BEHAVIOURAL ADAPTATION TO IN-VEHICLE NAVIGATION SYSTEMS

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Abstract

This PhD investigates driver behavioural adaptation to in-vehicle navigation systems (IVNS). Behavioural adaptation is receiving an increasing amount of research attention in traffic psychology, but few studies have directly considered the concept in relation to IVNS. The thesis aims were addressed using a range of quantitative and qualitative methodologies.

Using two online surveys, over 1300 drivers (including over 1000 IVNS users) were sampled, to identify a range of positive, neutral and negative aspects of end-user behavioural adaptation to IVNS in terms of both safety and navigational efficiency. The first survey (N=450) aimed at drivers in general, showed that IVNS users believe they commit some common driving errors (e.g. misreading signs when leaving a roundabout) significantly less frequently than ordinary drivers who do not use these systems, but that they also feel they drive without fully attending to the road ahead significantly more frequently. The second survey (N=872) was aimed at IVNS users only, and further explored distracted driving. This survey found that the majority of IVNS users have interacted with their system while driving (e.g. to enter a destination), and that some do so frequently. It also showed that system reliability is a key issue affecting most current IVNS users, revealing that some drivers have followed inaccurate as well as illegal and potentially dangerous, system-generated route guidance information in a range of different contexts.

A longitudinal diary study (N=20) then collected rich qualitative data from a sample of worker drivers who regularly used their IVNS in unfamiliar areas. The data collected illustrated the diverse contexts in which drivers experience aspects of behavioural adaptation to IVNS identified in the surveys. Both the IVNS user-survey and diary study also identified key demographic individual difference variables (most notably age and computing skill) that were associated with the extent to which driver's experienced different manifestations of behavioural adaptation to IVNS. Moreover, other individual difference variables (e.g. complacency potential, system-trust, confidence) were found to be associated with more specific behavioural adaptations.

Two simulator studies investigated system interaction while driving. The first (N=24) demonstrated the poor degree of correspondence between drivers' perceptions of driving performance when entering destinations while driving (relative to normal driving) and objective performance differences between these conditions. The second simulator study (N=24) showed that safety and training based

interventions designed to reduce the extent to which drivers use IVNS while driving or to improve their performance if they do had only a modest effect on dependent measures.

This thesis represents the first attempt in the literature to bring together research from diverse areas of human factors and traffic psychology to consider behavioural adaptation to in-vehicle navigation systems. By associating a range of these issues with behavioural adaptation to IVNS, it has indirectly increased the scope of several salient, previous research findings. Moreover, by investigating many of these issues in depth, using both quantitative and qualitative methodological approaches, it has set the foundation for future work. Such work should aim to explore many of the issues raised, and develop effective remediating or mitigating intervention strategies for negative behavioural adaptations that could adversely affect driving safety, as well as to encourage and support those which may be considered more positive.

The following paper was published during the PhD:

Forbes, N.L. & Burnett, G.E. (2008). Investigating the contexts in which in-vehicle navigation system users have received and followed inaccurate route guidance instructions. In L. Dorn (Ed) *Driver behaviour and training volume 3,* (pp.291-310), Ashgate.

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Chapter 1: Introduction to the Thesis

1.1 Introduction overview

This chapter will begin by outlining the purpose of this thesis. Then the term behavioural adaptation will be briefly defined in a transportation context. The introduction will go on to introduce the concept of automation. It will show how automation has been defined and classified. It will also show how both subtle vehicle modifications such as anti-lock brakes or power steering, as well as more advanced intelligent transport systems may be classified as automation at different levels. It will distinguish between two classes of intelligent transport system: advanced driver assistance systems (e.g. adaptive cruise control) and in-vehicle information systems (e.g. in-vehicle navigation systems). Following a brief description of two advanced driver assistance systems presently available to drivers, in-vehicle navigation systems (IVNS) will be introduced and described in greater detail.

The introduction will conclude by presenting specific aims and general objectives for this research. These will be followed by a synopsis of each chapter and a diagram illustrating the contributions each individual chapter makes to other chapters and the thesis as a whole.

1.2 Background and motivation for the research

This thesis addresses driver behavioural adaptation to IVNS. A multi-modal approach will identify the range of ways in which end-users adapt their driving behaviour in the presence of an IVNS. It will also explore individual difference variates in adaptations and test a method for remediating against a prevalent type of negative (in terms of safety) behavioural adaptation.

1.3 Behavioural adaptation

This thesis focuses on driver behavioural adaptation to in-vehicle navigation systems. Adaptation is defined in the Oxford English Dictionary (second edition) as “the process of modifying to suit new conditions”. Smiley (2000 p.47) describes adaptation as “intrinsically human…one of our most valuable characteristics…a manifestation of intelligent behaviour”. She suggests that our capacity to adapt to changing circumstances or unexpected outcomes is precisely the reason why humans are often recruited to supervise highly automated systems.

In traffic Psychology, the term behavioural adaptation was first coined in 1990 by an expert panel at the Organisation for Economic Co-operation and Development (OECD) as a global term to describe the range of behavioural changes that occur following the introduction of any changes to the road transportation system. They identified behavioural adaptation as a significant issue: "drivers employ the vehicle technology available to them in order to suit their driving purpose, motivation, driving style and current physical process". They defined behavioural adaptations as:

"*those behaviours which may occur following the introduction of changes to the road-vehicle-user system and which were not intended by the initiators of the change. Behavioural adaptations occur as road users respond to changes in the road transport system such that their personal needs are achieved as a result. They create a continuum of effects ranging from a positive increase in safety to a decrease in safety*" (OECD, 1990, p.23).

1.4 Automation

1.4.1 Defining automation

Over the past century, automation has gradually woven its way into most aspects of our daily lives. Presently we use automation in many contexts, both passively (by using products/services provided using automation), and actively (by interacting with automation directly). Some automation is already commonplace within our homes (e.g. central heating systems which automatically (dis)engage when the temperature exceeds/falls below some threshold) and at work (e.g. automated systems which calculate number of hours worked based on the time at which employees log in to their computers or performance statistics based on their telephone activity). This trend is set to continue. For example, Denning (2002) outlines a range of potential future automation scenarios such as "automated homes" with lights that switch on/off when inhabitants enter/exit rooms, curtains which open/close based on the time of day, ventilation systems which engage/disengage based on pollen counts etc.

The Oxford English Dictionary (2nd edition) defines automation as:

1. Automatic control of the manufacture of a product through a number of successive stages
2. The application of automatic control to any branch of industry or science
3. By extension, the use of electronic or mechanical devices to replace human labour

Sheridan and Parasuraman (2006) traced the first use of the term automation to a 1952 *Scientific American* article. However, they point out that the first definition above is now redundant as contemporary uses of the term have moved way beyond mere manufacturing processes. Presently automated systems are widely used in land and sea vehicles, aircraft, air traffic control, business systems, military systems, robotics, medicine, heating and ventilation systems and many more applications. The second and third definitions are fairly general and unspecific but are still applicable in a contemporary sense. It is important to note however, that with the advent of computerised rather than merely mechanical automation, human labour must also include mental as well as physical labour (see workload in chapter 2).

Modernisation and technological innovation (e.g. upgrading computer hardware, replacing cables with fibre optics) do not themselves constitute automation. Parasuraman and Riley (1997) defined automation as the execution by a machine agent (usually a computer) of a function that was previously carried out by a human. This definition is particularly useful when considering contemporary automation because it allows for the concept of automation to change over time. For example, in the last century clothes were washed by hand using water and a washboard. Automation (i.e. the washing machine) relieved people from this labour intensive work. However, in the 21st century automation is so pervasive that many devices and machines would barely even be recognised as automation by most people.

In many contemporary more complex automated systems, computers replace human operators by sensing and interpreting input themselves, making decisions and presenting output or even acting directly on these decisions without providing output. According to Moray, Inagki and Itoh (2000) contemporary definitions should include the range of processes from initial sensory input, to decisions made and actions taken. Lee and See (2004) (p.50) proposed such a definition. They viewed automation as "*technology that actively selects data, transforms information, makes decisions or controls processes*". Since automation is so pervasive in our daily lives, Billings (1997) coined the term *human-centered automation* to refer specifically to automation designed to interact with or be controlled by human operators. Human-centered automation is the type of automation discussed in this chapter and the thesis in general. However, to aid coherence from here on it will be referred to simply as automation.

1.4.2 Classifying automation

Automation should not be considered as all or none, rather that tasks/processes can be automated at different levels. This idea of considering different levels of automation has been frequently discussed in the literature for many years (e.g. Hopkin, 1975). Some forms of automation may require human intervention at certain points whereas others may run completely autonomously with little or no human intervention. Therefore automation should be thought of as a continuum with manual control at one end and fully automatic control at the other end.

To classify different levels of human interaction with automation Parasuraman et al (2000) proposed a four-way taxonomy. In the lower levels, automation is used in the acquisition, selection and filtering of information. In the higher levels, it is used first in the choice and selection, and then in the control and execution, of actions. Sheridan (2002) split these higher levels into a further seven levels, falling along what Goodrich and Boer (2003, p.326) refer to as a “responsibility spectrum”. At the lowest level automation merely suggests alternative courses of action which the operator must carry out. At the next level automation decides on an action, and performs the task if the operator approves. At the level above this, automation decides on an action, performs the task and then informs the operator, and at the highest level, automation selects the method, performs the task and ignores the operator.

Goodrich and Boer (2003) suggest that an automated system which shares some responsibility with a human operator should facilitate both flawless transitions between automated and human skills and unambiguous responsibility for switching between these skills. They extend the above frameworks by considering the importance of a timeline in human-automation interaction. They suggested that the following chronologically ordered questions are of central importance:

- How and by whom automation is initiated (Skill initiation)?
- Does automation execute the skill in a way that is transparent to the operator (Skill execution)?
- Is the operator or the automation responsible for switching the system off (Skill termination)?

According to Goodrich and Boer (2003), the above taxonomies primarily concerned skill initiation. However, the method by which automation executes and terminates skills is also very important. Operators should be able to understand skill execution so that it conforms to their expectations and preferences. A high level of transparency at skill execution, should keep operators “in the loop” so they are aware of what the automation is doing at any particular time and why it is doing it, and should not be surprised by any actions taken. They should also be able to understand how, when and why an automated system may cease performing a task, and therefore be prepared to adequately deal with this situation when/if it arises. An accurate mental model of system functions (see section 2.8.6) should facilitate this understanding.

Young, Stanton and Harris (2007) also distinguished between hard and soft automation. Their paper aimed to apply lessons learned from implementing automation in aviation to the driving domain. They showed that the two major aircraft manufacturers, Airbus and Boeing, had very different philosophies regarding the level of authority assigned to automation. Hard automation (used by Airbus) uses the technology to prevent human error. Critically, it has ultimate authority, and can override the human operator. Hard automation prevents pilots from pushing the plane outside its performance envelope, regardless of prevailing circumstances. For example, airbus systems have hard speed envelope protection which prevents pilots from stalling and pulling more than 2.5g (Hughes and Dornheim, 1995). Alternatively, soft automation (used by Boeing) uses the technology only to aid the pilot. The fundamental difference is that in the soft approach, pilots retain ultimate authority to override automation if they want to (or need to), and although it may make suggestions, automation will not override the pilot.

The authors showed that there are advantages and disadvantages to either approach. However, they reviewed aviation accident reports involving aircraft using each type of automation. Although their review was fairly simplistic (e.g. it failed to control for aircraft characteristics which may significantly affect accident statistics) it did indicate that hard automation led to more problems of human performance than soft automation. Both hard (e.g. automatic gearboxes, anti-lock braking systems, traction control systems) and soft (e.g. IVNS, adaptive cruise control, collision warning systems) automation approaches have been implemented in the driving domain. These and other automobile automation developments are considered in detail in the next section.

1.5 Automobile automation

The past century has seen the automobile develop from a simple horseless carriage to one of the most technologically advanced mass market commodities available (Young, Stanton and Harris, 2007). Stanton and Marsden (1996, p.2) view the trend to automate most aspects of vehicle operations as an "unstoppable force in modern automotive engineering". The automobile industry regularly cites increased safety, efficiency and comfort as the driving force behind vehicle automation (Walker, Stanton and Young, 2001).

This drive towards vehicle automation is not new. It can be first traced back to the 1940`s when automatic gearboxes first became widely available. These were followed by the introduction of electronic ignition systems at the beginning of the 1970`s (Weathers and Hunter, 1984). By replacing contact breaker points with transistorised switching and amplification, electronic ignition significantly improved efficiency (Walker, Stanton and Young, 2001). Soon after this, engine efficiency and power were further raised with the introduction of fuel injection systems in Chrysler and Ford models (Weathers and Hunter, 1984). These fuel injection systems heralded the beginning of computing control, they were the first to sense engine parameters, and use a computer to process data using closed-loop feedback and data-lookup tables (Walker, Stanton and Young, 2001). The tight control these computerised systems held over exhaust gases, in combination with the development of unleaded fuels facilitated the introduction of catalytic converters in the late 1980`s (Robson, 1997).

