	-.07
	TEMPORAL DEMAND	134	1.57	NS	.34
	PERFORMANCE	110	1.59	NS	.35
	OVERALL	148	1.13	NS	.25
TC	EFFORT	80.5	-.219	NS	-.05
	FRUSTRATION	84	.83	NS	.18
	MENTAL DEMAND	82	-.73	NS	.16
	PHYSICAL DEMAND	76	1.48	NS	.32
	TEMPORAL DEMAND	120,5	1.54	NS	.34
	PERFORMANCE	149	1.65	NS	.36
	OVERALL	140	1.31	NS	.29

Workload was also measured by a TDT. Participants had to press a button on their right index finger as soon as they felt the pulse from the sensor placed on their neck. Hit rate (in percentage) and response time (in milliseconds) were measured throughout the whole driving session, but this analysis only shows values obtained during task execution. The mean values for both measures are illustrated in Figure 8.9.

Hit rate and response time were analysed using t-tests (within) for each message task (T1/T2) with HMI as the independent variable. As can be seen in Table 8.11, there were no significant effects of the HMI on both measures for the critical and less-time critical conditions.

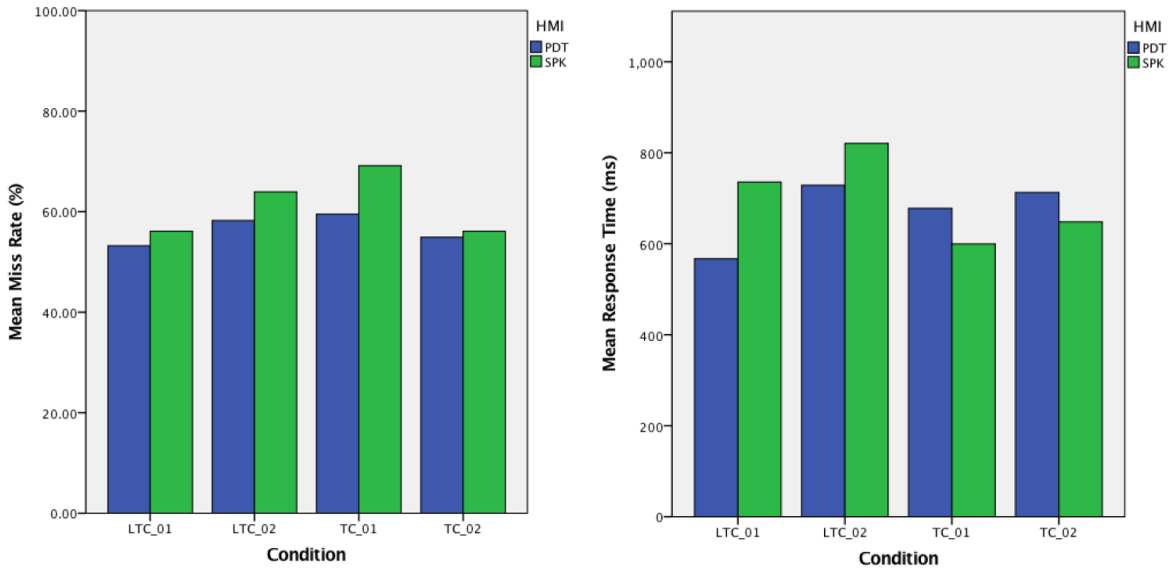


Figure 8.9. TDT mean values

Table 8.11. T-test results comparing two interfaces (speech and pre-defined menu) on miss rate and response time for each sub-task according to their level of time-criticality

		t	p	d
LTC	Miss rate T1	.196	NS	.05
	Miss rate T2	.731	NS	.16
	Response time T1	1.376	NS	.32
	Response time T2	.080	NS	.02
TC	Miss rate T1	1.516	NS	.33
	Miss rate T2	-.005	NS	.01
	Response time T1	-.634	NS	.14

	Response time T2	-.091	NS	.02

8.3.6 Driver acceptance

Driver acceptance was measured using a version of CTAM questionnaire with the five dimensions, displayed in Table 8.12:

Table 8.12. Driver acceptance dimensions

U	Perceived usefulness
EU	Ease of use
ATT	Attitude towards using this technology
BI	Behavioural intention to use this technology
PS	Perceived safety

Participants filled in the CTAM questionnaire at the end of each driving session. The ratings of these five dimensions were analysed using a Wilcoxon signed rank test for each criticality condition separately (TC, LTC) with HMI as independent variable. This data was collected for all participants in the study. Figure 8.10 shows the rating values for each dimension and condition.

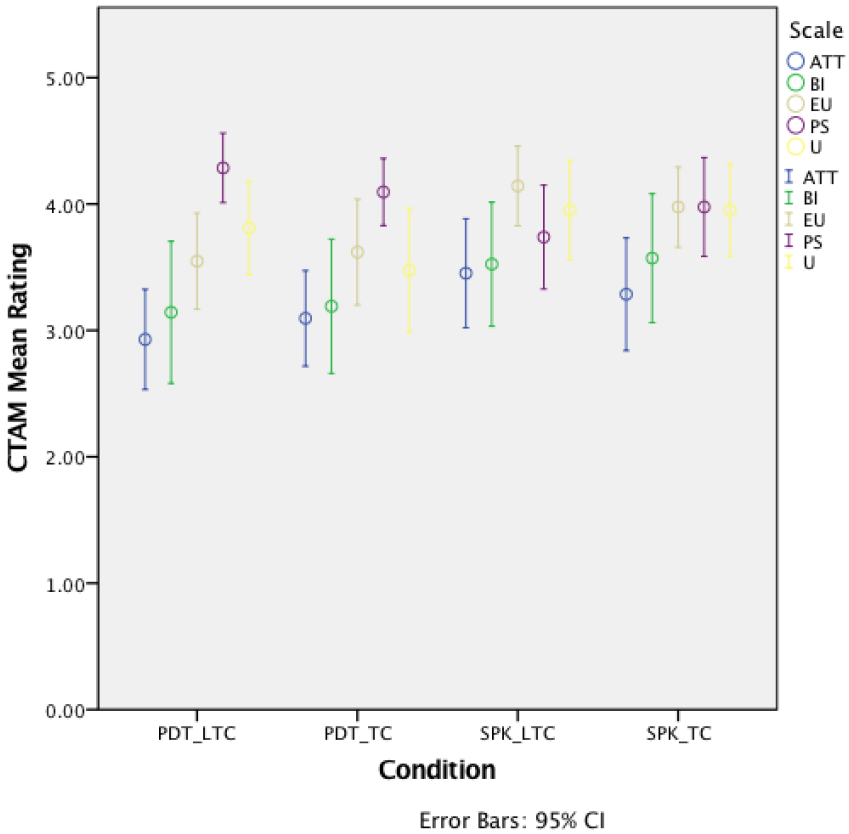


Figure 8.10. Driver acceptance

There were no significant effects of the HMI on ratings for all five dimensions for the time critical condition. For the less-time critical condition, there were no significant effects of the HMI on the U and BI ratings, while the ATT ratings were significantly higher and the EU and PS ratings significantly lower for the speech interface when compared to the pre-defined touch. Results from all Wilcoxon tests are shown in Table 8.13.

Table 8.13. Wilcoxon test results comparing two interfaces (speech and pre-defined menu) on each CTAM dimension for each level of time-criticality

		T	z	p	r
LTC	ATT	0	2.99	.003	.65
	BI	4	-1.38	NS	-.30
	EU	3	-2.52	.012	-.55

	U	12	-.91	NS	-.20
	PS	95	2.75	.006	.60
TC	ATT	22.5	-.98	NS	-.21
	BI	5	-1.55	NS	-.34
	EU	20.5	-1.47	NS	-.32
	U	13.5	-1.81	NS	-.39
	PS	66	.35	NS	.08

8.3.7 Vehicle identification

As part of the process of sending a message, drivers are initially required to identify the receiver of the message, by providing details of the vehicle. Participants in this study were asked to uniquely identify the vehicle by speech in all conditions. Identification by speech was the preferred method to instinctively identify a vehicle as found in STUDY D (see Chapter 07 page 206).

The same formal iterative analysis technique for qualitative data described in section 3.10 was used, which is based on the demarcation of words/short sentences (i.e. codes) linked back to the research aims. Before starting the analysis, a comprehensive list of main codes was produced based on the expected descriptors that would be used by the participants, including “vehicle colour”, “vehicle location”, “vehicle classification”. The researcher then analysed the transcripts for each participant. More codes related to unexpected descriptors were created during this process. The coding process continued in order to find common themes.

The analysis aimed to capture the most common descriptors used, the average number of descriptors and the sequence of descriptors used in a single identification.

8.3.7.1 Descriptors

Participants made 157 unique identifications. The categories of descriptors most commonly used by participants are displayed in Table 8.14:

Table 8.14. Vehicle identification – Descriptors

Category	**Values**
Colour	WHITE, RED, BLACK, TURQUOISE, GREEN, BLUE
Location	AHEAD, IN FRONT, BEHIND, AT THE BACK, ON THE RIGHT / TO MY RIGHT, ONCOMING, IN THE OPPOSITE LANE, ON THE OTHER SIDE OF THE ROAD, IN THE OPPOSITE WAY, ALONGSIDE ME
Classification	CAR, LORRY, VAN, TRUCK, VEHICLE, SUV
Action	COMING TOWARDS ME, PASSING, APPROACHING ME, GOING THE OTHER WAY
External	FEDEX

8.3.7.2 Number of descriptors

Participants used on average three different categories of descriptors to uniquely identify the vehicle to receive the message (see Table 8.15) with two descriptors also frequently used. An example of a three-descriptor identification would be “black SUV in front”.

Table 8.15. Vehicle identification - Number of descriptors

Number of descriptors	**Frequency**
01 descriptor	1
02 descriptors	65
03 descriptors	90
04 descriptors	1
TOTAL	157

8.3.7.3 Sequence of descriptors

The sequence in which each category of descriptor was used to identify a vehicle was also analysed. Table 8.16 shows the frequency for each category of descriptor and the sequence. The cells highlighted in grey show the descriptors most used in each position. Vehicle classification was the most used descriptor overall. This descriptor was used 154 times, mostly as a second descriptor in the identification process. Therefore, results show that a combination of COLOUR (1st) + CLASSIFICATION (2nd) + LOCATION (3rd) was the most commonly used sequence of descriptors applied to identify a vehicle.

Table 8.16. Vehicle identification - Sequence of descriptors

	COLOUR	CLASSIFICATION	LOCATION	ACTION	EXTERNAL	TOTAL
1st	138	17	1	0	1	157
2nd	1	135	17	2	0	155
3rd	1	2	81	7	0	91
4th	0	0	0	1	0	1
TOTAL	140	154	99	10	1	

8.3.8 Message content

The most important part of the process of sending a message is composing the message. Message composition in this study varied according to the HMI used by the participants. Free content messages were composed using a speech-based interface whereas pre-defined messages were selected on a menu-based touchscreen interface. Different analysis techniques were applied depending on the interface. The next two subsections describe the results of message content for each of the HMIs.

8.3.8.1 Free content messages

A thematic analysis technique was adopted to capture the main themes of the free message content for each one of the four communication situations (i.e. tasks) in which participants were required to send a message. These specific predetermined scenarios are representative of other very common situations and it was therefore considered important to investigate what different types of free content messages were sent for each of them. The content of the message varied across the tasks as each situation depicted a different communication scenario. The main themes for each one of the four tasks with their frequency count are shown in Table 8.17. It is important to notice that some messages contained more than one theme.

Table 8.17. Themes - Free content messages

Slow vehicle in front (LTC_T01)	
Theme	**Frequency**
Inform other driver they are going too slow	12
Ask other driver to speed up	8
Question other driver about their driving behaviour	7
Ask other driver to give way	2
Ask other driver if they have problem with their car	1
Inform other driver of their dangerous driving	1
Alert other driver in front they almost hit them	1
Problem with own vehicle (LTC_T02)	
Theme	**Frequency**
Inform driver behind of problem with participant's own vehicle	13
Send driver behind apologetic message	8

Inform driver behind they are driving too close	7
Ask driver behind to overtake	5
Inform driver behind participant is going to pull over	3
Other vehicle cut in front (TC_T01)	
Theme	**Frequency**
Inform other driver they cut in front	13
Alert other driver of their dangerous manoeuvre and request not to repeat	7
Inform other driver they pulled in front too quickly	3
Inform other driver they slammed on their brakes	2
Question other driver what about their behaviour	2
Alert other driver participant almost hit them	1
Curse other driver with swear words	1
Accident on the road (TC_T02)	
Theme	**Frequency**
Provide simplified description of accident to oncoming vehicle	12
Provide detailed description of accident to oncoming vehicle: Lorry with packages falling out on the carriageway FedEx truck turned over on the corner Lorry gone across the road Broken down lorry in your lane as you are approaching. It has turned on its side Overturned vehicle / truck upside down Broken down truck / FedEx vehicle on the road in front of you	8
Ask oncoming vehicle to drive carefully	4
Ask oncoming vehicle to slow down	3

8.3.8.2 Pre-defined messages

A frequency count was carried out to capture which pre-defined messages were selected for each one of the four tasks performed by the participants. More than one category of message was suitable for some of the communication scenarios. Participants in condition LTC_T02, for example, could send either an apologetic message to the vehicle behind or a message saying they have a problem with their own vehicle. As mentioned earlier, participants made a few mistakes when selecting which message to send to the other vehicle. A few participants did not send messages in some situations due to different reasons, such as not finding the category they were looking for, or they were too focused on the driving task. Results for the pre-defined messages are displayed in Table 8.18.

Table 8.18. Pre-defined results

Slow vehicle in front (LTC_T01)		
Message category	**Message**	**Frequency**
OTHER VEHICLE	SLOW SPEED	11
OTHER VEHICLE	GIVE WAY	5
OTHER VEHICLE	CUT IN FRONT	1
-	<<No message sent>>	4
Problem with own vehicle (LTC_T02)		
Message category	**Message**	**Frequency**
YOU/YOUR VEHICLE	PROBLEM WITH OWN VEHICLE	13
YOU/YOUR VEHICLE	SORRY	5
OTHER VEHICLE	DEFLATED TYRE	2
-	<<No message sent>>	1
Other vehicle cut up in front (TC_T01)		

Message category	Message	Frequency
OTHER VEHICLE	CUT IN FRONT	18
OTHER VEHICLE	GIVE WAY	2
-	<<No message sent>>	1
Accident on the road (TC_T02)		
Message category	**Message**	**Frequency**
ROAD ENVIRONMENT	ACCIDENT AHEAD	18
OTHER VEHICLE	DEFLATED TYRE	1
-	<<No message sent>>	2

8.3.9 HMI preference

At the end of the study, participants took part in a short semi-structured interview in which they were asked about their overall HMI preference. They were also asked if they would change their HMI preference when thinking specifically about time critical and less-time critical conditions.