Power steering was another development in vehicle automation that has increased efficiency. Later developments in vehicle automation were oriented towards increasing safety. The development of electromagnetic wheel speed sensors and microprocessor control as pioneered by Mercedes Benz and Bosch led to the introduction of antilock braking systems (ABS) (Nunney, 1998). Soon after this, more advanced computer control facilitated coordination between previously isolated vehicle systems, so that BMW for example, first combined engine management with ABS to introduce traction control (Robson, 1997). Further developments in computing processing power, sensor and actuator technology and system integration over the past two decades have optimised virtually every conceivable aspect of mechanical performance. Walker, Stanton and Young (2001) suggest that modern cars serve as a suitable paradigm for ubiquitous computing. Whether referring to microprocessor control of windscreen wipers or the engine management system, the computer has largely disappeared; instead it is embedded within the complex array of vehicle systems.

1.6 Intelligent transport systems

> *"Cars of the future will take the stress out of driving. Cars will be installed with an electronic system, which will enable them to travel at high speed, nose to bumper, without fear of collision. As soon as the car is on the guide track on the centre of the road the driver can sit back and watch an in-car video or snooze. Laser sensors will control the distance from the car in front and respond to underground indicators that replace traffic lights. A computer will ensure the vehicle follows a programmed route to the required destination". (Quest, 1989)*

Whereas traditional vehicle automated systems subsumed lower level vehicle control tasks, a wide range of more recent computerised systems have been developed (or are currently in development) that are poised to take over or support higher level tactical and strategic aspects of driving (Ranney, 1994). Young, Stanton and Harris (2001) refer to first generation automation of low-level vehicle control such as that outlined in the previous section as vehicle automation, and to second generation automation of higher-level cognitive driving tasks as driving automation. The range of second generation driving automation systems have been referred to in many different ways. Some researchers refer to them as driver support systems (DSS), but this term inadequately describes the wide range of systems presently available to drivers as some systems may actually replace certain driving tasks rather than merely supporting them (e.g. adaptive cruise control replaces acceleration and braking control tasks). The majority of researchers and authors (including the present author) prefer to refer to the whole range of driving automation technology as intelligent transport systems (ITS).

ITS can be broadly regarded as falling into two distinct categories: advanced driver assistance systems (ADAS) and in-vehicle information systems (IVIS). ADAS include adaptive cruise control, collision warning and avoidance systems, lane departure warning systems, intelligent speed adaptation, parking/reversing aids, vision enhancement systems, pedestrian/obstacle detection systems, road-surface warning systems and driver monitoring systems. IVIS include IVNS, traffic information systems, vehicle monitoring systems, audio/video devices, vehicle communication systems and driver convenience services (e.g. personal digital assistants - PDA`s, phone related services, hands-free equipment, driver identification systems). A small selection of ADAS and IVIS presently available to drivers are outlined briefly below. For comprehensive reviews of presently available (and soon to be available) systems, the reader is directed to Floudas et al. (2004) or Bayly et al. (2007).

1.6.1 Adaptive cruise control

Conventional cruise control (CC) systems simply adjust throttle to maintain vehicle speed. However adaptive cruise control (ACC) systems replace the cognitive tasks of perceiving lead vehicle speed, deciding whether to adjust own speed and taking the appropriate action (Young, Stanton and Harris, 2001). ACC systems utilise radar or laser based sensor equipment on the front of the vehicle to monitor and maintain a desired headway distance between a following vehicle and a lead vehicle (tactical level – see section 2.2) by adaptively adjusting acceleration and braking (control level – see section 2.2).

There are some situations ACC is presently unequipped to deal with, such as a stopped vehicle ahead. When this situation arises, ACC automatically disengages and the driver is supposed to resume vehicle control. To ensure drivers remain "in the loop" some ACC systems require the driver to tap the steering wheel in frequent intervals, to prove they are still attentive to the prevailing driving situation. ACC has already been introduced in some models by several manufacturers including Audi, BMW, Mercedes-Benz, Ford, Hyundai, Jaguar, Lexus, Toyota, Volkswagen, Volvo, Nissan, Renault and Range Rover to name a few.

1.6.2 Intelligent speed adaptation

A large volume of research has demonstrated strong associations between accident rates and driving speed (Elvik, Vaa and Östvik, 1989; Finch, Kompfner, Lockwood and Maycock, 1994; Nilsson, 2004) and speed variation (Salusjärvi, 1981; Finch et al., 1994; O'Cinnéide and Murphy, 1994). Carsten and Fowkes (2000) defined three distinct types of intelligent speed adaptation (ISA) systems:

1. Advisory informative systems – These systems simply inform the driver about the present speed limit
2. Advisory intervention systems – These systems provide a visual, auditory or haptic warning (i.e. increased resistance or vibration of the acceleration pedal) when a speed limit is exceeded.
3. Mandatory intervention systems – These systems physically limit vehicle speed so that it adheres to the speed limit.

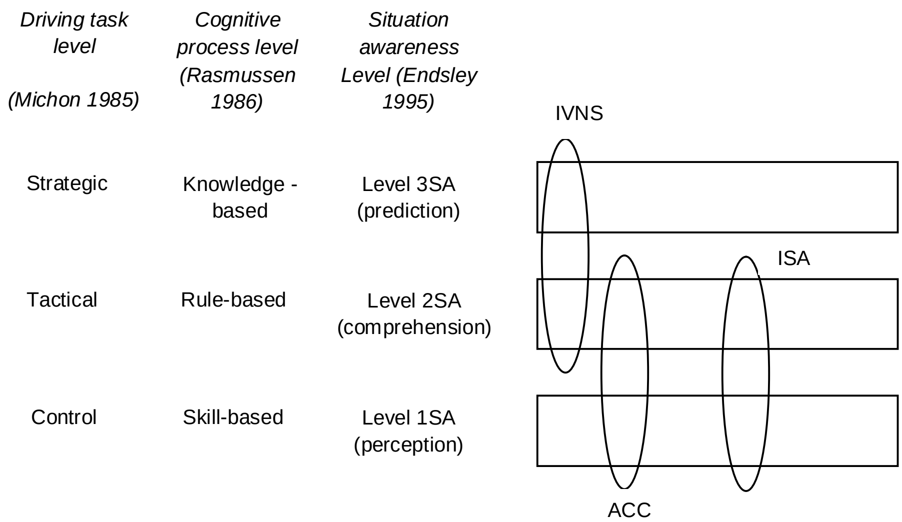
Using GPS technology, radio beacons, optical recognition systems or dead reckoning, ISA systems locate the vehicle and then compare actual speed with posted speed limits in that location.

1.6.3 In-vehicle navigation systems

Modern IVNS (also referred to as route guidance systems) typically use the global positioning system (GPS) to determine vehicle location with an accuracy of approximately 10 metres for commercial grade applications. They perform a route calculation using an on-board road map database.

IVNS support strategic level driving behaviour by assisting in trip planning and highlighting routes, and they support tactical level driving behaviour by providing turn-by-turn voice messages or visual symbology (see fig 1.1). Research concerning behavioural adaptation to IVNS will be considered in detail in chapter 2.

Figure 1.1 –Automation of driving task levels by intelligent transport systems



Source: redrawn from Ward et al (2000)

Fig 1.1 Key: IVNS=Navigation system ACC=Adaptive cruise control ISA=Intelligent speed adaptation

1.6.3.1 History and development of IVNS

First generation IVNS were static in nature. This means that they displayed visual maps and provided route calculations but vehicle position was not informed real time by GPS. In Japan, IVNS were first introduced by Honda in 1989, followed by Nissan in 1989 (Norris, 1999). These IVNS used gyros and dead reckoning to determine vehicle position. There is debate regarding which was the first commercially available static IVNS outside of Japan. The first truly digital static IVNS (also then referred to as advanced traveller information system) was the ETAK navigator, and the first dynamic IVNS informed by GPS signals were designed independently by Mitsubishi and Pioneer in 1990.

When they first started to appear in vehicles, IVNS were built into high-end luxury cars at the design stage. These are known as integrated IVNS (see fig 1.2). Their integrated nature meant that some vehicle manufacturers (e.g. Subaru, Lexus, Toyota) were able to limit aspects of system functionality when the vehicle was in motion. Since they were bundled with new vehicle models they were initially quite expensive options. However, over the past fifteen years an increasing range of much cheaper after-market systems have been developed (see fig 1.3).

Fig 1.2 – showing a selection of integrated IVNS available to drivers

All images last accessed 12/10/08. Sources of images:

http://media.washingtontimes.com/media/img/photos/2008/07/02/20080701-214757-pic-401977619.jpg

http://z.about.com/d/cars/1/0/0/h/ag_07civicsi_nav.jpg

http://www.navigadget.com/wp-content/postimages/2007/03/sl55-gps-353.jpg

http://www.classcarscanterbury.co.uk/images/mercedesGPSInDash.jpg

Fig 1.3 – showing a selection of aftermarket nomadic IVNS available to drivers

All images last accessed 12/10/08. Sources of images:

http://gpsinformation.info/bruce/n60i/Navman_N60i/navman_n60i.jpg

http://images.bountii.com/thumbnails/82/09/8209794897cf0a884ae32b6f6c21fa29

http://ecx.images-amazon.com/images/I/51V3DA5WQTL._SL500_.jpg

http://www.theautochannel.com/news/2006/12/14/031513.1-lg.jpg

Nomadic systems are typically mounted on the dashboard or windscreen using a simple bracket mounting device. As they are not linked to other vehicle systems (e.g. sensors), there is less scope for manufacturers to limit functionality when the vehicle is in motion.

Alternatively, some drivers use laptops connected to GPS receivers with CD-ROM based map databases and route guidance software. More recently with the mass market penetration of small portable computing systems, a whole range of other devices such as Java-enabled mobile phones or PDA`s can be uploaded with map databases and route guidance software and connected to a GPS receiver (see fig 1.4). These are referred to as portable navigation devices (PND). Given the unspecific nature of these devices, they may also run a wide range of other applications, related and unrelated to navigating, therefore vastly increasing the range of functionality.

Fig 1.4 – showing a selection of mobile phone and PDA based IVNS available to drivers

All images last accessed 12/10/08. Sources of images:

http://www.mobilewhack.com/Smart%20Rider.jpg

http://www.today-reviews.com/screenshot/2008/07/image231.png

http://www.cyberindian.net/wp-content/uploads/htc-p3300-mobilephone-maps.jpg

http://www.navigadget.com/wp-content/postimages/2006/10/acer-n35-gps-228.jpg

1.6.3.2 IVNS functionality

Typical IVNS offered today provide drivers with a digital map with several useful characteristics including turn restrictions, speed limits, vehicle restrictions, points of interest and address ranges to enable smooth and efficient in-vehicle route guidance. The route guidance function directs drivers along a planned route using auditory turn-by-turn instructions and detailed screen information displaying the digital map, time/distance to action, street names at junctions etc. Numerous driver preferences can be included or excluded in route calculations (e.g. avoid toll roads, only use motorways etc.).

The digital maps are based on extensive and structured digital geographical databases, and are primarily authored by two companies: Navteq and Teleatlas. Typically, IVNS manufacturers release annual map updates and charge consumers for these, although as will be shown later in this thesis, this trend is beginning to change. Some models display two dimensional maps, while other more recent models display maps in three dimensions. Maps are scalable and recent technological advances have vastly increased screen resolutions and illumination. Screen sizes on nomadic and integrated units are typically 6-7" or larger, but they may be considerably smaller on PND.

Most models provide a tactile interface so drivers can input destinations or navigate menus by touching the screen or buttons, and more recent models allow some functions (including destination entry) to be performed vocally. Several destination configurations are accepted including street names, postcodes and stored favourites.

Most recent models also provide real-time traffic information to enable drivers to conveniently re-route if faced with congestion, road closures, accidents etc. on their journey. The services are typically broadcast over FM radio (Svahn, 2004) and there are extensive variations in the way this service has been implemented both between and within countries.

1.6.3.3 Popularity and market penetration of IVNS

Early industry surveys in Japan (JGC 1994), where the market was most mature, have shown that vehicle navigation is the largest sector in the GPS market place. The J.D. Power and associates (2004) survey showed that the number of new vehicle models offering factory installed (i.e. integrated) IVNS rose from just 7 in 1998 to 116 in 2004, and current forecasts suggest that global GPS production value will rise from an estimated $21.5 billion in 2008 to $757 billion in 2017 (Research and markets). The JD Power and associates (2008) survey revealed that 25% of new vehicle owners reported having a IVNS installed, up from 20% in 2007. However, In the UK, the office of national statistics (ONS) omnibus survey (DfT, 2005) indicated that just 7% of UK drivers and passengers surveyed had an IVNS fitted.

Unfortunately, although extremely useful, the JD Power surveys do not tell the whole story, as they are only concerned with drivers using integrated IVNS. However, as shown above, the introduction of vastly cheaper after-market units has significantly increased market penetration. The GFK (2008) survey tracked worldwide market developments regarding portable IVNS. It showed that in Western Europe, a total of 14.4 million systems were sold in 2007 (up from 7.8 million in the previous year) and demand is expected to increase by 36% in 2008 given the decreasing prices of these systems. In 2007, the highest number of systems (3.6 million) was sold in Germany. This is up 1.53 million units (74%) from the previous year. During the Christmas shopping period 2007, portable navigation devices sold, accounted for 9% of the consumer electronics sector and 12% during July (i.e. summer holiday season).

Market penetration in Eastern Europe is much more modest, with only 55,000 units sold during 2007, although this is expected to rise to above one million in 2008. A primary reason for the slow Eastern European market penetration is the inflated price of these systems relative to other countries. For example, the survey showed that portable IVNS are cheapest in Italy (195 euros), Spain (202 euros), Finland (204 euros) and the UK (211 euros), but most expensive in the Czech Republic (339 euros) and Poland (303 euros). According to Sena (1997) in order for IVNS manufacturers to generate sufficient business revenues, these systems must be viewed by the driving public not as luxury gadgets, but as convenience applications or even necessity. Few surveys have addressed this particular point.

1.6.3.4 IVNS user demographics

The ONS (2005) omnibus survey examined UK drivers' and passengers' attitudes towards transport. In one section of this survey, they asked whether the car/van that participants used most often had a satellite IVNS installed. They also collected a range of demographic information (including age, gender, socio-economic group, gross annual income and driving frequency). The survey showed that an equal proportion of male and female drivers reported using an IVNS (7%) and that they were used by drivers of all ages, although the highest using age bands were 26-44 years (9%) and 45-54 years (9%). The GFK (2008) survey showed that in Germany, the highest purchasing age bands were 40-60 years (43%), closely followed by those under the age of 30 years (32%) and over 60 years (25%).

Interestingly, in the ONS omnibus survey (DfT, 2005), the frequency with which drivers reported using their car/van appeared to be poorly associated with IVNS use. The same percentage (8%) of frequent car/van users (those who used their vehicle every day) reported using an IVNS as infrequent car/van users (those who use their vehicle less than every day). Although the results failed to attain statistical significance, the survey did show a tendency for IVNS users to be from higher socio-economic positions - 10% of participants from managerial and professional occupations reported using them, compared to just 5% of participants from routine and manual occupations. These proportions are mirrored when considering annual gross income. While just 16% of drivers earning less than £13,519 per annum reported using an IVNS, over a quarter of those earning more than this per annum (27%), reported using one.

Svahn (2004) was primarily interested in IVNS usage patterns, but in his study he also collected a range of pertinent IVNS user demographics. This study utilised German respondents who used the Volvo RTI (road and traffic information system) only. This is an integrated (i.e. built into the car) IVNS. Just over three quarters of participants in this study were male (77.5%), and the mean age of participants was 45 years, with 45-49 years being the highest using age band. Most participants in this study lived in a large city or metropolitan area. Although the DfT (2005) study gave an indication of IVNS users' driving experience by considering the frequency of car use, Svahn (2004) went further by examining participants' annual mileage. The mileage band with the highest frequency of participants was 300-349 thousand miles per year (the mean annual mileage was 343 thousand miles). Svahn (2004) considered education level rather than job type as a crude measure of socio-economic status. He found that nearly three quarters of participants (72.4%) had a university degree or higher, suggesting that most IVNS users in this study too, were from higher socio economic groups.

Svahn (2004) also found that nearly two thirds of system users considered themselves as expert computer users or as having considerable skills, and just under a third thought they possessed only moderate or insignificant computing skills. He also examined associations between computing skill and IVNS usage and various user preferences. He found that IVNS users with good computing skills had more active behaviour when operating their IVNS, tended to use their systems more often, utilise greater functionality and worried less about safety considerations than those less skilled at computing.

1.6.3.5 IVNS human factors issues

A range of human factors issues have been considered in the IVNS user literature. As shown above, the main functions of IVNS are to provide route guidance functions (and in some models traffic information). Chapter 2 will also discuss tendencies for drivers to interact with their IVNS while driving. Therefore, the distraction potential of IVNS both when drivers merely follow route guidance instructions and interact with the system has received considerable research attention. Several studies have examined the impact of interface characteristics on driving performance and control and tactical level driving behaviour as well as mental workload and situation awareness. Usability has also been a key concern. More recently, researchers have begun to consider the effects of trust on system reliance in an effort to further understand aspects of tactical and strategic level navigation-related behavioural adaptation to IVNS. With the exception of usability, these issues will be discussed in detail in the next chapter.

1.7 Aims and scope of thesis

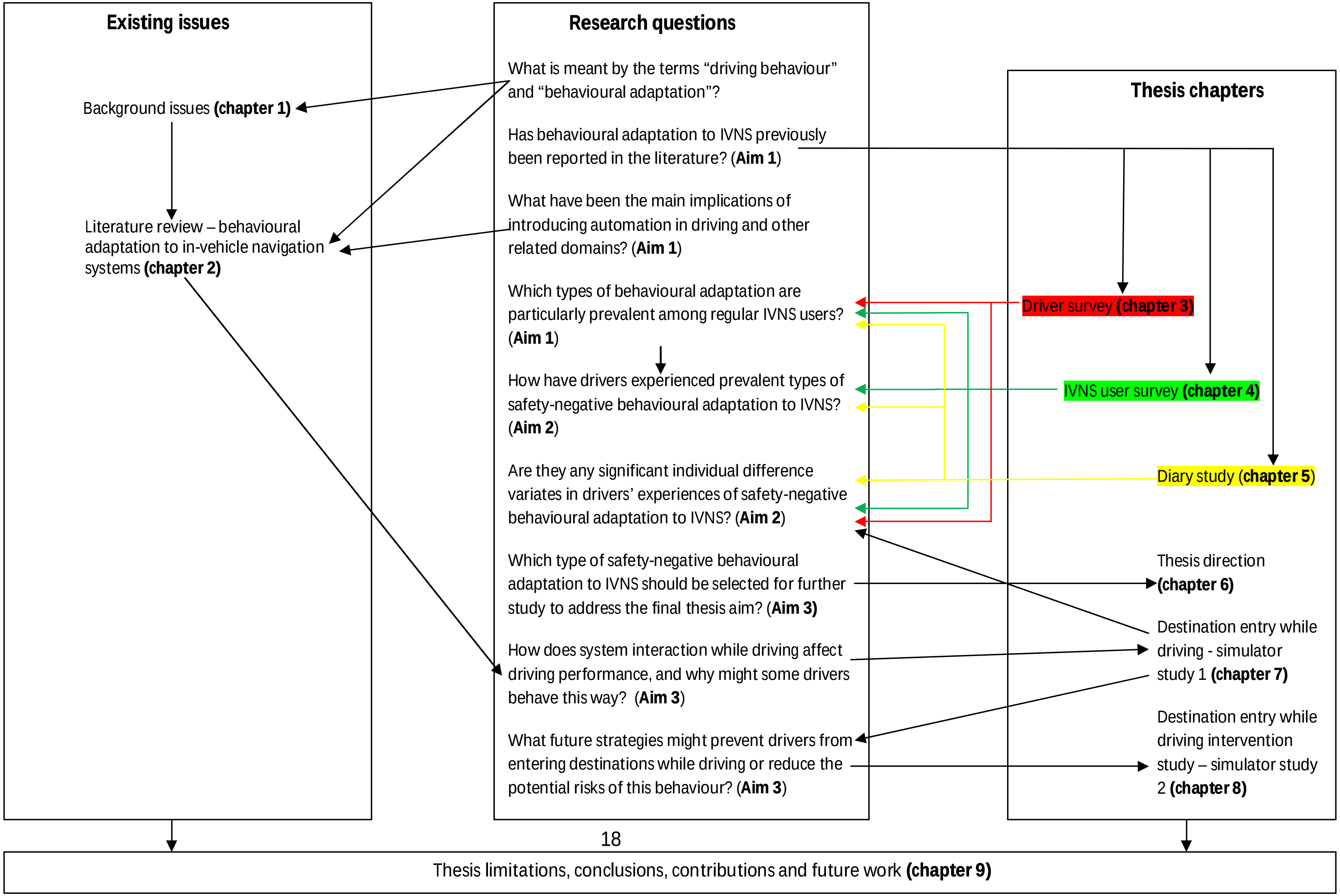
The specific aims of the thesis are to:

1. **Identify** the range of potential **types of driver behavioural adaptation** to IVNS including those which have a positive, negative and neutral impact on driving safety and navigational efficiency.
2. **Explore** those behavioural adaptations which have the potential to degrade driving safety, paying particular attention to any individual difference variates.
3. **Select** and **further investigate** a prevalent **safety-negative** type of behavioural adaptation to **understand** why some drivers behave this way. Use the findings to **highlight** potential strategies to remediate or mitigate this particular driver behaviour.

1.8 Thesis structure

This thesis includes one literature review and five studies. A multi-modal approach using both quantitative and qualitative methodologies has been used to address the central aims and objectives. The literature review consolidated the range of studies which have either directly or indirectly considered driver behavioural adaptation to IVNS. It illustrated the mixed range of findings from previous studies, some key difficulties in arriving at conclusions about behavioural adaptation from much of this data and potential avenues for further investigation in the thesis. The first two studies were designed to investigate the range of manifestations of driver behavioural adaptation to IVNS, including those which have a positive, negative and neutral effect on driving safety and navigational efficiency. These studies revealed two prevalent manifestations of safety-negative behavioural adaptation to be explored in greater detail in the thesis. The third study further explored these specific manifestations, and aimed in particular, to identify individual difference variates and potential avenues of explanation, based on participants' qualitative accounts of situations they had encountered as well as some quantitative data. The qualitative data informed the design of the fourth study which further explored the tendency for young drivers to use their IVNS while driving. In particular, it aimed to examine the performance effects of destination entry while driving as well as the degree of correspondence between subjective and objective ratings of driving performance during destination entry tasks. The final study explored and tested potential remediating and mitigating interventions, designed to prevent [young] drivers from behaving this way or lessen the negative effects of this behaviour on driving performance. Figure 1.7 illustrates the main thesis structure. It shows the contribution each chapter makes to the thesis as a whole as well as the interactions between each chapter.

Figure 1.5 – thesis structure diagram



1.9 Synopsis of thesis chapters

Chapter 2 – Literature review – behavioural adaptation to IVNS

This chapter focuses on current research that has either directly or indirectly examined aspects of driver behavioural adaptation to IVNS. It starts by reviewing research concerning behavioural adaptation to other forms of both low-level vehicle automation, and higher-level driving automation, to identify any potential similarities in behavioural adaptation across systems. It goes on to consider IVNS specifically. The literature review demonstrates that research concerning behavioural adaptation to IVNS specifically is scarce relative to other systems. While many early studies concerning distraction and other issues have been conducted that are relevant to behavioural adaptation, there are some key methodological difficulties in drawing firm conclusions from them (e.g. *the novelty effect* - behavioural adaptation of inexperienced users may differ substantially from the behavioural adaptation of those who have been using their system for some time; *system variation* – many early studies featured out-dated IVNS relative to those systems presently available to drivers). Additionally, few studies have considered higher strategic and tactical level behavioural adaptation to IVNS. Although some survey/questionnaire based research has briefly considered higher-level behavioural adaptation of established system users, the vast majority of studies have solely considered those drivers using integrated IVNS. The literature review concludes that since a much higher proportion of drivers presently use after-market systems, further research is urgently required to understand behavioural adaptation issues affecting these drivers too. It also concludes by showing that a multi-modal research approach, incorporating both quantitative and qualitative methodologies, would be best-suited to further understanding driver behavioural adaptation to IVNS, and that such an approach should help in examining users' understanding of system functioning as well as in identifying individual difference variates in drivers' experiences of behavioural adaptation, as these issues have received only scarce previous research attention.

Chapter 3 – Driver survey

This chapter describes an online survey (N=450) administered to drivers. This study aimed to examine IVNS user demographics and to begin investigating behavioural adaptation to IVNS. It used the driver behaviour questionnaire (DBQ) (Parker et al 1995) - a self-report scale which lists several driving errors, mistakes and violations. DBQ scores of IVNS users and non-users were compared to find out whether there were any significant differences in the frequency with which they committed different classes of error. This study addressed primarily the first aim of the thesis.