The same formal iterative analysis technique for qualitative data used in the free content messages was also applied to this interview. This analysis is based on the demarcation of words/short sentences (i.e. codes) linked back to the research aims.

Table 8.19 shows the results from these questions. Most participants preferred the speech-only interface for all conditions. Two participants, when asked their HMI preference in time critical and less-time critical conditions did not have a clear opinion about their preferences in these conditions. These participants explained their preferences according to the communication scenarios they experienced (i.e. accident, car cut in front, slow vehicle).

Table 8.19. HMI preferences

Post-trial interviews								
Overall Preference			Time Critical			Less-Time Critical		
PDT	None	SPK	PDT	No Opinion	SPK	PDT	No Opinion	SPK
3	1	17	1	2	18	8	2	11

The main themes found from the post-trial interviews are shown in Table 8.20. This table presents the pros and cons for each HMI according to participants' comments.

Table 8.20. HMI pros and cons

SPEECH-ONLY (SPK)		
COMMENT	**PARTICIPANTS**	
Few taps, quick	P01, P06, P12, P14, P17, P20	+
Can say more things, detailed description	P01, P06, P16, P18	+
Easier	P02, P04, P05, P06, P08, P09, P14, P18, P20	+
Less distractive – no eyes off the road	P02, P07, P09, P11, P12, P14, P15, P16, P17, P18, P20, P21	+
Instinctive, you can just say/talk about what you think, more spontaneous	P01, P02, P03, P05, P08, P12, P13, P14, P15, P17, P18	+
Drain less resources	P14, P17	+
More productive	P18	+
What might come out, might not be what you are as a person	P06, P10	-
Not appropriate for situations where driver might be quite frustrated, reactionary	P06, P10	-

High probability of getting into road rage situation	P06, P19	-
PRE-DEFINED MENU (PDT)		
COMMENT	**PARTICIPANTS**	
Needs to sieve through categories / menu options	P01, P03, P08, P16, P17, P18	-
Hard to find where topic of the message is	P01, P08, P15, P18, P20	-
Need to know application really well	P01	-
Longer interaction time	P01, P08	-
Going back and forth in the categories	P15, P20	-
Appropriate for situations that come from a computer rather than a human being	P06	+
Avoid swearing	P06, P19	+
More generic – (no need for details)	P10, P19	+
Less likely to come across as rude or aggressive or being misinterpreted	P10	+
Don't have to think what to say	P10, P13, P19	+

8.4 Discussion

8.4.1 Task times

According to the results, participants in this study took less time to send a message to other vehicles using the speech interface (average of 10 seconds for each condition) when compared to the predefined touch menu (average of 14.84 – 19 seconds according to the condition). On the one hand, the speech interface consisted of a two-step process, with one screen to identify the vehicle and another one to send the message. The predefined touch HMI, on the other hand, comprised of a minimum of three screens to navigate through to complete the process of sending the message, if the participant knew exactly

which message category to choose. Therefore, it was expected that, by using the speech interface participants would complete the task more quickly. These results are also in accordance with participants' subjective comments in the post-trial interview, in which most of them said they preferred the speech interface because it was easier to use and quicker to complete the task. The values from predefined touch HMI were longer than the 15-second rule defined by Green (1999), a guideline which states that motorists should take no longer than 15 seconds to complete tasks while interacting with in-vehicle devices.

There was little difference in the time to complete the task using the speech interface for all the four task conditions. However, for the predefined menu, participants took longer to send the message in the condition LTC_T01 (i.e. slow vehicle in front) when compared to the other three conditions. The main reason for this difference might be the location of the SLOW VEHICLE message in the menu structure. A few participants commented in the post-trial interview that they were not expecting the SLOW VEHICLE message to be located under the OTHER VEHICLE->DANGEROUS MANOEUVRE category. Therefore, the appropriate design of the menu structure is crucial.

8.4.2 Task errors

More errors were committed using the predefined menu HMI than using the speech interface, mostly by participants selecting the wrong message to send. There might be several reasons for selecting a wrong message from the menu choices, such as the urgent need to finish the task and a lack of understanding of the menu structure and/or the message content. One participant, for example, sent a message "DEFLATED TYRE" which is located under the menu "OTHER VEHICLE" when trying to express that their own vehicle had a problem in condition LTC_T02. The video recordings showed a couple of

participants struggling to find the right message to send after navigating through most of the menus. After an unsuccessful attempt, these participants just selected the first message they could find in order to complete the task. Participants also misunderstood the "GIVE WAY" message, which should be used when giving right of way to vehicles at junctions and thought it was a request to let them overtake. All of these problems confirm the importance of the appropriate design of the menu structure and the individual screen targets/icons.

Another common error found was not identifying the vehicle. The prototype system used in this study was designed to allow participants to move to the message composition stage without providing a verbal description of the vehicle. In the final version of the system, this would not be possible, as a description is required by the system to uniquely identify the car to receive the message. An error message would be raised if the driver tried to skip this step.

8.4.3 Driving performance

No significant differences on mean speed and speed variation were found when comparing the two HMIs. A possible reason for this result might be that participants were focused on driving as the main task while completing the process of sending the message. Although not significant, the speed variation for the predefined menu was higher than the speech interface in all conditions. This result is in accordance with other measures, which showed a higher time to complete the task and a higher number of off-road glances for the predefined menu interface.

8.4.4 Off-road glances

Driver distraction can be measured in different ways, with the number of off-road glances made by drivers being one of the most common measurements. According to extensive

research on driver distraction, speech interfaces are considered less distractive, as drivers are not required to take their eyes off the road while interacting with them (Barón & Green, 2006; Ranney et al., 2000). Similar to this, results from this particular study show that participants made a significantly higher number of glances towards the predefined menu interface when compared to the speech only interface. The number of long glances and mean glance duration were also higher for the PDT.

The total number of glances towards the device is also connected to task completion time. The speech-only interface required fewer steps for participants to complete the process of sending a message. Therefore, participants took less time to complete the task with significantly fewer glances made towards the speech-only interface.

The results were compared to the acceptance criteria described in the interface guidelines on visual distraction proposed by the National Highway Traffic Safety Administration (2012). Mean glance duration while sending the message was below 2 seconds for all conditions, which is in accordance with the guidelines. Moreover, less than 15% of the total number of off-road glances were longer than 2 seconds. However, for the PDT, the total glance time was higher than 12 seconds for most participants.

The heat map shows that participants also had a slight medium frequency of glances made towards the speedometer and the rear-view mirror. These glances are related to the nature of the communication scenario (i.e. condition). In condition LTC_T02, for example, participants had a vehicle behind driving too close to them. Therefore, a higher number of glances to the rear-view mirror was expected. Also in this condition, the speed of the vehicle was automatically reduced by the system to simulate a problem with the car. Participants were constantly checking the speedometer while trying to understand what was happening.

8.4.5 Driver acceptance

Driver acceptance was measured using a version of the CTAM questionnaire, which contained five dimensions. The first dimension was perceived usefulness, which had no significant differences in the ratings when comparing the two HMIs. Participants scored on average a minimum value of four out of a maximum of five for this dimension, which shows that, for the scenarios presented in this study, the DDCD can be considered a useful device regardless of whether it is used as speech interface or a predefined menu touchscreen device.

Ease of use was the second dimension used to measure driver acceptance. Participants found the speech-only interface to be easier to use than the predefined menu with higher ratings for this dimension and significant results for the less-time critical condition. This result is in accordance with subjective comments from the post-trial interview in which most participants clearly mentioned their preference for the speech interface due to several aspects, including its ease of use.

Participants ranked their attitudes towards using the technology for each HMI and task scenario (LTC, TC). A higher rank for this dimension may suggest an emotionally positive reaction overall and therefore higher acceptance of the technology. Although no significant difference was found for the time critical condition, participants ranked their attitudes towards using the speech interface significantly higher than the predefined menu for the less-time critical condition.

The behavioural intention to use the DDCD was the fourth item measured. No difference was found for each type of HMI in both criticality conditions. Although participants may have a more positive attitude towards the speech interface and consider it to be easier to use, their behavioural intention to use the device appears to be the same no matter which type of interface.

Information about the perceived safety of the DDCD was the last dimension investigated. There was an overall preference for the speech-only interface according to the subjective comments. In addition, the quantitative data indicates a speech-only interface to be safer (i.e. fewer off-road glances, less task completion time, less number of errors). However, there were no significant differences in terms of how safe the speech HMI might be when compared to the predefined menu. Contrary to expectations, the speech interface surprisingly had lower ratings of safety for the less-time critical condition. There is apparently no logical explanation for this specific result, especially when participants rated the speech-only interface as significantly easier to use for this same condition. Participants may have experienced a higher cognitive demand to express their message verbally in the two less-time critical scenarios, which required them to ask the driver in front to speed up (i.e. T01) and to inform the driver behind that they had a problem with their own vehicle (i.e. T02). This difficulty may have resulted in participants perceiving the speech-only interface to be less safe.

8.4.6 Workload

Workload was measured through a tactile detection task and subjectively using the NASA-TLX questionnaire. There was no significant difference in workload for the speech interface when compared to the predefined menu for all conditions.

Results from the tactile detection task show a slightly higher percentage of missed hits for the speech interface in all conditions. This could be interpreted as a consequence of participants concentrating more on finishing the task using the speech HMI, which took a significantly shorter time to complete.

Results also show a slightly lower mean response time value to the tactile detection task for the predefined menu HMI in the time critical condition. However, for the less-time

critical condition, a slightly higher mean response time value was found for the predefined menu HMI. However, these differences in response time were not significant. No significant difference was also found in the subjective workload ratings from all seven sub-scales of the NASA-TLX questionnaire. Overall, participants rated the workload they experienced with the speech HMI similar to the predefined menu interface. This result may indicate that with regard to workload, both types of HMIs for a DDCD could be effectively used in vehicles.

8.4.7 Vehicle identification

Results on the vehicle identification process from this particular study are very similar to the ones found in STUDY D (see Chapter 07, page 206). Overall, participants used either two or three descriptors to uniquely identify the vehicle to send the message to. The most common descriptors used were vehicle colour, vehicle classification and vehicle location in this specific order. This specific sequence was found with participants using the English language and could quite possibly be different for speakers of other languages. For example, some languages always place the adjective after the noun, so in this case CLASSIFICATION would come before COLOUR. Designers of a vehicle identification system should therefore focus on improving these categories of descriptors first, employing an extensive vocabulary of terms that may be used by drivers.

8.4.8 Message content

Results from free content messages sent using the speech interface, show that participants used a diverse range of messages for the same communication scenario. These results could potentially be used by designers of a PDL system to understand what the most common messages sent to other drivers are in each scenario and then use the most common ones to create a message entry in the menu.

Participants composed short and long free content messages. Long messages contained more details about the situation, such as information about the accident on the road ahead. Although very useful, drivers could take a long time to send these messages. If a speech recognition system is used, the longer the message is, the longer it may take to recognise the message. If the message is not converted into a simpler form, the driver who receives the message will also take more time to fully understand a long message than a short one. Even though a long message may aid the driver in providing details of the situation, this increased overall time in sending and receiving the message may prove to be a disadvantage.

Results from the pre-defined messages selected from the touchscreen interface, show that a few participants selected the wrong message category from the menu. It is important to fully test the menu structure with drivers using several methods in order to understand if these users have a thorough understanding of what they represent. Moreover, the design of the message is also very important. Two participants wrongly selected a "GIVE WAY" message, which was supposed to be sent when a driver wants to give way to another driver at a junction and not to a slower vehicle in front.

8.4.9 HMI preference and communication scenarios

Generally, participants reported they would prefer the speech-only interface as, if used correctly, they have the freedom to say what they want (P18). This HMI can also be used in both criticality conditions (P17). However, as pointed out by participant P01, the speech recognition system must be fast, otherwise it could take a long time to send the message. Unlike most participants, a few of them mentioned they did not know what to say to the speech recognition system (P04) and that they took a long time to articulate their thoughts (P10). A carry over effect from one HMI to the other was noted as one

participant said that the categories in the pre-defined menu helped them decide what to say in the speech-only condition (P08).

The pre-defined menu was seen as too distracting, especially in time critical conditions (P09), with higher mental workload (P14). Participants also reported they were unsure if they had selected the right topic of message (P06) and they did not understand why the "slow vehicle in front" topic was located under the dangerous manoeuvre sub-category (P08). One participant confessed that they panicked when they could not find the topic they wanted to send in any of the menu categories (P15). A few participants mentioned that once they became accustomed to the predefined menu after a longer period of use, they might prefer it to the speech-only system (P02, P13). This could be investigated with a longitudinal study.

A few participants suggested having some kind of HMI that could send messages quickly (P06, P10, P19), similar to the concept of the flashing of headlights, which is very quick (P06), without the need for extra details, just as a warning (P19). A combination of both HMIs was then suggested by P10, in which a predefined menu would be the base HMI with the possibility of this being overridden by speech in urgent time critical scenarios such as an accident ahead. The driver could, for example, just shout one word, e.g. "WARNING".

Most participants said that they would prefer the speech-only interface in time critical conditions. In these scenarios, there is a lot happening (P15), with not enough time to concentrate (P15) and therefore speed is of the essence (P01). There is no time to look at menus and search for the right option (P02). It is much quicker (P10) and easier to just say the message (P08) than to navigate through the predefined menu, which has a longer interaction time (P01).

Most participants still preferred the speech-only interface in the less-time critical condition as well, as they can have more time to think what they want to say (P16) or they can take this slightly extra time to concentrate on the driving task (P21). However, some participants reported they would prefer the pre-defined menu for this condition, as they would have more time to navigate through menu selections (P03, P06, P08, and P15).