Chapter 4 - Large-scale IVNS user survey

This chapter describes a large-scale online survey of IVNS users (N=872). It aimed to further investigate the two prevalent forms of safety-negative behavioural adaptation outlined above, and to identify any individual difference variates. This study addressed directly the second aim of the thesis. Results of this study were presented at the 2007 Driver Behaviour and Training conference in Dublin, Ireland. It provided detailed accounts of both forms of safety-negative behavioural adaptation to IVNS, and suggested that age and computing skill were salient individual difference factors in drivers' experiences of behavioural adaptation.

Chapter 5 – Diary study

This chapter describes a longitudinal diary study, in which 20 IVNS users were asked to record details of their behaviour over a 2-week timeframe, and complete several questionnaires (e.g. complacency potential rating scale, trust in automation scale) concerning their attitudes towards their IVNS. Participants were also asked to pay particular attention to recording aspects of their driving behaviour that had changed since they started using an IVNS. This study aimed to identify the wide range of potential manifestations of behavioural adaptation to IVNS, and also addressed the first aim of the thesis. It concludes that two prevalent safety-negative manifestations affecting end-users are (a) inappropriate system use while driving, and (b) a tendency to follow inaccurate or unreliable route guidance instructions.

Chapter 6 – Thesis Direction

This is a short chapter that specified the thesis directions, once the first two aims had been addressed. It discusses the reasons why destination entry while driving, was examined further in the thesis instead of other important behavioural adaptation topics. In doing so, it also describes a pilot driving simulator study (N=10) designed to examine [older] drivers' willingness to follow inaccurate, dangerous/illegal system-generated route guidance instructions. It shows how it would have been inappropriate to have studied this particular form of behavioural adaptation further using the simulator due to key validity concerns.

Chapter 7 – Subjective vs objective performance effects of destination entry while driving

Qualitative accounts from the diary study indicated that few participants who entered destinations while driving were aware of the potential for this behaviour to adversely affect driving safety and performance. This chapter describes a simulator study (N=24) designed to examine the objective driving performance effects of destination entry while driving, and the degree of correspondence between subjective and objective ratings of driving performance when entering destinations while driving, using a popular, after-market, nomadic IVNS presently available to drivers. Using a repeated measures study design, participants were asked to rate how dangerous they thought various actions were, in relation to perceived safety, risk and detriment to driving performance. These ratings were examined relative to their actual driving performance. Mirroring previous research, the results showed that using an IVNS while driving seriously affected measures of longitudinal and lateral driving performance. Additionally, the results demonstrated the poor degree of correspondence between subjective and objective performance ratings, suggesting that participants were not aware of the safety/performance implications of destination entry while driving. This study addresses the second and third aims of the thesis.

Chapter 8 – Destination while driving intervention study

This chapter describes a second simulator study in which the same 24 participants (except controls) were exposed to safety (i.e. remediation strategy), training (i.e. mitigation strategy) and safety & training (i.e. remediation and mitigation strategies) related interventions. They were then given several routes to drive in the simulator, and were told that if they reached them within a certain time limit, they would receive extra payment for participation. The results suggested that all interventions had only a modest effect on participants' willingness to enter destinations while driving or their driving performance if choosing to behave this way. This study addressed the final aim of the thesis.

Chapter 9 – Thesis conclusions, contributions and future work

Based on results of studies reported in previous chapters, this chapter shows how the thesis fully addressed the aims, by identifying several positive, negative and neutral behavioural adaptations, exploring many of these in much greater detail, and using the findings to inform the design of a potential remediating or mitigating intervention strategy. Several avenues for future research are also discussed.

Chapter 2 – Literature review

Behavioural adaptation to IVNS

2.1 Overview

The IVNS research literature is extensive. A large volume of empirical research spanning the past two decades has considered a wide range of IVNS issues including usability, interface characteristics and design, distraction, driving performance, training, usage trends, user trends, acceptance, trust and reliance. These issues have been investigated using a wide variety of both quantitative and qualitative research methodologies, such as surveys/questionnaires, driving simulators, instrumented road/test-track vehicles, observations, diary studies etc.

Behavioural adaptation has also received extensive research attention, especially over the past decade. However, the vast majority of research concerning behavioural adaptation to automobile automation has centered primarily on ADAS (particularly systems that automate key driving control tasks such as ACC, AS, CA, ISA etc.) and other low-level vehicle automation (e.g. ABS, airbags). This is not particularly surprising, as these systems automate safety-critical aspects of driving behaviour, so determining any behavioural effects that may (or may not) negate some of the anticipated safety benefits of these systems is clearly a major concern.

However, the following literature review will highlight existing knowledge concerning driver behavioural adaptation to IVNS. It will begin by outlining a framework for understanding driver behaviour drawing on some hierarchical and taxonomical approaches to driver behaviour modeling (i.e. Michon, 1985; Hatakka et al., 1999; Reason, 1990). It will go on to more rigorously define behavioural adaptation in a transportation context. Following this, the range of methodologies and driving behaviour and performance measures that have been used throughout the literature will be outlined. Research concerning behavioural adaptation to non-automated transportation interventions and driving automation will then be briefly described. Following this, literature concerning behavioural adaptation to IVNS will be reviewed in detail. The review will start by considering studies which have compared IVNS use with other more traditional navigational methods such as paper maps and memorized route instructions and will go on to discuss other surveys and experiments that have examined strategic level behavioural adaptation to IVNS and other forms of advanced traveler information. It will often cite papers that have not explicitly mentioned behavioural adaptation at all or those centered on some other issue prevalent in the driving behaviour literature, but nevertheless studies in which the results imply driver behavioural adaptation at some level will be reported. This is because many of the early studies were conducted before behavioural adaptation was a rigorously defined and researched topic, and many of the later studies consider a whole range of issues, but imply behavioural adaptation at some levels

Some studies have reported behavioural effects of particular IVNS characteristics (e.g. interface characteristics, position in vehicle, input/output modality). These will be considered in this review, but it will primarily focus on research considering complete working systems. A lot of this research has produced mixed and often contradictory findings. Some have indicated positive and some negative behavioural adaptation (in terms of safety) for the same measures. The direction of behavioural adaptation effects (in terms of safety and navigational efficiency/effectiveness) will be highlighted throughout this review. However, it will illustrate some of the difficulties in comparing these studies due to methodological differences and some other issues (e.g. novelty effect and system variation).

There is some evidence to suggest that wider automation issues are just as important in understanding driver behavioural adaptation to IVNS as they are in understanding aspects of behavioural adaptation to other forms of automobile automation. The literature review will go on to describe some fundamental automation issues that appear to be applicable to the implementation of automation across domains. It will go on to outline present research that has investigated these issues in the automotive domains. Due to the relative scarcity of available empirical evidence in this area in relation to IVNS, this review will also consider evidence from secondary sources (e.g. press articles), and predictions and hypotheses that have been proposed.

2.2 Understanding driving behaviour

A range of hierarchical models of driving behaviour have been developed. These are essentially lists which consider driving behaviour from different perspectives. Some of these (e.g. Michon, 1985;

Hattakka et al, 1999) consider driving behaviour from a task analysis perspective, and aim to break down the driving task into its constituent components. Others (e.g. Reason, 1990; Reason, Manstead, Stradling, Baxter and Campbell, 1990) focus on the components of driver error as the fundamental aspects of driving behaviour.

Michon (1985) proposed a hierarchical model proposed to underlie the cognitive control of driving. It views driving as a problem solving task comprising three hierarchically related levels. The highest level is the strategic (or planning) level, below this is the tactical (or maneuvering level), and finally below this is the control (or operational) level. For each level, Michon (1985) illustrates specific task requirements, a time-frame in which these tasks are carried out, and the cognitive processes involved. According to the model, decisions made at each level inform decisions and actions performed at the level below.

The strategic level focuses on the purpose of the trip and the overall goals of the driver. It consists of all processes concerning trip decisions, such as general trip planning, vehicle selection, route selection (and other navigational considerations), setting trip goals, trip safety considerations etc. Strategic decision making hardly requires any new/environmental information, it is largely memory driven. Decisions are processed consciously (i.e. with awareness), although constant repetition may lead to these decisions becoming habits. In general, decisions made at the strategic level are not constrained by time – they may take several minutes or even hours. Most strategic decisions will be made before the driver even enters the vehicle, but others (if time permits) may be made while driving, often several minutes before they are implemented.

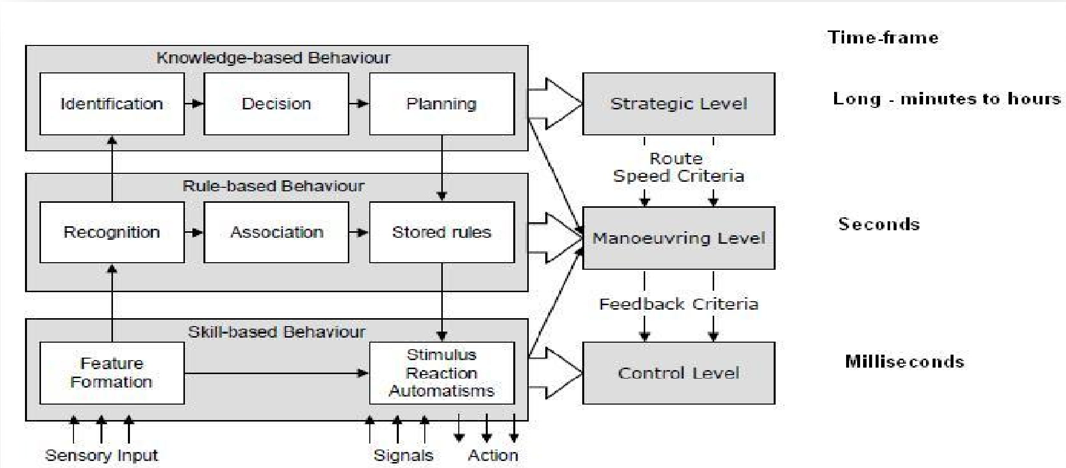
The tactical level focuses on the choice of maneuvers and immediate goals faced by the driver while trying to reach a destination. This involves negotiation of many common driving situations such as gap acceptance, speed selection, overtaking decisions, obstacle avoidance, lane choice etc. Tasks are largely completed at this level based on the strategic level requirements and the prevailing situation. Therefore tactical level behavior is influenced by both situational and motivational variables. Tactical level decisions are considered to take place in seconds.

Tactical level decisions are actually implemented at the control level. The control level focuses on the moment-to-moment operation of the vehicle. According to Norman and Bobrow (1975) control level decisions are largely data driven as they depend on the immediate prevailing situation. In experienced drivers, control level tasks are conducted without conscious information-processing. These largely automatic action patterns include acceleration, braking, steering, and gear shifting. Decisions made at the control level are implemented within milliseconds.

In their GADGET matrix, Keskinen (1998) and Hatakka, Keskinen, Gregerson and Glad (1999) extended Michon`s (1985) hierarchy to include an extra level above the strategic level that they refer to as “goals for life and skills for living”. This new level doesn’t contain any driving tasks, or deal with specific driving behaviours; instead it is concerned with driver characteristics such as personality, motivations, group identification, age, gender etc. The authors suggest that these driver characteristics can influence driving behaviour at lower levels, as they define how the driver functions as a person, and this can influence how they solve tasks at the strategic level (e.g. trip planning).

Rasmussen`s (1986) skills rules knowledge (SRK) framework defined types of human behaviour based on information processing. The original model did not specifically concern driving behaviour, but several previous authors have shown that the model also transfers to the driving context (e.g. Donges, 1982; Ranney, 1994; Vaa, 2001). In this model, the lowest level of behaviour is skill based. Once an intention has been formed, this type of behaviour requires very little or no conscious control to perform actions. It involves application of automatic schemata, which comprise well-learned procedures. In rule-based behaviour, drivers apply specific rules or procedures to complete a task. These rules may come from past experience in dealing with similar situations, or from some other source (e.g. driver training). Application of rules to behaviour is a largely automated process. However, knowledge-based behaviour represents a more advanced level of reasoning (Wirstad, 1988). It involves conscious problem solving, and is applied when drivers are faced with novel situations for which no existing sets of rules are applicable. Rule and knowledge based behaviours make greater demands on cognitive workload because drivers need to form explicit goals based on their analysis of the situation. Although Rasmussen`s (1986) model does not imply dynamic relations between the different types of processing, interestingly, Donges (1982, cited from 1999) showed how Michon`s (1985) model maps neatly onto Rasmussen`s (1986) model. This correspondence between models is illustrated in figure 2.1.

Figure 2.1 – showing correspondence between Rasmussen`s (1986) and Michon`s (1985) hierarchical model (adapted from Donges, 1982 cited from 1999)



Reason`s (1990) generic error modelling system (GEMS) examines the contribution of errors to driving behaviour. Reason (1990) distinguished three types of cognitive errors: Slips refer to attentional failures in task execution, and lapses are caused by memory failures. Both slips and lapses are unintended actions which occur at Rasmussen`s (1986) skill based level of behaviour. They occur during execution of routine tasks in familiar environments (e.g. using the wrong lane when approaching or exiting a roundabout). Mistakes are errors which result from intentional actions. They can occur at Rasmussen`s (1986) rule based and knowledge based levels of behaviour. Rule based mistakes involve misapplication of appropriate rules, or application of inappropriate rules for a given situation, whereas knowledge based mistakes may take a range of variable forms (Reason, 1990). In driving, mistakes would include attempting to overtake another vehicle or cyclist when they are indicating their intention to turn. The taxonomy also distinguished violations. Unlike other errors, these refer to deliberate infringement of some regulated or socially accepted codes of behaviour, such as speeding or driving while using a mobile phone.

2.3 Behavioural adaptation

2.3.1 Defining behavioural adaptation

As noted in chapter 1 the OECD expert panel (1990) defined behavioural adaptation as:

"*those behaviours which may occur following the introduction of changes to the road-vehicle-user system and which were not intended by the initiators of the change. Behavioural adaptations occur as road users respond to changes in the road transport system such that their personal needs are achieved as a result....They create a continuum of effects ranging from a positive increase in safety to a decrease in safety*" (OECD, 1990, p.23).

The expert panel stressed that behavioural adaptation was selected as the most appropriate term to describe the range of behavioural changes found in the field of traffic Psychology and road safety. However, its meaning in this context is not necessarily identical to its meaning in other fields such as perception, learning, social psychology and evolutionary theory. They describe behavioural adaptation not as a theory or hypothesis, but rather in a similar vein to a concept in a theory, with the precise operational definition dependent on the context of the research.

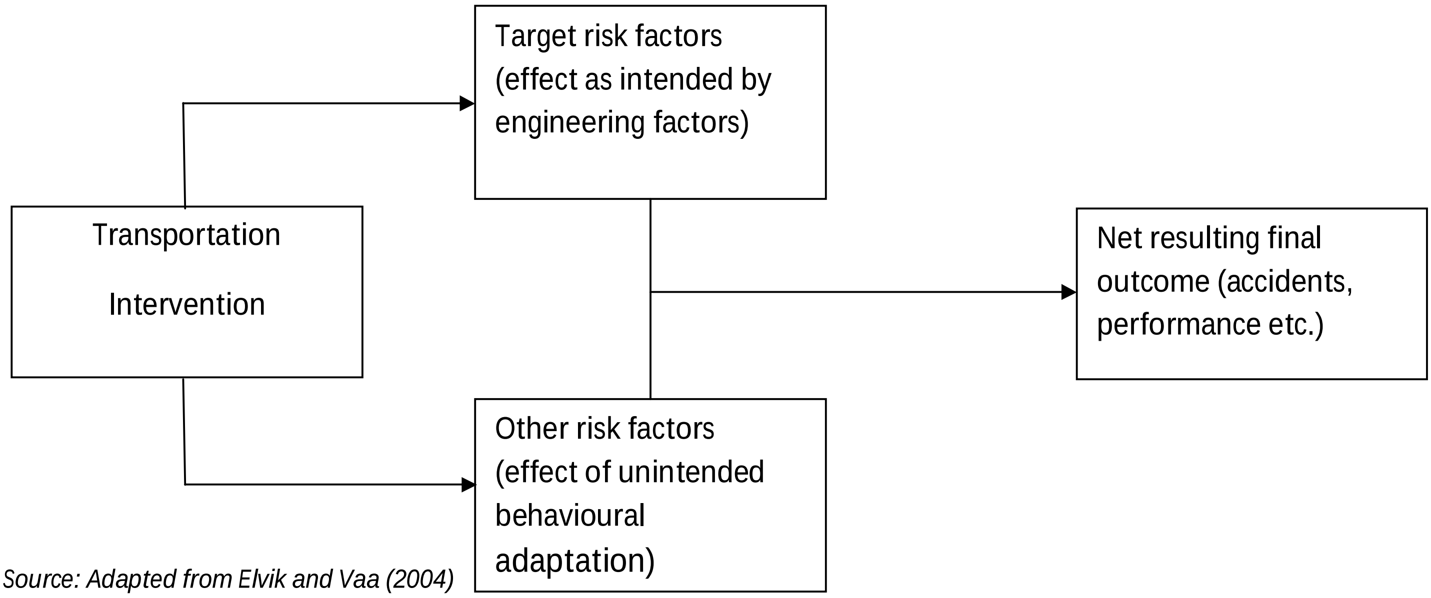
According to the panel, there are a number of pre-requisites for behavioural adaptation to occur. Firstly, the road user must receive and (not necessarily consciously) be able to perceive feedback. According to Evans (1985), road users use feedback to find out about changes in the road-traffic system, and it is primarily responsible for initiating behaviour change following an initial response to the system. Feedback may occur at a range of different levels (e.g. from the vehicle, the road, the driver, in-vehicle equipment), and may be immediate or more subtle, resulting from observing the road system over time. Secondly, drivers must be able to change their behaviour in response to feedback they receive, and finally they must be motivated to change their behaviour.

The panel stressed that, due in part to the lack of empirical data on behavioural adaptation in the research literature; their definition did not include any spatial or temporal range for behavioural adaptation. Evans (1985) suggests that the time taken for behaviour changes to occur will depend on the ability of road users to detect changes in the system, such that easily perceived changes will result in relatively quick behavioural adaptation (hours, days or weeks), whereas it may take much longer (months or years) to detect adaptation to more subtle changes (e.g. road width modification). According to Saad et al. (2004) behavioural adaptation to in-vehicle systems may not always appear immediately when the driving context is changed, but it usually appears after a familiarisation period.

Although the vast majority of behavioural adaptation research has focused on changes designed to increase road safety (e.g. seatbelts, studded tyres, antilock braking systems, collision/lane departure warning systems), the OECD panel stress that behavioural adaptation is by no means limited to these types of changes in the transportation system. Rather, it is concerned with how road users adapt to **any** changes in the system, regardless of whether they were instituted for the purposes of safety.

The OECD definition is the most pervasive definition of this phenomenon in the behavioural adaptation literature. It is used as the theoretical grounding from which the vast majority or research studies and articles are based (e.g. the AIDE project – see Saad et al., 2004). Although the definition specifically states that changes in the transport system can produce a continuum of effects ranging from a positive increase in safety, to a decrease in safety, the vast majority of behavioural adaptation research focuses specifically on negative behavioural changes (e.g. Dragutinovic, Brookhuis and Marchau, 2004 use the term to refer to **unintended** and **unwanted** changes in driver behaviour). As Brown (2001) points out, it is the negative effects of behavioural adaptation that are of most interest to road safety professionals. Figure 2.2 illustrates how both intended and unintended (i.e. behavioural adaptation) factors affect driving outcomes.

Figure 2.2 illustrating the effect of behavioural adaptation to transportation interventions on driving outcomes



Source: Adapted from Elvik and Vaa (2004)

Some authors also use the term counter-productive behavioural adaptation to refer to behavioural changes that negatively affect safety. Heijer, Brookhuis, van Winsum and Duynstee (1998) define counterproductive behavioural adaptation as a phenomenon where drivers start to behave in riskier ways because they are supported by a safety-raising device. The concept of counterproductive behavioural adaptation is derived from research concerning behavioural compensation (also referred to as risk compensation). Behavioural compensation refers to compensatory behaviours performed by drivers in response to any change in perceived risk. Several studies have illustrated safety-positive driver behavioural compensation following changes to the road/vehicle/user system that increased risk. For example, Taylor (1964, 1976) showed that drivers slowed down at former accident hotspots to adjust risk levels to a subjectively desired level and Haigney, Taylor and Westerman (2000) found that drivers compensated for the increased cognitive demand of driving while using a mobile phone, by driving more slowly. Several studies have also illustrated safety-positive behavioural compensation in older drivers, in response to age-related declines in cognitive (e.g. attention, reaction time), perceptual (e.g. vision, hearing) and motor function. According to Holland (2002, p. 37) "*older drivers almost invariably perceive that they are more at risk on the roads than they were ten years ago, and many report feeling quite* *vulnerable on the road".* Studies have shown that elderly drivers have a lower mileage (Holland, 2002), drive less at night time (Holland and Rabbit, 1992) and tend to avoid right turns and unfamiliar roads (Simms, 1993) in response to these age-related limitations.

Research has also illustrated safety-negative driver behavioural compensation following changes to the road/vehicle/user system designed to decrease risk (i.e. counterproductive behavioural adaptation). For example, in an early field study Ward and Wilde (1966) were interested in the extent to which visibility at railway crossings would affect compensatory behaviour in drivers. At the control site, the view of approaching trains was obscured but the experimental site was modified so that drivers had a clear view of approaching trains. Consistent with behavioural compensation, they found that drivers drove significantly faster at the experimental site, and they suggested that this negated the safety benefit of increased visibility. More recently using a driving simulator, Stanton and Pinto (2000) also found that drivers compensated for the reduction in risk when using a vision enhancement system by driving faster.

Counterproductive behavioural adaptation is often assumed to account for the discrepancy between engineering estimates of the net safety gains of a safety oriented countermeasure and actual experience (Rudin, Brown and Parker, 2004). According to Janssen and Van der Horst (1992), the engineering estimate of a device`s expected safety effect is the accident reduction that would be achieved if 100% of drivers had the device and they showed no behavioural adaptation to the new situation. Smiley (2000) noted that engineers who develop in-vehicle devices frequently assume that drivers will not change their behaviour when using them. Citing Hauer (date unknown), Smiley suggests that engineers are typically trained in the properties of inanimate objects (e.g. loads, stress, strain), however, she points out that drivers are human, and as such they adapt. Consequently, their speed and headway choices and their reaction times etc. cannot be considered as fixed properties that will remain unchanged following changes to the road/vehicle/user system. Given that adaptation is a valuable, intrinsically human manifestation of intelligent behaviour, Smiley suggests that the occurrence of behavioural adaptation *should* be predictable, and that we should be more surprised by its absence.

For the purposes of this thesis, a significant problem with the concept of counterproductive behavioural adaptation is that it is limited to compensatory behaviours that increase risk. Studying behavioural compensation would overcome this limitation but this concept would still be far too narrow to describe the range of behavioural changes that may occur in response to IVNS because behavioural compensation is specifically related to risk and therefore only concerns changes to the road/user/vehicle system that affect safety.

Although IVNS may positively and negatively affect driving safety in various ways, they are primarily purported by designers and manufacturers to increase efficiency and comfort, so they may also be associated with other safety-unrelated behavioural changes at the strategic and tactical levels of driving behaviour. Behavioural adaptation as defined by the OECD would be the most appropriate way to conceptualise behavioural changes that occur when drivers use IVNS as this definition also includes compensatory behaviours but does not exclude other behaviours that are not compensatory. As shown above, the OECD expert panel stated that behavioural adaptation may occur in response to **any** changes in the transport system regardless of whether they were initiated for the purposes of safety.

With the exception of two caveats this thesis will therefore adopt the OECD definition of behavioural adaptation to describe the reported research. The first caveat is that the thesis will use a narrower interpretation of the definition by focusing specifically on **driver** behavioural adaptation to IVNS. The OECD definition uses the term “road-users” to include both equipped and unequipped drivers, pedestrians etc. While it is acknowledged that all types of road users may adapt their behaviour in the presence of in-vehicle systems, only driver behavioural adaptation to IVNS will be considered here.

Safety-positive, negative and neutral adaptations to IVNS will be considered in this thesis. While control and tactical level driving behaviours can clearly affect driving safety, most strategic level behaviours (and tactical level navigational behaviours) cannot be expected to have many direct effects on driving safety as the timespan during which they occur can be so much longer. Therefore behavioural adaptation at the strategic level (and sometimes at the tactical level) will also be considered in terms of navigational efficiency. Positive, negative and neutral behavioural adaptation will signify improved, reduced and no-effect on navigational efficiency respectively. As shown above, the OECD expert panel stated that the precise operational definition of behavioural adaptation should depend on the context of the research. Since IVNS are often purported to increase navigational efficiency, any strategic and tactical level behavioural adaptations would clearly be interesting in this particular context. However, in some cases (e.g. where IVNS use has a positive effect on navigational efficiency) behavioural adaptation effects may actually have been intended by system designers. Although the OECD expert panel stated that behavioural adaptations are unintended by system designers, the second caveat in adopting the OECD definition for this thesis is that it will also consider positive behavioural adaptations at the strategic and tactical levels that were intended by system designers because the context of this particular research is IVNS user behaviour. However, in later chapters safety-negative adaptations will be singled out and explored in greater detail.