One participant stated that the time critical scenarios were more important than the less-time critical ones and that they would only use the DDCD in the time critical conditions (P09). The less-time critical communication scenarios were also viewed as situations that do not happen very frequently in real life (P06).

The communication scenarios presented to participants had an effect on their behaviour. One participant mentioned they would not trust herself to send messages quickly enough if they knew it would depend on the safety of others and they would also feel guilty about not being able to let other drivers know about an accident (P06). Conscientious, careful drivers would expect and hope that other similar drivers would be concerned about the safety of others on the road.

8.5 Limitations

Participants interacted with two different interfaces, each one with its own type of message. Ideally, the same types of messages should be available for each interface. Two possible combinations of HMI and message type were omitted from this study, i.e. free content messages on touchscreen interface and pre-defined message selection on a speech interface. The time constraints of driving communication scenarios make it impracticable for these two types of interfaces to be used as it could take a long time to complete the interaction. Moreover, extensive research on driver distraction has proved

that drivers should not text while driving as this is a major cause of road accidents (Klauer, Gut, Simons-Morton, Ouimet, Lee & Dingus, 2014).

The NASA-TLX and CTAM questionnaires were given to participants only at the end of each driving session, which comprised of two communication scenarios. Therefore, their response to these questionnaires, were based on the two communication scenarios they experienced. The main reason behind this decision was to allow participants to have a more natural driving experience without the need to stop the driving scenario after each task.

Finally, a few participants mentioned that they found the study to be very difficult in some communication scenarios, as it involved gear change due to sudden braking, the tactile detection task and the task of sending the message. All of these tasks occurred in a very short space of time.

8.6 Conclusion

Sending a message is an important part of the driver communication process. Different HMIs to send a message can have an impact on driver acceptance, driver distraction, driving performance and workload. The study revealed that, although there were no significant differences in driving performance and workload for the speech-only and pre-defined menu interfaces, participants had a higher acceptance rate for the speech interface. This acceptance was also confirmed in the interviews, in which most participants showed strong preferences for the speech-only HMI. Results from the eye tracking showed that a higher number of off-road glances were made using the predefined menu, which could lead to increased driver distraction.

Further work in predefined messages need to investigate the best ways to group these messages in a predefined menu structure as a few participants had difficulty finding a

specific message topic. It would also be important to research which graphic and textual symbols should be used for each message topic and investigate participants' understanding of each message. Further work on free content messages should investigate the time to complete the task using a working version of a speech recognition system in order to investigate the whole set of issues that could occur. It would also be necessary to investigate the length of messages with a combination of short and long verbal messages. Finally, further research could be carried out with a combined version of both speech and touch interfaces.

The next chapter extends the driver-to-driver communication framework introduced in Chapter 04 by adding a list of specific design recommendations for the DDCD. These recommendations are based on all studies described in this thesis including the one presented in this chapter.

9 Design guidelines for a driver-to-driver communication device

9.1 Guidelines and the driver-to-driver communication framework

This chapter extends the driver-to-driver communication framework introduced in Chapter 04 by including a list of design guidelines for a DDCD. Guidelines can be used as a means of transferring knowledge to designers and also as a direct source of reference and guidance for them to apply during the design process (de Souza & Bevan). According to Häkkilä and Mäntyjärvi (2006), design guidelines have the power to improve the usability of a product by helping designers to achieve the optimal outcome when designing a product. The authors suggest that guidelines should be thought of as a summary or abstract of current knowledge and a stimulus to the growth of further knowledge. Guidelines can include restrictions (Häkkilä & Mäntyjärvi, 2006), but most importantly they should be clear and straightforward, making it possible for designers to easily build systems that can validate their implementation (Abascal & Nicolle, 2005).

The research presented in this thesis investigated different aspects of a driver-to-driver communication such as the identification of vehicles, message presentation and system interaction. As part of this investigation, it was possible to generate a list of design recommendations based on the results of the studies conducted. Even though some of these recommendations relate to the results of this research, they could also be applied to any other in-vehicle device and therefore they are not unique to a DDCD. Examples of such generic guidelines are that the DDCD should be integrated with other in-vehicle devices, should be designed to reduce driver distraction or that drivers should be able to

switch off the device whenever they want to. Moreover, some of these generic recommendations could not be linked back to the driver-to-driver communication framework and therefore they are not presented in this chapter as separate guidelines.

Unlike some of the guidelines presented in the studies chapters, the recommendations presented here are not explicitly linked to how the HMI of the device should be designed or how the system interaction should be operated. This PhD research investigated several ways that the DDCD could be designed in terms of modalities for message presentation (e.g. audio, visual) and system interaction (e.g. free-air gestures, touchscreen gestures, speech recognition). Consequently, the guidelines presented in this chapter are flexible enough to be able to be applied to all these different types of interfaces. However, as a rule of thumb for any type of in-vehicle device, no matter what type of HMI is chosen, the DDCD should be optimised to that interface in order to minimise workload and reduce driver distraction.

The relatively small set of guidelines described in this chapter is very closely related to the driver-to-driver communication framework. One important component of the framework described in Chapter 04 is a set of variables that affect communication between two drivers. Each guideline presented in this chapter is linked to at least one variable that affects driver communication. Therefore, these design recommendations were incorporated into the framework. These recommendations can be used with the other components of the framework to help designers and developers of a DDCD in the automotive industry.

Table 9.1 shows all the 16 guidelines with their identification codes. The guidelines are not categorised in order of their importance, as all of them are equally relevant. The titles of the guidelines aim to follow the structure of other well-established guidelines in the areas of HCI such as Nielsen (1994) and Shneiderman (2003). The titles are succinct and

some of the guidelines aim to describe relevant functionalities that should be supported by the DDCD. The titles of other guidelines follow a different approach, describing what the user of the DDCD should be able to do.

Guidelines can be generated based on empirical data or from a review of the literature in the area of interest (Smith & Mosier, 1984). Most of the guidelines presented in this chapter are derived from the results of the studies carried out in this research. However, a few of them are also supported by relevant literature. In order to create these guidelines, the researcher listed all the results from the studies presented in this thesis and the main areas covered in the literature review. The researcher then combined any similar results and areas in the literature into one specific guideline. The final list of 16 guidelines was then designed.

The connection between the guidelines and variables is depicted in the diagram in Figure 9.1. The variables are presented with different colours in the diagram to make it easier and clearer for the reader to see the connections with the guidelines. In the next sections, each guideline is described in detail with examples and references to the results of the studies or the relevant literature which they come from.

Figure 9.1. Connection between variables and guidelines

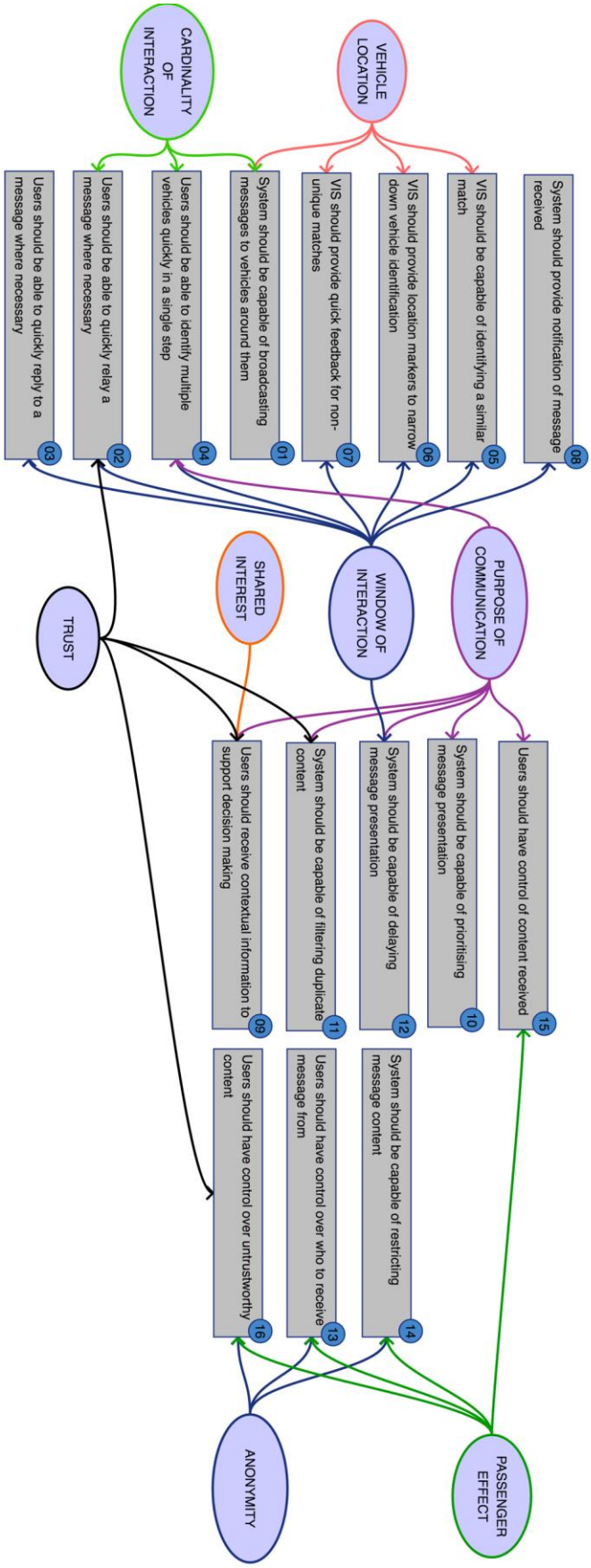


Table 9.1. Design guidelines for a DDCD

ID	GUIDELINE TITLE
01	System should be capable of broadcasting messages to vehicles around them
02	Users should be able to quickly relay a message where necessary
03	Users should be able to quickly reply to a message where necessary
04	Users should be able to identify multiple vehicles quickly in a single step
05	VIS should be capable of identifying a similar match
06	VIS should provide location markers to narrow down vehicle identification
07	VIS should provide quick feedback for non-unique matches
08	System should provide notification of message received
09	Users should receive contextual information to support decision making
10	System should be capable of prioritising message presentation
11	System should be capable of filtering duplicate content
12	System should be capable of delaying message presentation
13	Users should have control over who to receive message from
14	System should be capable of restricting message content
15	Users should have control over content received
16	Users should have control over untrustworthy content

9.2 Design guidelines for a DDCD

01 – The system should be capable of broadcasting messages to vehicles around them

As discussed in the literature review chapter, innovative research has been conducted on how to use in-vehicle technology to share information to promote social awareness to surrounding road users (see section 2.3.3). Among the areas of social/connected vehicles covered, there is relevant research on how drivers can use technology to express their current emotions and/or state to all drivers around, such as the fact that the main driver is in a hurry or in an emergency situation (Schroeter et al., 2012; Soroa et al., 2014; Wang, Gu, et al., 2014). This idea of sharing the drivers' current status was also investigated in STUDY A with high acceptance from participants (see section 5.3.3.6).

This guideline states that the DDCD should have functionality to allow drivers to set up special types of messages to be broadcast to all motorists around them. There may be some situations where a driver would like to broadcast a message to all vehicles nearby about something regarding themselves or as a means of justifying their driving behaviour. This situation could be, for example, the reason for driving slowly or their mood at the time. Moreover, this broadcast message could be automatically relayed to other drivers when they are within a certain distance of the sender. There would be no need for the sender to identify a target vehicle/s as this would always be a message relevant to all vehicles near the sender. Consequently, this guideline is linked to the location of the vehicles at the moment and the cardinality of interaction, which is one-to-many in this case. This special category of communication could be implemented either as a free content message or based only on a predefined list of possible broadcast topics.

02 - Users should be able to quickly relay a message where necessary

There may be some situations where a motorist would like to relay a specific message to other drivers, such as information about a road incident or adverse weather conditions. As reviewed in Chapter 02, different forms of CMC also allow users to relay messages, such as forwarding an email or sharing a text message using a mobile phone (see page 25). Similar to the email analogy, the sharing of information is highly beneficial, especially if the message is relevant to all addressees. More users would be able to receive and acknowledge the message covering a greater area.

This guideline states that the DDCD should be designed in such a way that users should be able to share information received quickly by relaying the message. This process of relaying a message should be much quicker than composing a message from the beginning, as the content of the message is already defined. Consequently, this functionality would allow drivers to complete the process of sending a message in a much shorter time. This means that drivers should be able to relay a message in time for it to still be valid and relevant at the moment it reaches the receiver/s.

This guideline is related to cardinality of interaction as the message can be relayed to either one driver or to multiple drivers, with the latter being the most common scenario. This guideline can also indirectly promote trust in the communication between drivers. A driver who receives a message related to a road incident, for example, would have more confidence that the message is indeed true if the receiver has information stating that more than one driver has actually sent that same message. This was one of the results from STUDY B (see page 153) and it was also investigated in STUDY C where a visual message was depicted with an icon stating the number of drivers who sent the same message (see page157). The relay of a message/s is therefore highly recommended in the design of the DDCD.

03 - Users should be able to quickly reply to a message where necessary

The literature presented in Chapter 02 explains that human communication is based on constant coordination mechanisms to establish common ground with one of the constraints in the communication being the act of receiving information in a sequential, consecutive manner (see Table 2.1). This concept applies to all forms of human communication where a person responds to the other in sequence and the conversation is therefore maintained. Driver-to-driver communication as an asynchronous type of conversation may also require this sequential form of interaction in which one driver could reply to another driver's message. Therefore, this guideline states that the DDCD should be designed in such a way that drivers should be able to reply to any message received in a quick way. This means that drivers should be able to reply to a message in time for the reply to still be valid and relevant at the moment it reaches the receiver.

According to the task analysis presented in section 4.2, the process of replying to a message should be quicker than composing a new message because there is one less step involved as the user does not need to identify the addressee. However, due to the significant effect of time criticality on driver communication, it is crucial that the reply to the message should be completed even more quickly, otherwise by the time the receiver replies to a message it may have lost its validity or purpose.

04 - Users should be able to identify multiple vehicles quickly in a single step

The task analysis presented in section 4.2 shows the identification of the driver/s to receive the message as a crucial task required by all users before actually sending a message. The review of the literature on human communication also indicates many costs involved in establishing common ground, one of which is the cost involved in starting a new conversation, or getting the addressee to notice that the speaker wants to

communicate with them (see Table 2.2). Different techniques may be adopted to reach this objective. These techniques vary according to the number of receivers involved, i.e. cardinality of interaction.