2.3.2 Modelling behavioural adaptation

Since this thesis does not purport to evaluate, update, utilise nor propose any particular model of behavioural adaptation, theories/models are only presented briefly here (see Vrolix, 2006 for a recent review of behavioural adaptation models), to help put some of the issues explained in the thesis in context. Behavioural adaptation may manifest itself in several different ways to a wide variety of vehicular and non-vehicular transportation interventions. Therefore a fully comprehensive model explaining all types of behavioural adaptation in all contexts may take some time to appear. Most recent attempts to model behavioural adaptation have considered adaptation to individual transportation interventions in isolation such as seatbelts (Reinhardt-Rutland, 2001), adaptive cruise control (Rudin, Brown and Parker, 2004) or road widening schemes (Denton, 1980; Godley, 1999). Others have attempted to explain the phenomenon more generally using driving behaviour models (e.g. risk models), social psychological models (e.g. attribution theory) or learning theories (e.g. classical/operant conditioning). The OECD authors criticise most general attempts to model behavioural adaptation as too vague, overly general and only indirectly related to behavioural adaptation. They suggest that Wilde`s (1982) risk homeostasis theory provides the most complete explanation for this phenomenon, and although controversial, this theory has received the greatest amount of attention from researchers.

Wilde`s (1982) risk homeostasis theory (RHT) is a motivational theory of driving behaviour based on risk compensation theory (RCT) in which driving is viewed as a self-paced task. As shown in the previous section, risk compensation (or behavioural compensation) concerns compensatory driver behaviours following an increase/decrease in safety in vehicles (e.g. seatbelts, antilock brakes, airbags), on roads (e.g. cats eyes, road widening) and even in drivers themselves (e.g. age related declines in cognitive, perceptual and motor functions). RHT proposes that that drivers have an inbuilt target level of subjective risk that they are prepared to accept, and that this does not change (although it may vary between individual drivers). Safety-enhancing features change the level of accepted risk, so drivers compensate by adopting riskier driving styles (e.g. driving faster, less cautiously), in order to re-establish their desired constant level of risk. Wilde proposed a homeostatic mechanism (similar to thermostats in home heating systems that activate/deactivate when the temperature falls below or exceeds some threshold) through which drivers adjust their level of target risk. The implications of this theory are that over time, vehicle/roadway improvements will fail to achieve any lasting safety impact.

However, Wilde`s theory has faced harsh criticism both as an explanation of driving behaviour and behavioural adaptation (e.g. OECD, 1990; O`Neill and Williams, 1998; Rothengatter, 2002). A major criticism relates to the difficulty in using a heating system analogy to explain complex psychological processes. It offers no explanation of the processes involved in regulating perceived and target risk (Michon, 1989). According to Trimpop (1996, p.127) "*while one key component of RHT, namely behavioural adaptation to perceived risks (RCT), has found strong empirical support both in the laboratory and in the field, the notion of a full homeostatic process has received mixed support and leaves important theoretical questions unanswered".* Cole and Stephen (1982) also argue that there are considerable problems in transferring individual motives and behaviours to a societal scale and according to several authors it is a difficult theory to disprove as compensatory behaviour may vary over time and between situations (Adams, 1988; McKenna, 1990; Hoyes and Glendon, 1993).

The previous section described how behavioural compensation was an insufficient definition to describe the range of behavioural changes that may occur in the presence of IVNS, similarly risk homeostasis theory cannot fully explain behavioural adaptation as it is primarily concerned with motivations for increasing/decreasing risk. However, driving behaviour may be motivated by many other factors, for example in their GADGET matrix, Hatakka et al., 1999 showed how a range of driver characteristics can also affect driving behaviour at lower levels in Michon`s (1985) hierarchy. As shown above, behavioural adaptations to IVNS at strategic and tactical levels may only have indirect effects on safety, but may also affect navigational efficiency which is unrelated to risk. The OECD expert panel concluded that the paradigm of objective and subjective risk can be used to partially understand adaptation mechanisms, but that other concepts such as perception and motivation are also likely to be involved. Closely related to the concept of risk, Jonah et al. (2001) invoked sensation seeking (Zuckerman, 1994) to account for behavioural adaptation. They propose that individuals differ in the level of arousal they are prepared to accept, and that risk taking activities such as speeding and overtaking affect arousal level. Smiley (2000) suggests that the primary motivations for behavioural adaptation are the intelligent re-allocation of attention and effort. This will not necessarily lead to constant accident rates but may lead to tradeoffs between mobility and safety. Other theories suggest behavioural adaptation may be a form of utility maximisation (Hoyes et al., 1996; Janssen and Tenkink, 1988).

2.3.3 Measuring behavioural adaptation

Before the concept of behavioural adaptation was widely acknowledged, when the term was used interchangeably with risk homeostasis or compensation, the phenomenon was typically reported based on aggregated accident statistics (e.g. Wilde, 1982). However, the OECD panel showed that this methodology is empirically unsound. They suggest that behavioural explanations should only be invoked from behavioural data. Unfortunately there are far too many drawbacks in utilising accident data that it cannot be used in isolation to indicate behavioural adaptation. For example, a particular safety measure (e.g. seatbelts) may reduce accident frequency/severity, but this does not necessarily mean it causes safety- positive driver behavioural adaptation. Some drivers may well drive faster due to the perceived increases in safety (safety-negative behavioural adaptation), but this behaviour will only rarely result in an accident. As well as being rare, infrequent events, traffic accidents are caused by a wide range of both controllable and uncontrollable and internal and external factors. Simply finding a change in the number of accidents does not allow researchers to deem any one factor or combination of factors responsible (Dragutinovic, Brookhuis and Marchau, 2004). Additionally there are many problems with the reliability of accident recording procedures both within and between countries. Often the data is incomplete or lacks validity (Ranney, 1994).

Fortunately the majority of behavioural adaptation research has incorporated a wide range of methodologies to study the phenomenon, so behavioural explanations may be invoked where appropriate. Research reported in this chapter includes naturalistic studies using instrumented vehicles on open roads (e.g. Dingus et al., 1989; Janssen, 1994; Lee and Cheng, 2008) and test tracks (e.g. Tijerina, Parmer and Goodman, 1998; Zwahlen, Adams and DeBald, 1988), observational studies (e.g. Pohlmann and Traenkle, 1993; Dingus et al., 1995; Forzy, 1999), driving simulator studies (e.g. Eick and Debus, 2005, Brook-Carter, Burns and Kersloot, 2002; Hoegma and Janssen, 1996) as well as questionnaires/surveys (e.g. Mackay, Dale and White, 1982; Khattak et al., 1999; Svahn, 2004; TNO, 2007).

2.3.4 Classifying behavioural adaptation

It is particularly useful when investigating behavioural adaptation to consider the level of driving behaviour at which adaptation occurs. Drawing on the hierarchical models outlined above, most research has examined adaptation to transportation interventions at the tactical and control levels. Strategic level adaptation has so far received considerably less research attention.

The most prevalent control level adaptations studied in the literature include lateral deviation in driving lanes, steering corrections and throttle/braking counts. As shown above, control level driving behaviour is largely automatic requiring little or no conscious control. While hierarchically influenced by decisions made at the tactical level, behavioural adaptations at the control level may also be caused by slips or lapses in otherwise routine, well learned performance.

The most prevalent tactical level adaptations studied in the literature are speed, following distance (headway) and hazard perception/avoidance. Tactical level driving behaviour requires application of specific rules to complete tasks. It is influenced by decisions made at the strategic level. Behavioural adaptations at the tactical level may involve conscious decisions to adopt riskier driving behaviours (e.g. increased speed or secondary task engagement while driving) due for example to strategic decisions to save time, or they may result from misapplication of otherwise appropriate rules.

Behavioural adaptation at the strategic level includes decisions about whether to use or not use in-vehicle devices or other vehicle/traffic/roadway/environmental related equipment, characteristics or conditions. For example, strategic level behavioural adaptation to a safety promoting device may manifest itself in terms of a driver`s decision to drive without wearing a seatbelt, in adverse weather conditions or along an unfamiliar or dangerous route. Drawing on the GADGET matrix (Hatakka et al., 1999) described in section 2.2, behavioural adaptation at the strategic level may be influenced by a whole range of individual difference driver characteristics.

2.3.5 Behavioural adaptation to non-vehicular and non-automated vehicular transportation interventions

As shown above in the OECD definition, behavioural adaptation can occur in response to any changes in the transportation system; this also includes changes outside the vehicle. Many studies have revealed tactical and control level driver behavioural adaptation to a whole range of non-vehicular transportation factors. For example, some studies have shown that in response to increases in road and lane width, people drive faster (Godley, 1999; DeWaard, Steyvers and Brookhuis, 1994; Leong, 1968), engage in more erratic manoeuvres (e.g. centre line crossings or steering corrections) (Messer, Mounce and Brackett, 1981) and drive closer to the road edge (vanDriel et al., 2004; Smiley, 2003). Other studies have found changes in driver speed related to street lighting (Rockwell and Lindsey, 1968; Huber and Tracey, 1968) and delineation (Johnston, 1983; Ranney and Gawron, 1984).

Over the past fifty years, several studies have examined behavioural adaptation to a whole range of vehicular changes. Interest in behavioural adaptation to vehicular interventions can be first traced back to Gibson and Crooks (1938). They referred to behavioural feedback as a driver`s offsetting response to technical safety measures. Gibson and Crooks (1938, p.458) wrote:

> *"More efficient brakes on an automobile will not in themselves make driving the automobile any safer. Better brakes will reduce the absolute size of the minimum stopping zone, it is true, but the driver soon learns this new zone and, since it is his field-zone ratio which remains constant, he allows only the same relative margin between field and zone as before"*

Many early advances in automobile technology were primarily aimed at increasing driver safety (e.g. seatbelts, airbags, studded tyres, high mounted brake lights) by reducing accident severity rather than frequency. There is little doubt that seatbelts have significantly reduced accident severity worldwide (Hedlund, 1985; Scott and Willis, 1985; Evans, 1991; Wyatt and Richardson, 1994). Widespread implementation of seatbelt legislation makes it very difficult to effectively study behavioural adaptation to seatbelts, though some attempts have been made. Adams (1982) performed time series comparisons of fatality rates in countries with and without mandatory seatbelt legislation. While he found no significant differences, he did conclude that protecting drivers and passengers from the consequences of bad driving encourages bad driving, and that this may therefore increase accident risk for other road users (e.g. pedestrians and other drivers).

Using a survey methodology, Mackay et al. (1982) examined the self-reported speed behaviour of a large random sample of UK drivers who drove on rural roads before seatbelt legislations became mandatory. They found that on average, those wearing seatbelts reported that they drove 1 mph faster than those who did not, but they also found that a range of other factors (e.g. vehicle size/age, presence of passengers) affected average speed more significantly. In an instrumented vehicle study Janssen (1994) investigated three groups of Dutch motorway drivers over the course of one year: regular seat belt users, regular non-seatbelt users and new seat-belt users who had previously been regular non-seatbelt users. He found that relative to the other groups, new seatbelt users increased their speed by 1.6 Km/h and adopted riskier headways (i.e. following distances). Although, using a different methodology which compared responses of drivers from countries with mandatory and non-mandatory seatbelt legislation, Evans, Wasielewski and Buseck (1982) found no significant differences between drivers in choice of headway distance. Janssen (1994, p.260) also cautioned that it was impossible to quantify the observed effects in terms of overall accident risk or the effect of long term seatbelt wearing on speed, only that in the short term "*starting to wear the seatbelt appears to lead to changes in behaviour that, in a quite general sense, are counterproductive to the beneficial effects of that measure itself*".

As seatbelts are a transportation intervention primarily designed to decrease accident severity, and since research suggests (albeit only modest) driver behavioural adaptation to them, it would be logical to hypothesise that drivers also adapt their behaviour in response to other similar interventions such as studded tyres (primarily used in cold countries where there is commonly snow or ice on roads). Research suggests both positive (Krebbs, Lamm and Leutner, 1974) and negative tactical level driver behavioural adaptation to studded tyres (Rumar, Berggrund, Jernberg and Ytterbom, 1976) in terms of speed behaviour. It is not particularly surprising that although present, adaptation effects are fairly modest in response to injury-reducing transportation interventions such as the above. Indeed, Lund and O`Neill (1986) hypothesised that behavioural adaptation to such interventions would be much less pronounced than adaptation to collision-reducing interventions. One reason for this is that collision-reducing interventions, and indeed other interventions unrelated to accident frequency, typically replace, augment or simplify aspects of driving behaviour via some automated intermediary. As will be seen in the next section, research shows that behavioural adaptation is a particularly significant issue when an automated dimension is applied to drivers and driving.

2.3.6 Behavioural adaptation to driving automation

2.3.6.1 Adaptive cruise control (ACC)

Most research has considered behavioural adaptation to adaptive cruise control at the tactical and control levels of driving behaviour. Since speed and headway are directly affected by ACC, these driving performance measures have been most widely studied. Speed increases and headway decreases would indicate negative behavioural adaptation. This would be consistent with the risk perceptive (e.g. Wilde, 1982), where drivers adopt riskier driving styles because these control behaviours are automated, empirically however, there have been mixed results. Many naturalistic and driving simulator studies have shown increases in mean speed and speed deviation (Brook-Carter, Burns and Kersloot, 2002; Hoedemaker and Brookhuis, 1998; Hogema, Horst and van der Janssen, 1994; Ward, Humphreys and Fairclough, 1995) for ACC equipped drivers, whereas others have found a decrease (Hoedemaker and Kopf, 2001; Hoegma et al, 1994; Hogema and Janssen, 1996; Nilsson and Nabo, 1996) or no effect (Nilsson and Nabo, 1996; Stanton, Young and McCaulder, 1997).

Similarly, many naturalistic and driving simulator studies have shown that ACC equipped drivers adopt shorter headways (Brook-Carter et al., 2002; Eick and Debus, 2005; Hoedemaker and Brookhuis, 1998; Ohno, 2001; Ward et al., 1995), whereas other have found either the opposite (Nilsson and Nabo, 1996; DeWaard et al., 1999; Seppelt et al., 2005) or no effect (Hogema et al., 1994; Hogema and Janssen, 1996; Stanton et al., 1997).

Other studies have considered manifestations of behavioural adaptation to ACC that may appear once the driver has been put back in manual vehicle control. Levitan and Bloomfield (1998) suggested that there may be carryover effects in automated highway scenarios, if drivers are given back control of the vehicle at high speeds. Eick and Debus (2005) suggested that these carryover effects are well established on German highways. They conducted three driving simulator studies. In the first they established that participants did exhibit riskier time headways (THW) after driving with small headway gaps in the automated mode. However, in a later study, some participants were given short THW while others were given long THW in automated mode. They found that these carryover effects only occurred in the first condition, suggesting that drivers adopted riskier headways if they were given small headways while ACC was engaged. So the degree of precision offered by automated driving might dangerously affect a driver`s self-confidence in manual driving mode.

Although ACC equipped drivers are supported in longitudinal vehicle control, they remain in control of steering. Most studies indicate that drivers perform this task poorly when ACC is engaged. Several studies have demonstrated increased lateral deviation (Ohno, 2001; Ward et al., 1995) and lane position variability (Rudin-Brown et al., 2004) for ACC equipped drivers, although others (e.g. Stanton et al. 1997) have found no effect.

2.3.6.2 Intelligent speed adaptation (ISA)

The majority of studies concerning behavioural adaptation to ISA have considered driving speed, and unsurprisingly most have shown changes in the speed of equipped drivers. According to Saad et al (2004) their review of relevant studies showed that in general, the most intrusive systems had the greatest speed reduction effect. For example, Nilsson and Berlin (1992) found that informative systems had very little effect on driving speed. Hjalmdahl (2004) showed that although advisory intervention systems were fairly effective at reducing driving speed, the speed limit was occasionally exceeded. Obviously a range of studies have also shown that drivers equipped with mandatory intervention systems didn’t exceed the speed limit while using the system (Carsten and Comte, 1997; Carsten and Fowkes, 2000; Duynstee, Katteler and Martens, 2001).

However, Carsten and Comte (1997) found that drivers drove faster in hazardous conditions (e.g. fog, slippery roads) when equipped with a mandatory ISA system than when driving unsupported. Brookhuis and DeWaard (1999) found that some ISA equipped drivers were using their system to stay within the zone of socially accepted speeding (i.e. speeds 10% higher than the speed limit). Persson et al. (1993) also found that ISA equipped drivers drove faster on corners while using the system, but in Varhelyi and Makinen (2001), drivers reduced their approach speed at junctions.

ISA behavioural adaptation research has also considered car following behaviour. Several studies using different methodologies such as in-car observations (Persson et al., 1993) instrumented road-vehicle (Varhelyi and Makinen, 2001) and driving simulators (Carsten and Comte, 1997) have shown increased time headway when drivers have used ISA in urban areas. From a safety perspective this would suggest positive behavioural adaptation. However, other research using a driving simulator (Carsten and Fowkes, 2000), found an increase in safety-critical close following distances on rural and urban roads. Additionally, Varhelyi and Makinen (2001) found that following distances were reduced on rural roads.

Some studies have shown that ISA systems have affected drivers' interaction with other road users. For example, Persson et al (1993) found some problems with the behaviour of drivers equipped with mandatory ISA systems towards other road-users, particularly at junctions. However, other studies have found improvements in the driving behaviour of ISA equipped drivers in relation to other road users, such as increased stopping distances for pedestrians or favourable give-way behaviour (Carsten and Comte, 1997; Almqvist and Nygard, 1997; Varhelyi and Makinen, 2001).

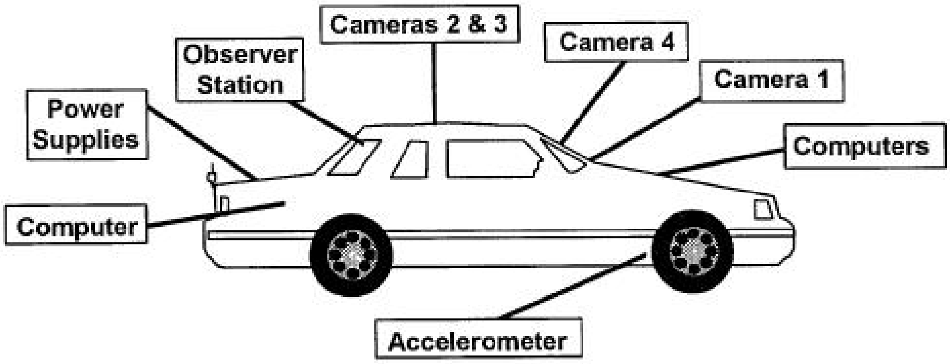
2.4 Measuring behavioural adaptation to IVNS

The studies included in this literature review have employed a range of behavioural and performance measures at each of Michon`s (1985) levels of driving behaviour. The longitudinal (acceleration/braking) and lateral (steering) control tasks are the most important in driving. Control and tactical level measures typically studied include speed and speed variation, throttle/braking counts, longitudinal acceleration, steering wheel holds, lateral deviation, lane position and hazard perception/avoidance.

The potential for drivers to be distracted by using IVNS has been a primary concern since their introduction. Most IVNS convey route guidance information to the driver using both visual and auditory modality displays. Although both affect driving behaviour, the visual modality has received most attention in distraction research, due to its relative contribution to normal safe driving behaviour. Wickens et al. (2004) demonstrated that the longitudinal and lateral driving control tasks both critically depend on the primary visual attention lobe (PVAL). According to Mourant and Rockwell (1972), this extends from a few metres to a few hundred metres outside the vehicle. Glancing at IVNS displays, can temporarily divert attention from this PVAL, which can have knock-on effects for the primary driving performance measures outlined above. Bhise, Forbes and Farber (1986) examined the attentional demand of in-vehicle system displays. They found that drivers visually time-share between the system and the roadway. They suggested there was a maximum glance duration (eyes off-road time), beyond which drivers would be unable to maintain safe control of their vehicle. By placing video recording equipment in vehicles (or simulators), researchers can closely examine drivers' eye glance behaviour. Figure 2.3 shows the design of an instrumented vehicle used in Dingus et al`s (1995) Travtek IVNS evaluation study. This design is fairly typical of instrumented road vehicles used in IVNS user research. Using these instrumented vehicles, researchers can find out when, where and for how long drivers glance at both the IVNS display and the road ahead. Glance behaviour has therefore been examined in several studies reviewed in the next section that have compared IVNS use with more traditional methods such as paper maps or memory, and others which have investigated the effect of input/output modalities on driving behaviour. Some studies have also investigated drivers' ability to detect and appropriately respond to hazards in the roadway and inside the vehicle while using an IVNS.

Strategic level adaptation to IVNS has not been widely studied but has received some research attention. Since IVNS replace the strategic task of optimal route selection, they should have a positive impact on strategic level driving behaviour. Studies which have examined strategic level behavioural adaptation have looked at the time taken to complete journeys, characteristics of roads used along the route, familiarity of chosen routes etc. Some studies have also considered more tactical-level navigation measures such as turn errors.

Figure 2.3 showing a typical instrumented road vehicle used in IVNS user research



Source: Dingus et al. (1995)

The most logical starting point to find evidence of behavioural adaptation to IVNS is to compare the driving (and navigating) behaviour of drivers using an INVS with driving behaviour using traditional navigational methods (e.g. paper maps or memorized route). Several studies have done this, and following an introductory section concerning the effects of IVNS on accident rates and insurance data, these have been considered first. Other studies have used the above methodologies to examine the effects of IVNS on driving behaviour and performance directly without such comparisons. These studies have helped to put some of the results from the comparative studies in context, and have shown that although mixed, findings from the comparative studies may not be as clear-cut or definitive as they appear.

An advantage of the simulator and on-road or test track research methodologies employed above is that valid and reliable driving behaviour measures at each of Michon`s (1985) three levels can be employed. However, surveys and questionnaires have proved to be a useful tool in understanding strategic level behavioural adaptation to IVNS. An additional advantage of using surveys is that they can be used to target real long term IVNS users. A criticism of much of the experimental research is that participants were inexperienced IVNS users. IVNS experience can affect behavioural adaptation to IVNS. This issue will be discussed in greater detail later in this chapter.

2.5 Behavioural adaptation to IVNS

2.5.1 Accident and insurance data

As was mentioned earlier, analysis of accident data is fraught with complications (see also Dragutinovic, Brookhuis and Marchau, 2004; Ranney, 1994). Any associations found between IVNS use and accident statistics could very generally illustrate some of the negative effects of IVNS in terms of safety. Although such data could not implicate any behavioural explanations, it could highlight relevant avenues for more focused behavioural research. In Japan, IVNS have been a regular feature in many cars for some time. Using data collected by the National Police Agency, Takubo et al (2002) found that between 1998 and 2000, there were 600 personal injury accidents, where use of an IVNS was deemed at least partially to blame. Green (2000) further analyzed data pertaining to 1999 only, and found that nearly three quarters of accidents were attributed to looking tasks. Although in the UK, accident statistics still do not cite presence of IVNS, recent independent research conducted by the Dutch transport institute TNO, published in collaboration with a major IVNS manufacturer (TOMTOM), examined associations between presence of IVNS and insurance claims. They found that lease car drivers without IVNS, submitted 12% more claims per million kilometers driven than those with INVS, and ordinary drivers without IVNS claimed 5% more in costs than those with IVNS (TNO, 2007).

2.5.2 IVNS vs traditional navigational methods

Streeter, Vitello and Wonsiewicz (1985) compared several traditional navigation methods such as paper maps, recorded vocal directions, customized route maps and a combination of the latter two. They found that recorded vocal directions on their own produced shortest routes (in terms of distance and time), and resulted in the fewest navigational errors. However, Parkes (1990) criticized the claim that vocal directions are superior because Streeter et al (1985) didn't test screens capable of showing pictures. Parkes argued that vocal directions (e.g. left, right, straight on) may be more demanding than pictorial symbolic information (e.g. arrows) because they need to be interpreted in a particular context.

Antin et al (1990) investigated navigational effectiveness and strategy, driving performance measures as well as glance behaviour when drivers used the ETAK IVNS, paper maps and memorized route instructions. They employed a repeated measures study design and participants drove an instrumented road vehicle on public roads. Their results also suggested safety-negative behavioural adaptation at the control level, as on average, participants spent significantly longer glancing at the IVNS display than at the paper maps (33% of glances were directed at the IVNS display compared to only 7% for the paper maps). Additionally, they found that when participants navigated using a memorized route, 85% of glances were to the road ahead, but with paper maps this was reduced to 78% and with the ETAK IVNS only 57% of glances were to the road ahead. The study also provided further evidence of safety-negative control level adaptation, as there were fewer steering wheel holds when participants used the IVNS compared to the other navigational methods. However, they found no effect of navigational method on other control level measures such as lane deviation, brake usage and acceleration. They found no significant differences in travel time or mean driving time, suggesting that the IVNS failed to supply an expected (by manufacturers) strategic advantage, but they did find that participants using the paper map took significantly longer (approximately twice as long) to plan their route prior to setting off. This could be interpreted as positive strategic level behavioural adaptation, but in terms of efficiency, rather than safety.