This PhD research specifically investigated the identification of a single vehicle (see STUDY D - Chapter 07). However, there are many situations in which the driver may want to send a message to more than one vehicle at the same time. Some of these scenarios were adopted in this research. One example of such a situation, i.e. a one-to-many interaction, would be to alert oncoming drivers of an accident on the road ahead of them. Some of these scenarios involve very short periods of interaction. Therefore, the whole process of sending a message, including vehicle identification, must be optimised.

This guideline aims to cover situations in which a driver may need to send a message to multiple vehicles. The DDCD should be designed to allow its users to identify multiple vehicles quickly, preferably in one single step. By completing this task quickly, users would be able to move to the next step and compose the message while it is still relevant to the context, i.e. within the window of interaction.

This guideline is not only related to the variables of cardinality and window of interaction, as explained in the previous paragraph, but also to the location of the vehicles. The DDCD should be able to cover situations in which the receivers of the message could be situated in different locations (e.g. all oncoming vehicles, all vehicles in front, vehicles within a specific radius range).

Different approaches to multiple vehicle identification can be used according to the message type. For example, a message that aims to alert multiple drivers of an incident on the road (e.g. accident, pothole, animal) could be linked to a specific location on the road where the incident took place. All vehicles travelling towards that specific location would automatically receive the message. There is no need to identify multiple vehicles

in this case, only the exact location of the incident. Therefore, this guideline is also closely related to the purpose of communication, which is another variable that affects driver communication.

05 – The VIS should be capable of identifying a similar match

One of the most common errors in the process of a single vehicle identification, as described in Chapter 07 (see page 218) is when the exact description provided by the driver does not generate a unique identification. There are many reasons for this kind of error to occur. One reason might be that drivers provide a similar, but not exact description of the vehicle at the moment of identification. Results from STUDY D showed that drivers were uncertain about some of the descriptors used, such as the make and model of the vehicle (see section 7.4.6.2). Visual limitations may also affect a perfect identification, as described on page 219. Examples of these limitations would be too much darkness or brightness and long distance from the target vehicle. Due to these visual limitations, the driver may describe a vehicle as a brown SUV when it is actually a dark red one. Drivers may also describe a vehicle as being a blue saloon from one specific car manufacturer when it is actually a blue saloon from another car manufacturer with very similar design.

This guideline states that the VIS should be capable of identifying a similar match as a unique match based on the vehicles around at the moment of identification. One example of how this could actually be implemented is by having a comprehensive and up-to-date database of the synonyms or related content for the descriptors most commonly used. The most commonly used descriptors are described on section 7.4.1. This database would need constant updating to include new categories of descriptors and their values. As soon

as an identification task is performed and no match found, the VIS would query this database to find similar values that could lead to a unique match.

As previously mentioned, a long distance from the vehicle in front may affect precise identification. This unique and clear identification may also be affected if the target vehicle is an oncoming vehicle or located behind the main driver. Therefore, this guideline is closely related to one of the factors that affect driver-to-driver communication, which is the location of both vehicles involved.

This guideline is important because it can help reduce the overall time required to complete the process of sending a message to another vehicle. This is particularly relevant for some situations in which there is very brief moment of interaction. Therefore, this guideline is also closely related to the variable window of interaction.

06 – The VIS should provide location markers to narrow down vehicle identification

One of the three most common ways to identify a vehicle to receive a message is by providing a description of its location (see page 206). This research found that there are many verbal ways to provide the location of the vehicle, from the basic ones such as "vehicle in front" or "oncoming vehicle", to more advanced ways, which make use of other points of referential identities such as "vehicle at the bus stop" or "vehicle in front of the traffic lights". Drivers might also use finger pointing gestures (see section 7.4.5).

However, results from STUDY D also found alternative ways that could be implemented which could help narrow down the location of the vehicle. One of these alternatives, described on page 221, is to provide location markers on the windscreen (see Figure 9.2). The DDCD could be designed in such a way that it could present a set of areas displayed on the windscreen in front of the driver. The driver would then simply select in which

area the target vehicle is located. This guideline is not restricted to specific HMI designs as the system interaction could be achieved in different ways, such as by providing speech commands ("P1"), by using pointing a finger/s in the air on the windscreen or by touching the area on the head-down display. This same approach could also be used to identify oncoming vehicles.

This guideline is related to two main variables of the driver-to-driver communication framework, the location of the vehicle and window of interaction. The former is easily explained as this guideline is entirely concerned with how the location of the target vehicle could be further developed by enabling drivers to narrow down possible results quickly. Similar to the previous guideline, this would aid drivers in completing the task of sending a message faster, which would be particularly helpful for time critical situations in which drivers encounter a very short window of interaction to communicate to other drivers.

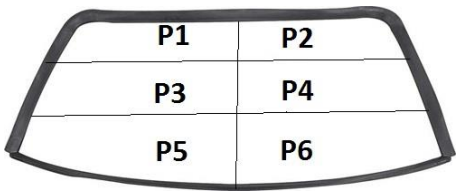


Figure 9.2. Location markers

07 – The VIS should provide quick feedback for non-unique matches

This research found that one of the most common errors in a single vehicle identification is when the users do not provide enough information to be able to narrow down the identification to only one car (see section 7.4.6.4). Consequently, the identification process is not successfully achieved, as more than one vehicle could potentially receive the message, which was intended for only one driver. This guideline states that the VIS should be designed in such a way that, if the system is not able find only one match, it

should successfully support the users by providing prompt and helpful feedback. This feedback should be quick enough so that the driver can move to the next step of actually composing and sending the message.

As mentioned in Chapter 07, there are several ways that this can be accomplished (see page 225). One particularly useful approach is for the DDCD to present the vehicles found as the result of the non-unique identification quickly so that the drivers could narrow down their identification. The identification process could be completed more quickly if the DDCD, for example, provided extra information to the driver on significant differences between the vehicles found. This significant difference could be any commonly used descriptor such as the colour of the vehicle or the make and model. Drivers could then narrow down their identification to only one vehicle by informing the DDCD of the specific description, which differentiates one vehicle from the others.

For example, a user may want to send a message to another driver in a red saloon in front and initially only identifies the vehicle as a red car in front. The identification provided by the user returned three potential red vehicles, one saloon, one SUV and one van. The driver could then inform the DDCD they want to send the message to the saloon. Alternatively, if this approach proved unsuccessful, a clear, simple and unambiguous error message must be presented, which would force the driver to restart the identification process.

No matter how the feedback to a non-unique match is implemented, it must be provided very quickly, otherwise drivers would not be able to move to the next step in time to send the message to other motorists. For this reason, this guideline is closely connected to the window of interaction. This guideline is also directly related to the location of the vehicles. It was found in STUDY D that one of the main descriptors used to identify the target driver is the location of their car (see page 206). The DDCD could also present the

location of the vehicle as a descriptor, which would help narrow down the identification process.

08 – The system should provide notification of message received

Human communication involves a person trying to communicate with another person and this other person acknowledging the communication. Different forms of communication require different forms of acknowledgement to establish common ground with different costs in terms of the reception (see page 18). For example, in face-to-face communication, just a nod or a facial expression might be enough for the speaker to know if the listener understood what they were trying to communicate. This same concept applies, but somewhat differently to driver-to-driver communication. The driver who sends the message must have some way of knowing that the other driver has successfully received and acknowledged the message sent. This guideline states that the DDCD should provide some form of confirmatory notification that a message was successfully sent and acknowledged by the other driver. The early stages of this research also found the need for this functionality (see page 130).

The process is two-fold. Firstly, the driver needs to know that the message was successfully sent, i.e. that there was no communication error whatsoever when trying to send the message. Secondly, and equally important, the driver needs to know if the other driver has received and acknowledged their message. This feature is particularly helpful in a one-to-one communication scenario. The message may be successfully sent, but the other driver may not have acknowledged the message due to many reasons. For example, the driver could have the DDCD turned OFF or could have blocked that particular type of message. The driver could have received the notification of a new message but decided not to acknowledge it at that moment. Therefore, the driver who sent the message must

receive this information to help support their decision-making. These confirmatory notifications can also promote responsible use by notifying the sender that the message was successfully sent and that there is no need to re-send the same message.

These notifications could be implemented in different ways, which can vary according to the HMI, but it is very important that they should minimise workload. This guideline can be particularly beneficial for time critical situations. For some scenarios, however, this second notification of driver acknowledgement may not be necessary as the behaviour of the other driver may already indicate that they have received and understood the message. Even so, the notification should still be provided.

09 - Users should receive contextual information to support decision-making

There are driving communication situations that could be considerably improved if the message is transmitted with additional contextual information to support drivers' decision-making process. This research investigated some of the situations that could potentially benefit from this functionality with ways of how this could be implemented.

One particular scenario in which this was thoroughly investigated was to provide contextual information about an incident on the road. According to the results of STUDY B, messages should be designed to contain an extra piece of information whenever possible indicating that it came from a reliable source such as the traffic police (see page 153). Drivers would feel more secure if the message had some indication that a higher authority endorsed it.

In case more than one driver sends the same message, the DDCD should group the messages, presenting an extra piece of information stating the number of vehicles that have sent that message (see section 6.1.3.2). This was investigated in STUDY C and would contribute to an increase in trust, as already discussed in other guidelines.

Results from STUDY E showed that some drivers felt the need to provide extra details about the incident on the road, such as information about the vehicle/s involved and the condition of the road (see Table 8.17). In this case, drivers should be able to use free content to provide more information to offer specific details about the exact context.

Results from STUDY B also show drivers would like to know the distance from the incident and traffic delay times (see page 153). These two pieces of information could easily be presented if the DDCD is integrated with an IVNS.

This research also investigated other situations in which contextual information could prove beneficial. Results from STUDY B found that some drivers might feel obliged to respond to all messages, depending on how they were phrased (see section 6.1.3.1). An example of such a situation is the scenario where a driver would like to pull in front of other drivers. This same message could be rephrased, and instead of a simple request to pull in front (e.g. "Let me in") it could be a clear indication as to which direction the driver wants to go (e.g. "I need to make a U-turn just ahead"). The driver who then receives this message could decide if they want to let the car pull in front of them or not. Again, the senders would need free content messages in this case to explain the reason for a request. Consequently, the way that the contextual information is presented can vary according to the purpose of communication.

10 – The system should be capable of prioritising message presentation

The DDCD could be used in any driving scenario where drivers need to communicate with others to make their intentions clear, especially in situations where there is no other form or pre-established signal (e.g. indicators). Although this statement is true, this research found that there are some specific communication scenarios where the DDCD proved to

be especially useful. This research investigated driver acceptance of the DDCD in several different driving communication scenarios.

Results from previous studies of this PhD research, show that most motorists are not willing to send and receive messages in scenarios not related to driving, such as simple social interactions (see pages 153, 187). There is, however, a group of situations in which the use of the DDCD is highly desirable, as the results of previous studies indicated. These communication scenarios include potentially dangerous situations that could lead to accidents if the driver is not well informed or at least not quickly warned beforehand. The DDCD proved to be particularly useful in keeping the driver informed of potentially dangerous situations. The use of traditional communication such as flashing headlights does not help the driver to identify these instances uniquely or unequivocally.

There may be some moments when motorists may be driving in demanding conditions, which may prevent them from instantly acknowledging all messages received. The DDCD could store messages received while driving in these conditions and present them to the users later. A backlog of messages would then be formed, which the users would be able to acknowledge only later, when driving in less demanding situations. This concept is also covered in Guideline 12, i.e. system should be capable of delaying message presentation.

This guideline recommends that the DDCD should be capable of automatically prioritising which message in the backlog should be received first by the users. Messages should be prioritised according to how relevant the purpose of communication is and not by their timestamp (i.e. the moment they were received). Therefore, the DDCD should present relevant messages first, such as messages related to accidents or adverse weather conditions. These messages have a direct effect on the driving task and are considered more important than other categories of messages such as social messages.

11– The system should be capable of filtering duplicate content

There are some situations where a driver may receive the same message two or more times within a short period of time. For example, two or more users may send the same message to a group of vehicles to alert them about an animal on the road ahead. A driver may also send the same message repeatedly to another vehicle, either in abusive way or by mistake. Therefore, this guideline states that the DDCD should be capable of automatically noticing and filtering messages with duplicated content sent within a short period of time. As soon as the first message has been presented, the system could screen out the other messages with the same purpose and content as duplicates. This would allow drivers to be less distracted by messages that they have already acknowledged and understood. For this reason, this guideline is closely related to the variable purpose of communication.

Alternatively, this duplicated content could be represented as an extra piece of information stating the number of vehicles that sent the same message. This form of presentation was investigated in STUDY C (see Table 6.3) and is a way that the guideline number 09 could be implemented. This extra piece of information could be particularly useful in situations such as an accident ahead on the road or changes in weather conditions. Users would have higher trust in the content of these messages, as there is less probability of misuse of the device by several users at the same time.

12 – The system should be capable of delaying message presentation

There are moments when motorists may be driving in difficult conditions, which may prevent them from instantly acknowledging all messages received. During these moments, drivers may experience a higher cognitive workload, which requires them to focus their attention and cognitive resources primarily on the driving task (Ranney et al.,

2000). Therefore, message presentation must be avoided in these situations. This guideline states that the DDCD should be capable of automatically noticing these demanding situations and delaying message presentation to the users. The DDCD could store messages received while driving in these conditions and present them to the users later. A backlog of messages would then be formed, which the users would be able to acknowledge only later, when driving in less demanding situations. This guideline would use the same infrastructure discussed in Guideline number 10, i.e. system should be capable of prioritising message content.

Even if the driver is willing to receive all types of messages, the DDCD should be able to postpone the notification of a new message if the circumstances prove to be too demanding for drivers. An example of such a circumstance could be driving at high speed with vehicles either in front or behind, but very close to each other. As soon as the driver reached a situation where the DDCD can detect that they can receive the message without negatively affecting their driving performance, the notification of a new message could be presented to them.

This guideline could be implemented using workload managers. Workload managers are able to adjust the availability of the information presented to the drivers according to several external factors such as the users' current state, the vehicle and the environment, specifically in situations where the driver has an overload of mental activity or is distracted (Green, 2004; Hameed & Sarter, 2009). Drivers' current state could be captured by the direction of their gaze or their heart rate. However, the current user state is the most difficult aspect to capture (Green, 2004). Regarding the environment and the vehicle, the DDCD could be integrated with sensors available in the car such as proximity and speed detection. The DDCD could receive information from all the sensors available in the vehicle before making a decision as to whether the driver should send or receive a

message at any particular moment. Message presentation could also be optimised if the DDCD is integrated with other devices in the vehicle. IVNS has the potential to work very well with the DDCD, especially in situations where a map is required or when drivers need to change their routes due to a message received. This was a design recommendation based on results from STUDY B (see section 6.1.3.2).

There is a significant risk involved in delaying the presentation of any message. The main risk involves the message losing its relevance after a short while due to a time critical situation (i.e. very short window of interaction). The delay of message presentation could also be related to the purpose of the message. Messages very relevant to the driving scenario could be presented immediately while the other types of messages could be delayed.

13 - Users should have control over who to receive a message from

It was found in the early stages of this research that the DDCD could lead to a range of situations where drivers could make abusive use of it (see section 5.3.2.2). It is therefore crucial that the DDCD should be designed in such a way as to avoid these inappropriate actions. Based on this issue, a few design recommendations were created to protect the users of the device. This specific guideline states that users should be able to have control over who to receive messages from. For example, drivers should be able to block another driver and not receive any more messages from them if they wish, especially if the main drivers are constantly receiving inappropriate messages from these abusive motorists.

According to the results of STUDY A, abusive messages could affect the usage of the DDCD especially if there are passengers in the vehicle that may feel offended by the content of the messages (see page 133). The abusive use of the device is also linked to anonymity.

Research shows that anonymity in technology-mediated communication could have negative effects if the sender of the message cannot be easily traceable (see section 2.2.2).

14 – The system should be capable of restricting message content

As described in Guideline 15, this research found that not all users are interested in using the DDCD in all communication scenarios investigated and therefore users should have control over the content they are receiving. However, even when the users have established some form of control over which content they would like to receive or not, inappropriate or irrelevant messages may still be sent to them. Some messages may be categorised as being part of a group in which users are willing to receive, but the content of these messages may contain bad language, for example. According to results from STUDY A, one of the main concerns of participants is that other drivers could abuse the DDCD especially if free content messages are allowed (see page 129). The anonymity of the sender could increase this abusive use, which could have negative effects on driver acceptance, especially if there are passengers involved who might feel offended. Therefore, this guideline states that the DDCD should be capable of restricting the content of messages independently of users' pre-established choices.

One way this restriction could be applied is that the system must be able to block inappropriate words automatically. Expressions not relevant to the communication should also be blocked. The DDCD should also restrict private information such as personal contact details of the sender. The DDCD should be designed in a way that it can learn from the content that is generated. As mentioned in Guideline number 15, drivers should be able to flag a message as inappropriate. The DDCD could then learn from this action and add to the database the characteristics of the message that was flagged as inappropriate and based on this, restricting future messages similar to this one.

15 - Users should have control over the content received

In order to have a higher acceptance rate, any new device should provide a wide range of functionalities (François et al., 2016). More specifically regarding this PhD research, drivers would not be interested in using the DDCD if they were severely restricted in terms of the content they can exchange with other motorists.

However, this research also found that not all drivers would be interested in using the DDCD to send and receive messages in all the different communication scenarios investigated. Some drivers, for example, would not like to receive messages on topics not specifically related to driving. Other drivers may not be interested in receiving specific types of messages if they have passengers, who might feel offended by the content of these messages (see page 133). The purpose of communication is therefore an important factor in terms of usage of the DDCD.

This guideline states that users should have control over the content they are receiving. There are several ways that this control could be implemented, some of which are linked to the way the message was created, i.e. if it was content free or a fixed message from a pre-defined list. For example, drivers could block all pre-defined messages from one specific category (e.g. social interaction) while being able to send and receive messages from other categories. This functionality must allow drivers to block the messages on a permanent basis or only for a short period. The latter would be particularly useful if drivers would still like to receive the message, but not particularly at the moment due to several reasons such as the presence of a passenger. Drivers could have control of free content messages by blocking some specific words or by flagging a specific message as inappropriate.

16 - Users should have control over untrustworthy content

Trust can have a significant effect on driver-to-driver communication as described in Chapter 04 (see section 4.1.1.6). Trust in the driver communication context is concerned with how the content of the message actually represents the feelings and intentions of the other driver. There may be several reasons for a driver to send a non-legitimate message. Results from studies A and B show that drivers may have trust issues with some of the messages sent by other drivers (see pages 136, 153). According to STUDY A, drivers may have second intentions when using the system. An example of this would be for a driver behind to send a message stating that the driver in front has a problem with their car. This could be a fake message to make the driver pull over and then assault and rob them.

According to the results of STUDY C, drivers may also not trust an apologetic message sent by another driver (see section 6.2.3.2). Drivers may not feel convinced that the other driver was truly sorry for their wrong driving behaviour, especially if they are not able to detect any of the other drivers' emotional cues (e.g. tone of voice, facial expression). The other driver could continue their aberrant driving behaviour and make use of the apologetic message to justify their acts.

Consequently, there are situations which may not have been covered by the two previous guidelines, numbers 14 and 15. Drivers may be willing to receive a specific type of message and the message itself does not have any inappropriate content, which would automatically be blocked by the system. However, the message may still be viewed as untrustworthy for the reasons presented in the previous paragraphs.

This guideline states that users should have control over untrustworthy messages. Drivers, for example, should be able to flag the content of the message as not real or untrustworthy, similar to flagging inappropriate content on social media (Kietzmann,

Hermkens, McCarthy & Silvestre, 2011). In case of messages being broadcast to more users, this information could also be shared with them. If a driver constantly sends messages that are flagged as untrustworthy, this information should be available to other drivers to denote abusive use. Research on social media shows that providing quick positive or negative feedback (e.g. thumbs up or down) can help other users to determine how trustworthy content available online is (Agichtein, Castillo, Donato, Gionis, & Mishne, 2008). Alternatively, drivers could block the sender, as suggested in Guideline number 14.

10 Overall discussion and conclusions

10.1 Summary of research findings

This research aimed to investigate several aspects of driver-to-driver communication in order to inform the design of a hypothetical DDCD. The work presented in this thesis was structured around this overall aim and the six objectives introduced in Chapter 01. The findings are therefore summarised and revisited in relation to each one of these objectives and how they were accomplished.

10.1.1 Objective 01 - Investigate how drivers communicate with each other using traditional means of communication

The term traditional means of communication refers to all forms of interaction between drivers without the use of an electronic device. This essentially means using the vehicle signalling tools (e.g. indicators, lights), but can also refer to other forms of communication such as gestures, eye contact and the position or movement of the vehicle.

This research found that these traditional means of communication between drivers varied according to the context of the communication. For example, drivers used more signalling devices (e.g. honking the horn, flashing the headlights) to request a slow vehicle in front to speed up, whereas they used more finger pointing gestures to inform a driver near to them about a problem with their vehicle.

It was also found that most of the time drivers use a combination of more than one of these traditional means of communication to make their intentions clearer. For example, in order to let a vehicle behind overtake them, drivers would first slow down, then they would use an indicator to inform the other driver that it was safe to overtake and finally they would pull over if it were safe to do so.

Some of the forms of communication used had a negative connotation such as tailgating, honking the horns or some rude gestures. These were used in situations where drivers were more likely to feel angry.

Even when using more than one traditional form of communication, this research found that these means of communications are not clear and in most case ineffectual. For example, flashing headlights from an oncoming car and gestures from the driver can have different meanings, such as an incident on the road, a police check or that the other driver's headlights are not turned on. The receiver of the message might change their driving behaviour with a sense anxiety expecting something to happen on the road without properly knowing what to expect. Any combination of honking the horn, flashing headlights and gestures from a car behind could easily lead to misinterpretations and could have negative results even though the driver's intention could be positive, such as trying to alert the driver in front of a problem with their vehicle. The driver in the vehicle in front may then become angry unnecessarily.

This research focused specifically on driver-to-driver communication. However, further research into driver-to-pedestrian communication could also provide relevant findings regarding traditional means of communication in the road environment.

10.1.2 Objective 02 - Provide a driver-to-driver communication framework

The review of the literature on models of driver-to-driver interaction, which was presented in section 2.3.2, showed that there is currently a research gap regarding the means of communication adopted by drivers using an electronic device and all the relevant factors that may influence this usage. Therefore, a driver-to-driver communication framework was introduced in Chapter 04 and then extended in Chapter 09 with a set of design recommendations for a DDCD.

The results from the studies showed that the framework variables affected either positively or negatively driver communication and the interaction with an electronic DDCD. The findings regarding each one of the variables are described in the subsections below.

10.1.2.1 Trust

Trust in driver-to-driver communication relates to how trustworthy the content of the message sent by the other driver is felt to be by the receiver of the message. Results from studies A, B & C show that drivers may have trust issues with some of the messages sent by other drivers. There may be several reasons for a driver to send a non-legitimate message. According to STUDY A, drivers may have ulterior intentions when using the system. A typical example of this would be for a driver behind to send a message stating the driver in front should stop due to a problem with their car – in order to subsequently assault and rob them.

According to STUDY C, drivers may also not trust an apologetic message sent from another driver (see page 187). Participants were not convinced that the other driver was truly sorry for their bad driving behaviour, especially if they are not able to detect any of the other drivers' emotional cues (e.g. tone of voice, facial expression). The other driver could continue with an aberrant driving behaviour and make use of the apologetic message to justify their acts.

Results from STUDY B showed that the trustworthiness of a message could be enhanced if the DDCD provides an extra piece of information that the message was acknowledged by a higher authority such as the traffic police (see section 6.1.3.2). Another way to confirm that a message is reliable would be for the DDCD to store messages with similar content recently sent by different drivers and present them only once with an indication

of the number of vehicles that sent that message. This is related to the concept of crowdsourcing, in which a heterogenic group of people perform a task, in this specific case sharing information, with the purpose of mutual benefit (Estellés-Arolas & González-Ladrón-de-Guevara, 2012). In this scenario, it would be highly unlikely that many vehicles would send an untrustworthy message at the same time. A specific recommendation for the DDCD was designed based on this aspect of trust. This recommendation was incorporated into the framework and is described in Chapter 09.

10.1.2.2 Cardinality of interaction

The cardinality of interaction is directly related to the context of the communication. There are some types of messages that are relevant to only one driver, for example an apologetic message for cutting in front, whereas sharing information about an incident on the road ahead would be relevant to all oncoming vehicles. The cardinality of interaction is also closely related to the task of vehicle identification. Different techniques are required to identify a single vehicle and multiple vehicles. Specific design recommendations were created based on the results of STUDY D. These recommendations specify that the device should be able to provide prompt and quick feedback to a non-unique match and also to accept similar identifications, as the driver may not be able to provide an exact description of the target vehicle due to limited visual constraints.

10.1.2.3 Location of the vehicle

Different techniques may be required by the driver to identify the vehicle according to their location. The specific DDCD recommendations related to this variable are all related to this important task of identifying the vehicle, which was investigated in detail within STUDY D. Whatever way the DDCD is designed, it is important that it must be able to assist

the driver in identifying vehicles in different locations, even in situations with a short window of interaction or with limited visibility where drivers may not be able to fully describe the vehicle to be identified.

10.1.2.4 Purpose of the communication

This research found that there are some specific communication scenarios where the DDCD proved to be more useful than others with higher acceptance rates. Results from STUDIES A, B & C show that most drivers are not willing to send and receive messages in scenarios not related to the context of driving, such as simple social interactions when they do not know the other motorist. Social scenarios could also be highly abused by other drivers. Social communication scenarios and other non-driving scenarios could be designed only in future versions of the DDCD once the device has been firmly established and a general etiquette of use of the DDCD has been established. However, there are some situations in which drivers may be willing to interact with others if they know each other or if they belong to the same or similar social group. Motorcyclists, for example, travel in groups and may display appreciation of having a brief, unexpected encounter with other unknown bikers on the road and be willing to share information on their equipment or organize meetings (Esbjörnsson et al., 2003a).

There is, however, a group of situations in which the use of the DDCD is highly desirable, as the results of previous studies indicate. These communication scenarios include potentially dangerous situations that could lead to accidents if the driver is not well informed or at least not warned quickly beforehand, such as a hazard on the road or a problem with their vehicle. The DDCD proved to be particularly useful in keeping the driver informed of potentially dangerous situations. The use of traditional

communication such as flashing headlights does not help the driver to identify these instances uniquely or effectively.

10.1.2.5 Shared interest

Shared interest was investigated in this research as a concept of social connectedness where one driver may have a similar interest to another driver. Results from STUDY B showed that in some scenarios participants felt connected to other drivers and "part of something bigger" (see page 150). Results from STUDY A and C showed that some drivers would even be willing to engage in prolonged conversations with other drivers they came into contact with on the road. However, this would only happen when they are not driving, as participants suggested talking to other drivers at a rest stop or later by sharing their telephone contacts (see page 132). Even though a shared interest could be seen as something positive, this research found that, overall, drivers would not be willing to share information which was not specifically related to the road environment.

10.1.2.6 Window of interaction

This research adopts the term "window of interaction" to describe the period of time required by one driver to send a message so that when the message reaches the receiver it is still relevant. This research explored some scenarios where a driver might need to communicate with other drivers with a very short window of interaction. An example of such a time critical scenario is when the recipient of the message is in an oncoming vehicle at high speed on a motorway. This research found this particular use case to be very difficult for the driver to identify the vehicle and send the message without risking delaying the message (see page 221) and resulting in it becoming irrelevant. Results from STUDY D showed that very few unique identifications were made of oncoming vehicles

at high speed. In the identifications that were made successfully, participants experienced great difficulties in quickly identifying the vehicle.

Scenarios with a very short window of interaction may also have an effect on drivers' beliefs and behaviour according to STUDY E. Drivers may not trust their own ability to complete the process of sending crucial safety-critical messages in time to alert the other drivers in a time critical scenario such as an accident on the road (see section 8.4.9).

10.1.2.7 Passenger effect

This research investigated what effects passengers may have in different driver-to-driver communication scenarios. Two opposite results were found. On the one hand, participants reported that they would rather not use the DDCD if they had passengers with them, especially if the passengers were children or their parents (see section 5.3.3.3). The reason for this is not to let passengers receive possible abusive messages from other motorists. On the other hand, two female participants mentioned they only would send certain specific messages if they were with other passengers in the vehicle. Participants reported that they would feel more secure knowing they had other passengers with them, preferably male adults, in case of retaliation from the other driver. Passengers can also support the driver in interacting with the DDCD. According to results from STUDY A, drivers could ask a passenger to interact with the DDCD, especially when the drivers are facing high cognitive load. Although the driver will interact with the DDCD most of the time, the passenger can also occasionally be the user and interact with the device in certain situations. This might also improve social engagement between the occupants in the vehicle.

10.1.2.8 Anonymity

The concept of driver anonymity in this research involves the importance of being identified or not as the sender to the driver of the other vehicle who receives the message. Results from STUDY A showed that sender identification helps to prevent abusive use of the device (see section 5.3.3.5). However, there are a few specific situations where a particular vehicle does not need to be identified as investigated in STUDY C (see Table 6.3). This involves situations in which the DDCD would store the same message sent by different vehicles and present them only once. If many vehicles send this same message, they do not need to be individually identified, and general information such as the number of vehicles that sent the message could be used instead.

10.1.3 Objective 03 - Investigate drivers' emotions when receiving messages using the DDCD

Drivers' emotional feelings when receiving messages can have an effect on the outcome of the interaction and on the use of a DDCD. This research found that drivers might experience negative emotions when receiving messages via the DDCD. STUDIES B & C showed that drivers have mixed opinions about how they would feel receiving messages from non-driving related scenarios (see pages 150, 189). Drivers would also not like to feel obliged to react to a message from another driver.

This research also found that drivers might experience positive emotions in some communication scenarios. These feelings varied according to the purpose of communication, but in general, drivers felt a sense of gratefulness for receiving a message, especially if this contributed to their safety on the road.

Drivers' emotions can be transmitted via several qualities of voice, such as tone, pitch and volume. This research found that drivers would not be willing to send free content

messages with their own voice since this might represent their negative feelings at that moment (see page 283). This is particularly relevant in communication scenarios that could lead to road rage incidents, such as a car cutting in front of the other vehicle. According to results from STUDY C, drivers would not like to receive an apologetic message with a voice which sounded too condescending (see page 187).

10.1.4 Objective 04 - Investigate drivers' acceptance of the use of the DDCD in different driving communication scenarios

Drivers' acceptance of the DDCD was investigated in this research in relation to each driving communication scenario presented to participants. Overall, higher acceptance rates were found for the DDCD in scenarios directly related to the road environment when compared to other social scenarios. Most drivers would not be willing to exchange messages in situations not related to the road environment. Messages about incidents on the road or about issues with the vehicle were reported to be highly useful and relevant as these may present new information not known to the drivers and require them to change their driving behaviour. Social scenarios where drivers share a mutual interest and scenarios where drivers apologise for their behaviours had lower acceptance rates and were viewed as inconsequential and with no new information being provided. Based on these results, design recommendations were created to address this issue. The recommendations aim to give precedence to scenarios related to the road environment in terms of message presentation and the possibility for drivers to block content not directly related to their chosen preferences.

The CTAM model and Van der Laan's scale used in this research have many advantages which were described in the review of the literature in Chapter 02. However, they do not cover other factors that can have an effect on driver-to-driver communication. These

factors are included in the framework presented in this thesis. For example, drivers may have a very short window of interaction to use the device which can have an effect on technology acceptance. Drivers can also experience trust issues in terms of the content of the message received. A new model, based on the CTAM, could be created adding these new contributing factors, specifically related to the driver-to-driver communication context.

10.1.5 Objective 05 - Explore alternative HMI designs for the DDCD

This research explored different HMI designs for the DDCD. Due to the potential distractive nature of using a DDCD, it was found in STUDY A that the least distracting way to interact with the device would be a combination of voice-activated interface with a control button on the steering wheel. This research also investigated ways of presenting information. In STUDY B, HCI and HF/E experts reported that messages could be presented either in audio mode or visually using a HUD. Based on these results, a multimodal presentation of both auditory and visual messages in a HUD was explored in STUDY C in the form of video-based scenarios. This study investigated particular aspects of message design such as content, duration and the visual and auditory elements used to represent it.

The task analysis presented in Chapter 04 shows that drivers could send two different types of messages. They could send a free content message stating whatever they want to, or select from a list of pre-defined messages. Each one of these has advantages and disadvantages, which are briefly described below.

For instance, it was found in STUDY A that free content messages could significantly increase the possibilities of abusive use of the DDCD, including situations that could lead to road rage with potentially dangerous consequences (see page 129). In contrast, pre-

defined messages can limit the scenarios where the DDCD can be used and can also have a longer interaction time (see Table 8.20) This could therefore prove to be inappropriate in some time critical scenarios with a very short window of interaction. Moreover, it was found in STUDY E that some drivers would prefer the pre-defined list because it was considered less cognitively demanding to choose a message from a menu than trying to articulate the content of a free message. Choosing between free content and pre-defined messages proves to be a difficult decision, especially because the abusive use of the DDCD can also occur with pre-defined messages (e.g. overload of messages) while the abusive use in free content messages can be avoided by adopting a blocking restriction to some words or sentences, as suggested in one design recommendation described in Chapter 09.

Free content messages have the advantage of providing extra information for the driver (e.g. number of cars involved in an accident). However, according to results from STUDY E (see section 8.4.9), some drivers suggested they do not need this extra information. They perceived a need for some type of alert or notification similar to what can be found nowadays with traditional communication (e.g. use of headlights and horns). Drivers could then, for example, reduce their speed because of the notification of a hazard without necessarily knowing if it is an accident and the number of vehicles involved.

Message composition is closely related to system interaction and a DDCD should optimise its interface according to the type of message. In STUDY E, two prototypes to send messages were evaluated: a speech recognition system to compose free content messages and a touchscreen system to select pre-defined messages. Results from this study showed an overall preference for the speech recognition system due to its easy use and for being considerably less distractive.

This research also investigated possible HMI designs for a vehicle identification system. Results from STUDY D showed that drivers naturally identify single vehicles nearby using verbal descriptions or free pointing gestures in the air (see section 7.4). However, contrary to what was expected, gestures were used much less frequently than verbal descriptions.

In the future, drivers may be able to communicate with other drivers using the surface of their own vehicle as a pervasive display or by projecting their messages onto the road (Diewald et al., 2014; Hwang et al., 2011). The PhD research described in this thesis did not investigate the use of more futuristic interfaces for the DDCD. The reason for this was, firstly, that a linear approach was adopted in which the results of one study were applied to the next one. No results were found which justified further investigation into the use of technologies not currently available. Secondly, it was deemed important to be able to pragmatically test some of these technologies with prototypes in order to obtain concrete and relevant results. This would have been very difficult with futuristic interfaces. However, some existing, novel technologies such as free air gestures (STUDY D), natural language processing (STUDY A, E) and augmented reality (STUDY B, C) were investigated as possible input and output modalities of a DDCD. They were evaluated in this thesis in relation to vehicle identification, message composition and message presentation.

10.1.6 Objective 06 - Provide general design recommendations for a DDCD

General design recommendations for a DDCD were provided at the end of each study chapter and are based on the results from these studies. These general guidelines cover several different aspects of the DDCD, such as system interaction, information presentation, message content, user protection, vehicle identification, system notification and system optimisation. An example of a general guideline created in this research is

that the DDCD should be integrated into other in-vehicle devices (see section 6.1.3.2). This research also presented recommendations concerning message content and audio and visual aspects of the message according to the results of STUDY C. Recommendations on the task of vehicle identification are described in STUDY D.

10.2 Novel and unique contribution of the work

The main aim of this research was to explore various aspects related to an electronic means of driver-to-driver communication in order to inform the design of a hypothetical DDCD. For several decades, there have been no significant advances in terms of the instrument panel of vehicles to allow drivers to communicate with other drivers. The use of horns, indicators and lights has not been significantly improved since they were first incorporated into vehicles. Motorists have been able to drive vehicles and interact with other drivers using this basic set. However, as this research shows, there are many driving situations, which could benefit from a more advanced set of communication mechanisms.

The idea of an electronic communication device is only possible nowadays due to recent advances in technology. An electronic communication device can use the framework provided by connected vehicles technology, which allows cars to be fully connected to the Internet, to exchange messages with each other and with the road infrastructure. This idea of an electronic communication device to improve drivers' communication was envisioned by Wilde as long ago as 1976, but at that time there was no technology that would allow this to function (Wilde, 1976).

The main outcome of the research presented in this thesis is therefore novel as it focuses specifically on providing a set of design recommendations for an electronic driver-to-driver communication device. The work conducted for this thesis is based on the theories

of common ground and on previous research on driver communication, both reviewed in Chapter 02. This research is also significant because it establishes a driver-to-driver communication framework, which aims to provide a thorough understanding of the driver communication process with the inclusion of an electronic communication device to support the users. Previous models of driver interaction, which were reviewed in Chapter 02, did not take into consideration the possibility of having an electronic communication device to assist in the process. Therefore, this PhD research builds on the literature review by closing this gap in knowledge.

Several areas of research such as automotive user interface design and HCI will benefit from this PhD research. The findings of this research can also be particularly relevant to other areas of research such as Computer-Mediated Communication (CMC). Many of the principles relevant to other forms of technology-mediated communication such as anonymity and trust are applicable to a driver-to-driver communication device. However, this research also described some intrinsic characteristics of the road context, such as the short window of interaction and the effect of passengers, which have not been thoroughly investigated before and could be potentially helpful to other areas. The automotive industry can also benefit from the work conducted in this thesis as discussed in the next section.

10.3 Key questions

This research is further revisited here in terms of four main questions that aim to examine the potential of DDCDs as a concept to be developed by stakeholders in the automotive industry.

01) **Why are DDCDs not installed in production vehicles**?

There are several possible reasons that might explain why DDCDs are not currently installed in all production vehicles. Firstly, in order for DDCDs to be fully functional they would require vehicles to be connected 24/7. Connected vehicle technology has only been developed recently, with most of the research focusing on safety and navigational use case scenarios, to exchange information from one vehicle to another (V2V) or between vehicles and road infrastructure (V2I). DDCDs follow a different approach as the driver is the main actor responsible for initiating the exchange of information and not the vehicle itself. Prior to connected vehicles technology, the only communication device that drivers could use to exchange messages with each other was the CB radio (Applin & Fischer, 2015). However, CB radios differ from a DDCD as drivers cannot specifically direct their communication to one vehicle, but only broadcast messages to drivers nearby who would need to be connected to the same frequency or channel of communication. Secondly, as this PhD research extensively described, a DDCD which allows free communication between drivers could be misused and abused, especially if no control of content is enforced. DDCD with pre-defined content needs an extra layer of interaction in order to select the topic of communication and this could increase driver distraction. Finally, the main automotive stakeholders may not be able to justify investing resources and money in a device that might not offer significant advantages over their competitors. These might be reasons why the automotive industry has not already installed a driver communication device in production vehicles.

02)**What are some of the most likely uses of DDCDs in a practical context**?

This research investigated a specific set of use case scenarios of representative situations in which there was some sort of communication need between drivers. In

a practical context, DDCDs are more likely to be used in some of these scenarios than in others.

This research found that drivers are perfectly willing to use a DDCD in scenarios explicitly related to the driving context. These scenarios involve situations in which the presence of a message can have a different outcome for the driving experience and/or journey. Examples of such scenarios involve sending messages about a hazard on the road ahead or problems with the recipient's vehicle. Social interactions regarding a shared interest had the lowest acceptance rates of all situations investigated. These scenarios also have higher possibilities of misuse and abuse if no blocking restrictions are adopted.

The nature of the road environment requires motorists to be focused on the primary driving task while travelling from point A to point B. Moreover, since drivers are most of the time travelling in different directions and not stationary, they are less likely to have the same set of drivers around them for a very long time. Most communication situations can take place with a very short window of interaction where drivers may not have enough time to complete the whole process of sending messages. Therefore, unlike other forms of human communication which benefit from longer interactions such as telephone calls or electronic instant messages, currently DDCDs are more likely to be used for very short interactions. These short interactions can be characterised by quick messages without back and forth of message exchanges.

03) **Are DDCDs likely to be advantageous enough for drivers to warrant introduction into vehicles**?

The main advantage of a DDCD is that it has the potential to make drivers' intentions clearer, avoid misunderstandings and provide an enhanced experience for the driver.

However, there are many challenges that need to be faced in order for the device to be advantageous enough for drivers to warrant introduction into vehicles. These challenges are presented in the next question. As soon as these barriers have been overcome, there could be significant potential for a DDCD.

04) **What are the main barriers that currently exist for the successful introduction of DDCDs**?

One barrier is the need for a DDCD to be available in all vehicles in order for the device to be able to fulfil its potential. This would require a major adoption by the automotive industry with all manufacturers conforming to an established norm. Drivers would be less willing to use a DDCD if they were limited to only being able to communicate with vehicles from the same manufacturer. Alternatively, different types of DDCDs could be produced. For example, a DDCD could be designed as a separate device which could be connected to any vehicle similar to IVNSs.

A transitioning period would be required for a communication device to become fully operative. During this transitioning period, not all drivers would have the device in their vehicles and feedback for the sender of the message would be required to inform them of this. This would limit the use of the communication device in the initial stages, but this would improve in the future as more and more vehicles have the device installed.

Other barriers investigated in this research include the following:

- Trust issues not only in terms of the content of the message but also the intention of the sender;
- User acceptance of the technology;

- Difficulty identifying vehicles especially due to poor visibility such as at night or in foggy conditions;
- Short window of interaction to complete the whole process of sending a message while travelling;
- Abuse and misuse of the system especially if the sender of the message remains anonymous;

05)**How could this picture be different in the future**?

Current automotive research predicts that, in the not-too-distant future, there will be fully automated driving systems (ADS) travelling on the roads. Motorists would no longer drive the vehicle, and therefore major issues such as driver distraction that are nowadays relevant will no longer be important.

A DDCD may have different uses in this future scenario. First of all, drivers will be able to have prolonged conversations with other motorists since the driving task will no longer be the primary task anymore. The interaction with the DDCD can take different forms as drivers will not need to keep their eyes on the road at all times. For example, drivers could use touchscreen displays to send and receive messages or even more futuristic HMIs which will probably be widely available.

Different use case scenarios for a communication device would need to be investigated. Further research would also then be required as presented in section 10.4.5.

However, before reaching the point of fully ADS vehicles only, it is expected that there will be a transitional period of at least 30 years where manual and semi-autonomous vehicles will coexist (i.e. mixed-driving). The research conducted in this PhD will therefore not become quickly outdated, as there are many relevant use case scenarios

for a DDCD in this situation. The driver of a manual car may not be able to fully understand what a semi-autonomous vehicle will do next, due to the lack of an explicit means of human-to-human communication (Eden et al., 2017). For example, a human driver may use nonverbal communication to request permission to pull in front of a semi-autonomous vehicle at a junction or an attendant of an ADS vehicle may need to communicate the intention of their vehicle to a human driver in a manual car. These forms of communication may not be available if the receiver is an ADS vehicle and not another human being. One of the ways of making the intentions clear for all the vehicles involved in these mixed-traffic scenarios is via an electronic communication device.

A DDCD could also be used as a mean of communication from one ADS vehicle to another ADS vehicle and not only for human-to-human communication. An example of such communication, would be an ADS vehicle alerting another ADS vehicle of an accident on the road. This is also presented as further research in section 10.4.5.

10.4 Future work

This thesis raises a series of questions related to the different aspects of driver-to-driver communication and the use of an electronic device to improve this process. Future work can build on the results of this thesis to investigate these questions, some of which are described in the following subsections.

10.4.1 Driver communication and culture

One of the models of driver communication described in the literature review chapter defines culture as one factor that can affect the interaction between drivers (see page 49). Moreover, extensive research shows differences between culture in several aspects such as risk perception skills, driver behaviour and symbol use (Nordfjærn, Şimşekoğlu, &

Rundmo, 2014; Özkan, Lajunen, Chliaoutakis, Parker, & Summala, 2006). The research presented in this thesis focused on western culture only. Further research could investigate the effectiveness of the use of a DDCD in other western countries and more importantly on eastern cultures in countries such as India and China where driver behaviour, traffic regulations and the road environment can be very different. Several factors could be investigated such as different use case scenarios, driver acceptance of the technology and message content.

10.4.2 Multiple vehicle identification

The identification of the recipient of the message is one of the main tasks involved in the process of sending a message to another vehicle/s. There are many situations in which drivers need to send a message to more than one vehicle at the same time. Some of these one-to-many situations were covered in the early stages of this research. However, this research focused specifically on the one-to-one cardinality for this specific task and did not investigate how drivers could send messages to multiple vehicles. Further research could be carried out to investigate different techniques or approaches for multiple vehicle identification and how this could actually be implemented as part of a VIS.

10.4.3 Next design stages of the DDCD

The focus of this research was on the initial design stages of a DDCD with five studies investigating different aspects of communication between drivers. Further research can build on the results presented in this thesis to investigate other aspects related to a DDCD. The last study of this research investigated specifically the task of sending messages using a prototype version of the DDCD in a driving simulator. Further research can build on this last study to investigate the whole process of both sending and receiving messages between two drivers at the same time. This initially could be carried out in two

interconnected driving simulators, which would allow two drivers to share the same road environment. This approach would be particularly helpful to understand the whole process of interaction between two drivers. This approach has been successfully adopted before to investigate driver emotional behaviour while in a platoon of vehicles (Cai, Lin & Mourant, 2007) and the passing behaviour at intersections by non-experienced drivers (Oeltze & Schießl, 2015).

Further stages of prototype development could replicate this investigation in an on-road study, in which participants actually drove the vehicle while performing secondary tasks related to the DDCD. It is crucial to investigate several aspects such as workload and driver distraction with participants driving a real vehicle and interacting with a prototype of the DDCD.

Finally, all the components of the driver-to-driver communication framework could be validated in future studies by other researchers and/or by designers and developers of a DDCD. After this validation process, the framework could then be extended and revised by adding new elements such as variables that affect the driver-to-driver communication process or new design recommendations for the DDCD.

10.4.4 Vehicle-to-vehicle communication

This PhD research is based on the principle that the intention to communicate should come from one driver and should be directed to another driver. Some of the scenarios investigated in this research could also be applied to vehicles exchanging messages with each other. Drivers can have different attitudes and opinions regarding a message received if it is clear that the message came from their own vehicle or another vehicle and not from a human being. It would be particularly interesting to investigate aspects of acceptance, trust and the effect of passengers in message reception. Vehicle-to-vehicle

communication can benefit from not having issues inherent to human beings such as abuse and misuse.

10.4.5 The future of the road

Extensive research on ADS vehicles shows rapid advances in this area and predicts that in the near future there will be many fully ADS cars travelling on the roads. There are many factors that are currently being explored related to ADS vehicles and therefore it is important to understand the role of an electronic communication device in this specific context. Further research should then be carried out in order to fully understand all communication scenarios involving ADS vehicles in which an occupant-to-occupant communication device could be useful and effective. Scenarios with a mix of partially ADS and fully ADS vehicles could also be explored and improved to allow their coexistence without any danger to any vehicles involved (Riener, Jeon, & Ferscha, 2016; Eden et al., 2017). A new set of communication scenarios could then be developed and explored in a series of studies.

10.5 Concluding statement

This research investigated several aspects related to an electronic means of driver communication in order to inform the design of a DDCD. The traditional means of communication commonly used are often ambiguous and ineffectual, with drivers being unable to clearly understand the purpose of communication. An electronic communication device can make drivers' intentions clearer by allowing drivers to exchange messages with other motorists and thereby improve safety on the roads. However, this research found that some drivers would not be willing to use this device in all situations. Moreover, there are situations in which the device could be misused and abused by some motorists. These situations could provide a negative outcome for the

interaction, which is the exact opposite of the original purpose of the device. Some driving situations in which the driver would be required to use the device may also impose risks to their safety, due to high cognitive workload and/or a short window of interaction. Consequently, this research shows that all the factors that affect drivers' communication, both positively and negatively, must be taken into consideration when designing an effective electronic communication device.

This thesis provides the initial, fundamental research into driver-to-driver communication and the essential guidelines for a future electronic device. In spite of possible drawbacks to the use of a DDCD, this research clearly shows that the device has the potential to provide an enhanced, positive experience whilst staying within safe boundaries.

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Appendix I: STUDY A – Interview Questions

These are the main questions the researcher may ask participants for each scenario. Depending on the answers they give, other questions not listed here might also be asked.

SCENARIOS 01 AND 02

What would you do in this scenario?

What do you want to express? / What message do you want to convey?

Would you send a message to the other driver using this device? If so, what would you say?

What would you do if the driver:

Replies to you:

- Saying he was sorry?
- With angrier and offensive language?
- How would you feel in this case?
- Does not reply at all?

Would that change your behaviour?

How effective do you think the communication device is in this scenario?

What would you do in this scenario if you didn't have the communication device?

Would you do anything different if there was a passenger with you in the car?

What would you do if you experienced the same situation on a regular day (not on such a stressful day, when you're not late for an appointment)?

What would you do if you had a device to show the mental state of the driver (e.g. how he is feeling) beforehand? (c.f. L plates)

Would you consider using the device alongside other means of communication to reinforce your message?

What issues do you see in this scenario in general?

SCENARIO 03

What would you do in this scenario?

Would you accept the message from the other driver?

In case you did not accept the message, what do you think would be the reaction of the other driver?

What would you do if the content of the message was regarding you driving at a speed slower than the minimum:

- With a standardized message?
- With offensive language?

How would you feel in this case?

How would you react?

Would you reply to the message? If so, what would you say?

How do you think your response would affect the other driver?

How effective do you think the communication device is in this scenario?

Would you do anything different if there was a passenger (e.g. child, boss, mother, client etc.) with you in the car?

What issues do you see in this scenario in general?

SCENARIO 04

What would you do in this scenario?

What do you want to express? / What message do you want to convey?

Would you send a message to the other driver using this device? If so, what would you say?

What do you think might be the reaction of the other driver?

Would you engage in a prolonged conversation with the other driver if the device allowed you to do so? Can you see any benefit in this?

How effective do you think the communication device is in this scenario?

In which other situations similar to this one (i.e. friendly compliment) do you think this device might be useful?

What issues do you see in this scenario in general?

SCENARIO 05

What would you do in this scenario?

What do you want to express? / What message do you want to convey?

Would you send a message to the other driver using this device?

If so, what would you say?

Would you send the message anonymously or not?

How effective do you think the communication device is in this scenario?

If you had a problem with your car (e.g. loose exhaust pipe, passenger door open) that you were unaware of, how would you feel if you receive a message from another driver letting you know about that?

Would you reply to the message? If so, what would you say?

What issues do you see in this scenario in general?

SCENARIO 06

What do you think of this scenario?

In what other situations do you think it might be useful to receive messages sent from other vehicles?

How effective do you think the communication device is in this scenario?

Would you send a message to other vehicles if you had just passed by a serious accident or if the weather suddenly changed?

What do you think of the idea of anonymity in this scenario?

What benefits do you see in this scenario?

What other issues do you see in this scenario in general?

SCENARIO 07

What would you do in this scenario?

What do you want to express? / What message do you want to convey?

Would you send a message to the other driver using this device? If so, what would you say?

What would you do in this situation if you did not have the device to help you?

How effective do you think the communication device is in this scenario?

Would you consider sending this message to all drivers waiting for the traffic light to change?

POST INTERVIEW QUESTIONS

Regarding the electronic device and taking into consideration all possible scenarios where it might be used:

How would you prefer the content of this message to be?

How would you prefer to use this device to send the message?

How would you prefer to use this device to receive the message?

Do you think the way you use the device to send/receive messages might be different (i.e. better) depending on the scenario?

Have you ever experienced any other situation, not mentioned previously, in which you want to communicate something to the other driver but couldn't or felt that the communication wasn't effective?

What do you think of the idea of a social network of drivers and their vehicles that you could post comments related to the driver and also rate how good or bad they are driving?

What do you think if you could have access to the average rating of this driver before sending/receiving a message? Do you think it would make a difference to how you could respond/read the message from the device?

Appendix II: STUDY A – Scenarios

SCENARIO 01

Imagine that you have an important meeting or appointment (e.g. job interview, final exam, university entrance exam) today that you can't be late for and that you feel your life depends on it! You've just left home 40 minutes before the time and it usually takes no longer than 15 minutes to get to this destination by car during this time of the day (i.e. off-peak time). So you know you will get there in plenty of time for the appointment.

However, the traffic is much heavier than usual today and you start to get really stressed out, because you know you are not going to make it on time. You are on a single carriage road, almost reaching your destination with a few minutes left for the appointment, when a person starts driving too slowly in front of you. You don't know why this person is driving so slowly and you can't overtake him/her. You consider honking the horn or flashing your headlights at this person.

Imagine also that you have an electronic device in your car that could send a message to the driver in front of you. The device is available on both cars, so you know the driver in front of you can receive your message.

SCENARIO 02

Imagine that you are calmly driving on a single carriage road on a sunny day. It's a Sunday morning, you are not working today and you are going to visit a friend in a city nearby. You are listening to the radio and enjoying the scenery when suddenly a car from behind drives up close to your bumper. You notice he looks very angry and continues to tailgate you. The angry driver then starts to flash his headlight and honk his horn. You have no idea why he is acting with this crazy behaviour.

Imagine also that you have an electronic device in your car that could exchange messages with other drivers. You receive a message from the car behind you. The device is available on both cars, so you know the driver behind you can receive your message.

SCENARIO 03

Imagine that you are driving in the left-hand lane on a motorway. Both you and the vehicle in front of you are moving at at least 60 mph. You then move to the middle lane and you are about to overtake this vehicle when you notice something about the car in front that attracts your attention. This could be:

- A sticker on the back window of the football team you support and that has just won an international tournament;
- A sticker on the back window of a TV show you are the biggest fan of and an active member of an online community;
- A sticker on the back window of your small town (You would never imagine you would find someone from your home town here);
- The fact that the vehicle in front of you is a rare make/model and you, as an automobile fanatic, have never seen such a fantastic car!
- The person driving the car is a famous celebrity who you are a fan of;
- The person driving the car is an old school friend who you have lost contact with;

You could honk the horn at the other driver but he/she may not know why you are doing this. It would be difficult to make gestures or try to speak aloud because both of you are on the motorway travelling at a relatively high speed.

Imagine also that you have an electronic device in your car that could send a message to that driver. The device is available on both cars, so you know the other driver can receive your message.

SCENARIO 04

Imagine that you are driving on a motorway in the middle lane about to overtake a car in front of you. You suddenly notice that the other car has a flat tyre and that the driver apparently is not aware of it. This could lead to a serious accident and the driver should stop as soon as he/she can. You think about what you should do in this situation. The other driver would probably not understand if you honk your horn at him. Any kind of gestures would not be effective either, since both of you are on a motorway travelling at a relatively high speed.

Imagine also that you have an electronic device in your car that could send a message to that driver. The device is available on both cars, so you know the other driver can receive your message.

SCENARIO 05

Imagine that you are leaving a car park, but you have to stop at the exit because there is a traffic light at the end of the street, which is full of stationary vehicles waiting for the red light to change. This exit is also located right in front of a zebra crossing and you can't stop your car on it. Besides that, this is a very busy street and you know that if you don't enter the road immediately the traffic light turns to green, it will be difficult to have another chance to drive into the road. You then decide to inform the driver on the road right in front of you that you want to pull in in front of him as soon as the traffic light turns to green.

Imagine also that you have an electronic device in your car that could send a message to that driver. The device is available on both cars, so you know the other driver can receive your message.

SCENARIO 06

Imagine you are on the way to work on your usual route. The traffic is normal and fast-flowing today. You are crossing a junction when suddenly all the cars in front of you stop for no apparent reason. This is something you weren't expecting and you don't know what has happened in front. Traffic comes to a standstill and your car gets stuck in the middle of the junction. The traffic lights for the other road turn green and you notice that your car is the only one blocking the cars coming from this road. You feel bad about this and you start thinking about the reaction of the other drivers. They are probably really angry with you, but it wasn't your fault.

Imagine also that you have an electronic device in your car that could send a message to the drivers around you. The device is available on all cars, so you know drivers around you can receive your message.

Appendix III: STUDY A – Demographic Questionnaire

01) Sex

☐ Male ☐ Female

02) Age _____

03) Nationality _____

04) Year original driving licence was issued _____

05) On average, how many minutes do you spend driving in a week?

(Including time you are in a traffic jam)

☐ Less than 30

☐ 30 - 60

☐ 61 - 90

☐ More than 90

06) How competent are you generally using technology?

Tick the appropriate box below. On a scale from 1 to 5, where 1 would be extremely incompetent and 5 would be extremely competent.

	1	2	3	4	5	
Extremely Incompetent						Extremely Competent

Date: _____/_____/_____

Thank you for taking time to fill in this questionnaire.

Appendix IV: STUDY C – General Questionnaire

Participant No.: _____

01) Sex

☐ Male ☐ Female

02) Age _____

03) Nationality _____

04) Year original driving licence was issued _____

05) How many years have you been driving in this country? _____

06) On average, how many minutes do you spend driving in a week?

(Including time you are in a traffic jam)

☐ Less than 30 ☐ 30 - 60 ☐ 61 - 90 ☐ More than 90

07) How competent are you generally using technology?

Tick the appropriate box below. On a scale from 1 to 5, where 1 would be extremely incompetent and 5 would be extremely competent.

1	2	3	4	5
Extremely Incompetent			Extremely Competent	

Appendix V: STUDY C – Driver-to-driver communication questionnaire

Participant No.: _____ Scenario No.: _____

Please tick the appropriate boxes below according to the driving scenario you have just experienced:

	Strongly disagree	**Disagree**	**Undecided**	**Agree**	**Strongly agree**
The message made the intention of the other driver clearer					
I would have replied to the message if it was possible					
I would have sent the same message if I had experienced the same situation					
I would have tried to communicate with the other driver in some way if I had experienced the same situation					
The message made me feel happy					
I would have blocked the message so as to not receive it anymore if it was possible					
The message could change my driving behaviour					
The message could change my moods while driving					
I would be willing to receive more of this same type of message					
I felt an obligation to reply to the message					
The message could make me feel more distracted from driving					
It was unclear to me what to do after receiving the message					
The message made me feel annoyed					
The message was very useful					
The message increased my awareness of the situation					
The message made me feel angry					
It was unclear to me why the message was sent					
The message made me feel stressed					
The duration of the message was what I expected it to be					
The message made me feel more aware of the other driver's feelings and actions					
I would have preferred to receive a traditional type of communication (e.g. signs, honk horns, flash headlights etc.)					

	Strongly disagree	Disagree	Undecided	Agree	Strongly agree
I trusted the other driver that the content of the message was true					
The message didn't really change my understanding of the situation					
The message made me feel excited					
I would have acted differently if I have not received the message					
I could quickly identify the driver who sent the message after receiving it					
The message made me feel closer to the other driver(s)					
I would have rephrased the message in a different way					
I did NOT have any difficulties understanding the message					
The message itself was complete and there was no need for extra information					
It took me a while to understand the message					
The message was rude					
The message seemed to be reliable					
The message was too long					
The message was too personal					
I could feel the other driver's emotional feelings from the content of the message					
The message was too vague					
The message didn't provide me with any new information					
The visual representation of the message was clear					
I could understand everything in the audio message					
It was possible to detect the other driver's emotions from the tone of voice					
I would prefer to receive the message in a different format					
I would prefer to have a different voice to represent the driver					

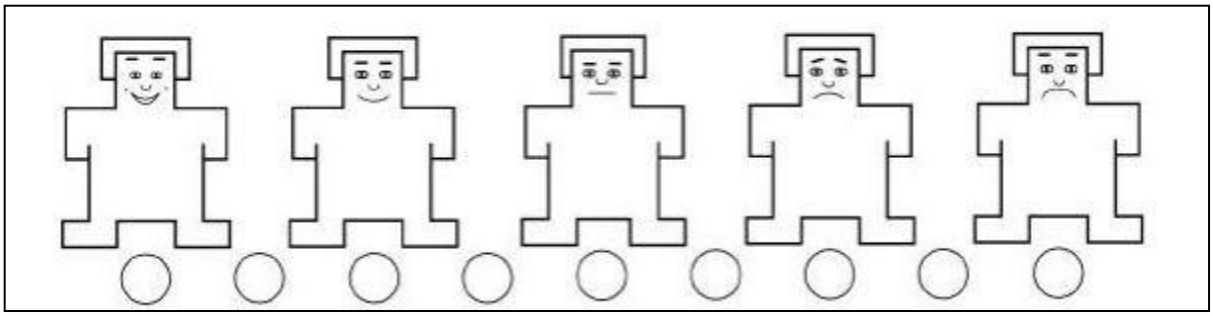
WRITE OR DRAW HOW WOULD YOU LIKE THE CONTENT OF THE MESSAGE TO BE

Appendix VI: STUDY C – SAM

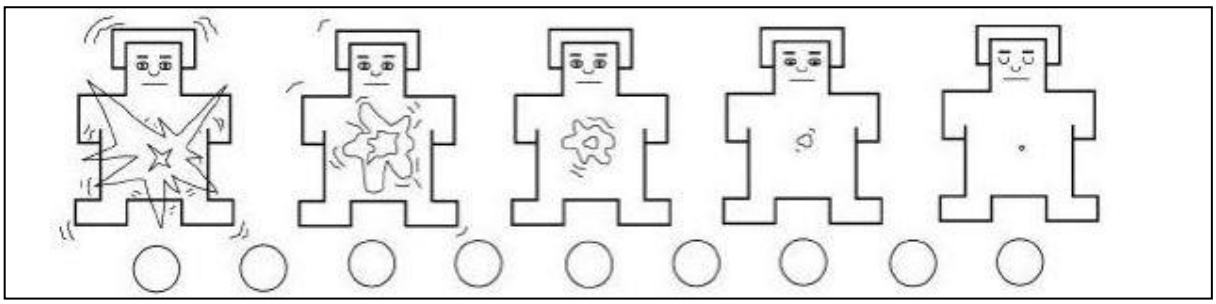
Participant No.: _____ Scenario No.: _____

How did you feel when you received the message?

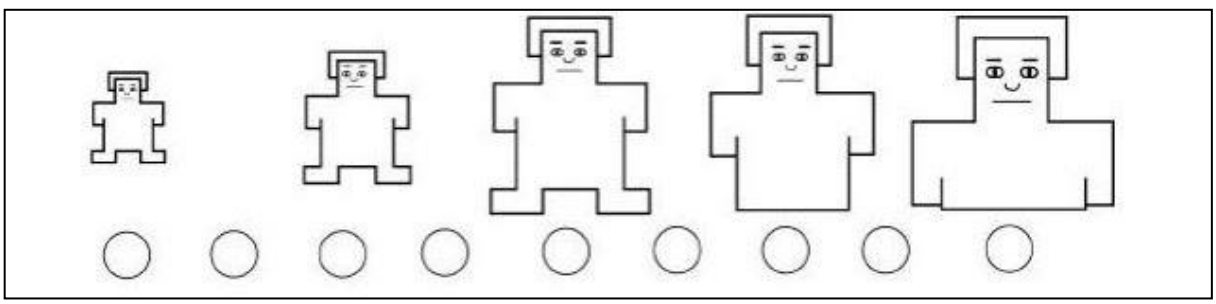
HAPPY vs. UNHAPPY DIMENSION



EXCITED vs. CALM DIMENSION



CONTROLLED vs IN-CONTROL DIMENSION



Appendix VII: STUDY C – Van der Laan Scale

Participant No.: _____ Scenario No.: _____

My judgments of the driver-to-driver communication system for the specific scenario I've just watched are ...

useful	○	○	○	○	○	useless
pleasant	○	○	○	○	○	unpleasant
bad	○	○	○	○	○	good
nice	○	○	○	○	○	annoying
effective	○	○	○	○	○	superfluous
irritating	○	○	○	○	○	likeable
assisting	○	○	○	○	○	worthless
undesirable	○	○	○	○	○	desirable
raising alertness	○	○	○	○	○	sleep inducing

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

Appendix VIII: STUDY D – General Questionnaire

Participant No.: _____

01) Sex

☐ Male ☐ Female

02) Age _____

03) Nationality _____

04) Year original driving licence was issued _____

05) How many years have you been driving in this country? _____

06) On average, how many minutes do you spend driving in a week?

(Including time you are in a traffic jam)

☐ Less than 30

☐ 30 - 60

☐ 61 - 90

☐ More than 90

07) Annual Mileage _____

Appendix IX: STUDY E – CTAM – Questionnaire

U	The system would be useful when driving
EU	I find the system easy to use
EU	Learning how to operate the system is easy for me
ATT	Using the system is a good idea
ATT	The system makes driving more interesting
ATT	Interacting with the system would be fun
ATT	I would enjoy interacting with the system
BI	Assuming I had access to the system, I would use it
PS	Using the system requires increased attention
PS	The system distracts me from driving

U	Perceived usefulness
EU	Ease of use
ATT	Attitude towards using this technology
BI	Behavioural intention to use this technology
PS	Perceived safety

The University of Nottingham

User Experience Questionnaire

Condition:	
Participant:	

Please answer the questions below according to the driving scenario you have just experienced:

		Totally Disagree	Disagree	Neutral	Agree	Totally Agree	
1	Using the system is a good idea	○	○	○	○	○	1
2	The system distracts me from driving	○	○	○	○	○	2
3	Learning how to operate the system is easy for me	○	○	○	○	○	3
4	The system makes driving more interesting	○	○	○	○	○	4
5	Assuming I had access to the system, I would use it	○	○	○	○	○	5
6	Interacting with the system would be fun	○	○	○	○	○	6
7	I find the system easy to use	○	○	○	○	○	7
8	The system would be useful when driving	○	○	○	○	○	8
9	Using the system requires increased attention	○	○	○	○	○	9
10	I would enjoy interacting with the system	○	○	○	○	○	10

Appendix X: STUDY E – General Questionnaire

Gender: Male ☐ Female ☐

Age: ……

For how many years have you held a UK driving licence?

☐ Years

What is your approximate annual mileage?

☐ Miles

Are you left-handed or right-handed?

Left-handed ☐ Right-handed ☐

Do you own a touch screen device (e.g. smart phone or tablet)? If so, please give details if possible.

Yes ☐ No ☐

……

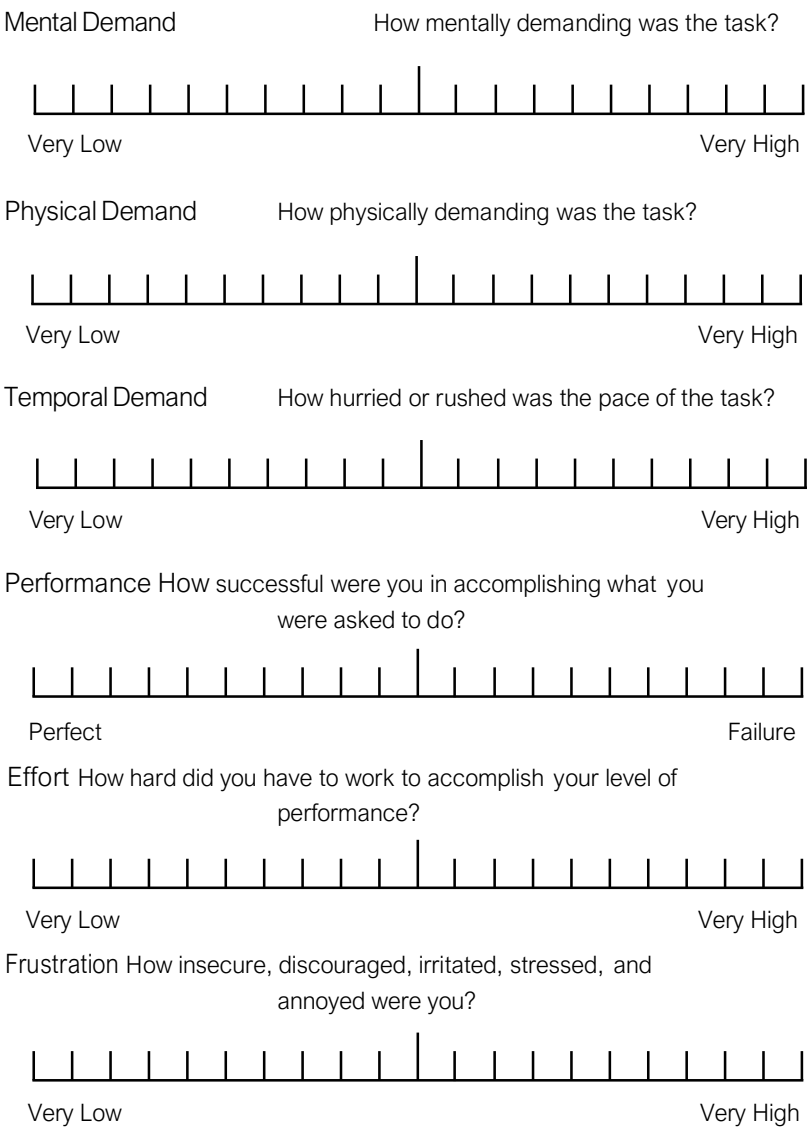
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Appendix XI: STUDY E – NASA TLX

Hart and Staveland's NASA Task Load Index (TLX) method assesses work load on five 7-point scales. Increments of high, medium and low estimates for each point result in 21 gradations on the scales.



Appendix XII: STUDY E – Simulator sickness questionnaire

Please tick the one that applies for each symptom

	None	Slight	Moderate	Severe
1. General discomfort				
2. Fatigue				
3. Headache				
4. Eyestrain				
5. Difficulty focusing				
6. Salivation increased				
7. Sweating				
8. Nausea				
9. Difficulty concentrating				
10. “Fullness of the head”				
11. Blurred vision				
12. Dizziness eyes open				
13. Dizziness eyes closed				
14. Vertigo				
15. Stomach awareness				
16. Burping				