In a field study, Fairclough and Parkes (1990) examined visual attention when drivers used a paper map and an IVNS. Control participants received no navigational assistance. 92% of control participants' visual attention was directed at the road ahead compared to 76% for those using an INVS and 67% for those using paper maps. In a longitudinal naturalistic experiment Kostynuik et al (1997) compared reports of participants when they had driven using the Tetrastar INVS with unaided driving. They reported that using the IVNS had no effect on their attention to traffic signs, street signs, traffic signals, other traffic or vehicle equipment (e.g. fuel gauge, speedometer, mirrors). A recent survey by a leading insurance company asked drivers how distracting they found using an IVNS compared to paper maps. It showed that only a slightly higher proportion of IVNS users (19%) admitted to losing concentration than paper map users (17%) (Privilege, 2006).

Contrary to Antin et al (1990), Inman et al (1996) found that relative to paper maps, an IVNS significantly improved travel time. They used a similarly designed study, but their participants used the Travtek IVNS. In support of Antin et al (1990), this study also showed that pre-trip planning time was significantly shorter for those with the IVNS. Dingus et al. (1995) also conducted an on-road instrumented vehicle study using the Travtek INVS. They compared several Travtek interface characteristics (route-map display, route-map display with voice guidance, symbolic guidance map display and symbolic guidance map display with voice guidance) with paper maps and written directions. Their research had several objectives, in addition to investigating the most appropriate interface combinations (in terms of driving performance, navigational performance, usability and safety), they also examined the effects of age and type of user (familiar local vs unfamiliar stranger) on these measures. Driver workload measures indicated that participants found navigating using paper maps and Travtek route map (without voice guidance) to be most difficult. Eye glance (frequency and duration) and other driving performance data indicated that the Travtek route map (without voice guidance) entailed the greatest visual attention demand. However, they found that visual attention demand was significantly reduced when participants used the Travtek route map with voice guidance (this is the typical combination in contemporary IVNS). Dingus et al (1995) found that although single glance durations were high, the paper map condition entailed a low frequency of glances. However, although their results showed relatively low visual attention demand for paper maps, performance (number of abrupt braking maneuvers, mean speed) and subjective workload measures suggested that paper maps entailed high cognitive demand. They also found that older drivers (>65 yrs) glanced for longer at navigational aids than younger drivers, and that strangers glanced more often at navigational aids than locals.

In terms of safety, the results showed that the route-map display without voice guidance resulted in significantly more safety-related errors (e.g. lane deviations, braking errors) than either paper maps or written directions. However, the authors concluded that adding voice to the display generally improved overall safety-related performance.

The study also found that all conditions in which participants received turn-by-turn guidance resulted in the best navigational performance. Travel times were shorter when participants used Travtek configurations and written directions than paper maps and some participants got lost using paper maps.

Navigational performance suffered most in those cases where turn-by-turn guidance was provided least effectively (i.e. using paper maps and Travtek route-map display without voice guidance). They also found that experienced users and younger drivers (<65 yrs) had shorter travel times and preparation times than inexperienced or older drivers.

As part of the European DRIVE program, Parkes, Ashby and Fairclough (1991) conducted two field experiments using instrumented road vehicles. In the first experiment they compared the effects of graphical route information displays, textual routing displays and paper maps on driving behaviour. They were particularly interested in the attentional demand imposed by each navigational aid. They found that paper maps imposed the greatest attentional demands on drivers. In their second experiment they compared two types of information displays that were both available in commercial IVNS at that time. The first was a graphical and text based display (i.e. LISB, Ali-Scout) and the second was an electronic map based display (i.e. Bosch Travelpilot). In this experiment they were particularly interested in drivers' navigational behaviour. They found that when drivers were navigating from pre-determined origin-points to specified end-points, the routes taken were significantly different depending on which system was used. According to Abedel-aty et al. (1993), this study illustrates the complexity of trying to understand route choice behaviour, as even subtle variations in the ways information is presented to the driver can significantly affect their route choice decisions.

Using an on-road vehicle and experimenter observations, Pohlmann and Traenkle (1994) examined driving and navigational performance while participants navigated using a TRAVELPILOT IVNS, paper maps and spoken guidance instructions. When participants navigated used the IVNS they drove more slowly than those using paper maps (some participants stopped completely), particularly when approaching junctions. Although this may appear to be safety-positive tactical level behavioural adaptation, the authors noted that speed reductions occurred without consideration of traffic regulations, right of way or other road users. When driving and navigating with IVNS participants also made significantly more lane departures than when using conventional navigation methods. Galsterer, Fastenmeir and Gstalter (1990) also reported a significant increase in lane departures by drivers using the LISB IVNS, compared to trips without an electronic navigational aid.

In terms of navigational performance Pohlmann and Traenkle (1993) found no differences between groups in their abilities to find the shortest route. However, the reason this finding differs from some others in this review may be due to limitations of the device itself. The TRAVELPILOT IVNS they used was an extremely early model commercially available IVNS, it presented map information on an electronic display, but did not offer route recommendations, and this is a standard feature on modern IVNS (including many of those studied in other research cited here).

In an observational study, TNO (2007) found that while driving in an unfamiliar area, IVNS users engaged in 50% fewer cases of unsuitable driving behaviour than those using conventional navigation methods. Researchers made only 0.56 notes/observations per journey when participants used an IVNS compared to 1.3 notes/observations per journey when participants used conventional navigation methods. They also found that while driving through unfamiliar areas, journey distances and durations were shorter for those using IVNS than those using conventional navigation methods. Specifically, the number of kilometers driven was reduced by 16% (IVNS users drove an average of 18.1km whereas those using conventional navigation methods drove and average of 21.5km) and the average journey time was reduced by 18% (IVNS users average journey time was 26 minutes compared to 32 minutes for those using conventional navigation methods). Also when travelling in unfamiliar areas, participants using IVNS made 25% fewer stops, when they did stop, they stopped for 35% less time, and they turned around less frequently than those using conventional navigation methods. Although the TNO (2007) study didn't examine glance behaviour specifically, it did also employ an IVNS user survey sampling drivers from the customer portfolio of a leading insurance company. Two thirds of participants did not agree with the statement that they are more distracted by using an IVNS and nearly half the participants (45%) thought they have been more alert since they started using an IVNS.

Using an instrumented road-vehicle, Forzy (1999) examined driving and navigational behaviour when participants used paper maps and the CARIN IVNS. In contrast to the majority of comparative studies, participants were familiar with the IVNS. They used each of the navigational aids while driving in unfamiliar environments. In terms of navigational performance, Forzy (1999) examined two scenarios: route planning and route following. In the route planning situation, no significant differences between groups were found in relation to journey distance (mileage), but closer analysis of the route data showed that when using paper maps, drivers were able to plan much smoother, (Forzy uses the terms less "choppy") routes than the IVNS. The IVNS suggested routes that changed in direction more often and were less easily memorized. Also in the route following situation, no significant differences between groups were found in relation to journey distance. However, the study reported far greater standard deviations of journey time when participants used paper maps. As Forzy points out, this shows that navigational performance using the IVNS was more uniform than performance using paper maps. Overall the author concluded that navigational performance was not improved by using this IVNS. In terms of driving behaviour, the study found that when driving using paper maps, participants made significantly more Highway Code errors (e.g. ignoring traffic lights, lane departures) and vehicle control errors (e.g. late braking, late lane changes) than when driving using the IVNS, but there were no significant differences in terms of errors that cause a nuisance to other drivers.

Using a fixed-based driving simulator, Srinivasan and Jovanis (1997) investigated the impact of paper maps, head-down and head-up turn-by-turn displays, a head-down electronic map and audio guidance on drivers' reaction times to a scanning task. They found that reaction times were lowest when drivers used the audio guidance and highest when they used paper maps. Also using a fixed-base driving simulator, Walker et al. (1991) compared several types of IVNS including maps, auditory messages and visual displays. Participants were given a hazard detection task in which they were required to monitor various dashboard instrument gauges to ensure they remained within designated parameters. They found that participants using paper maps performed most poorly at the gauge monitoring task, followed by those using a complex visual display, and that older participants performed most poorly at this task using each of these navigational methods. This isn't particularly surprising as drivers heavily depend on the visual modality for driving-related information (Lansdown, 1997). The auditory navigation messages and less complex visual displays were associated with much better performance on the gauge monitoring task. Walker et al. (1991) also found no effect of navigational aid on lateral placement and lane position measures. However, they did find that participants using paper maps drove more slowly than those using other devices. Of all the IVNS they studied, they found that participants using complex visual displays drove most slowly. They also found that those using the visual IVNS reduced their speed more than those using the auditory IVNS, and that device complexity also influenced the speed at which participants drove.

McKnight and McKnight (1992) compared five navigational displays (area map, strip map, position information, guidance information with an audible alarm and position/guidance information). They found that the best system for facilitating accurate tactical level turn behaviour was the guidance information with audible alarm. Other systems produced turn error rates in excess of 30%, but the error rate for this system was just 14.3%. Several other studies also suggest that drivers using auditory route guidance make fewer driving errors (Wetherall, 1979; Verwey and Janssen, 1988) and complete journeys in less time and distance (Parkes and Coleman, 1990).

Allen et al (1991) presented participants with sequences of slides on a computer which showed a motorway scene every five seconds along with some driving instrument information. Participants were motivated to avoid delays in their trips, using rewards and penalties based on their ability to avoid delays and estimate congestion. They compared static maps, dynamic maps and an advanced experimental IVNS. They found that with the dynamic map and experimental IVNS drivers successfully anticipated congestion and diverted much earlier than those using the static map or controls.

Using an instrumented road vehicle, driving on public rural and urban roads, Lee and Cheng (2008) compared the driving performance and navigational efficiency of drivers using a paper map and those using a portable navigation device (e.g. PDA or mobile phone). Typically the display size on a PND is much smaller than the screen on most nomadic and integrated IVNS, so driving/navigating performance results may differ from those in previous research using more traditional IVNS. In contrast to most of the above studies, Lee and Cheng (2008) used a between groups design. In terms of navigational efficiency, they found that the drivers using paper maps spent longer during pre-trip planning, took longer to complete journeys and drove longer distances under different road environments than those using PND. The results suggested that drivers using paper maps also made more mistakes than those using PND as those using PND drove 6% and 2% further than the planned urban and rural routes respectively, whereas those using paper maps drove 15% and 4% further than the shortest possible urban and rural routes respectively. Interestingly, their analysis confirmed that the PND failed to plan the shortest possible route. Lee and Cheng (2008) used yaw rate (calculated using the heading angle of a car) as a measure of driving performance. This could be considered as a control level driving performance measure. A low yaw value indicates better stability and vehicle control, whereas a high value indicates a greater proportion of course corrections, and therefore less safe driving. Those drivers who used a PND had a lower mean yaw rate and standard deviation of yaw rate than those who used paper maps, suggesting that the PND led to safer vehicle control.

Using a fixed base driving simulator, Liu (2001) compared the effects of several visual and auditory display modalities, but did not include traditional navigational methods. Driving performance measures included lateral acceleration, lane deviations, variance in lateral lane position and variance in steering position. Navigational performance measures included near misses, misses and wrong turns. Liu (2001) found that driving performance was least affected by the multi-modality display, and that participants using this display also made fewer navigational errors.

In a review of studies which have examined the effects of different display modalities, Green, Fleming and Katz (1998) concluded that in general:

1. Turn errors have indicated interface differences in most studies
2. Longitudinal and lateral control input measures (e.g. steering wheel variance, throttle variance etc.) have not proven sensitive to interface differences
3. The longitudinal output measures speed and speed variance (and trip duration) are sometimes sensitive to interface differences
4. The lateral output measure standard deviation of lane position appears to be more sensitive to interface differences than number of lane excursions

2.5.3 Other factors which affect driving and navigational behaviour

Several other studies employing driving simulators and instrumented road vehicles have furthered the investigation of glance behaviour while drivers navigate using IVNS. Although some of the above studies suggest negative behavioural adaptation in terms of glance behaviour for IVNS, relative to traditional navigational methods, some of these studies mentioned below suggest that drivers may tailor glance behaviour to prevailing circumstances and IVNS characteristics. This also is a form of safety-positive behavioural adaptation, except this time, in addition to occurring in response to an in-vehicle system it occurs in response to other factors such as driving workload.

The Dingus et al (1995) study above showed that glance duration was sensitive to driver age and glance frequency was sensitive to driver familiarity with the local area. Using an instrumented road-vehicle, Dingus et al. (1997) also showed that glance frequency and duration were sensitive to IVNS experience, where experienced IVNS users glanced at the IVNS display less frequently and for shorter durations than novices. Also in a road-based evaluation, Burnett (2004) found that IVNS display position affected the frequency of glances to the display and number of navigational errors, such that a low position resulted in less glances and more navigational errors. Bhise and Rockwell (1973) found that duration of glances towards road traffic signs were almost twice as long in low density traffic as in high density traffic. Using an instrumented road vehicle, Wierwille et al (1988) examined the impact of driving complexity on glances to an INVS display. They found that as driving complexity increased, so the probability of a glance to the IVNS decreased and the probability of a glance to the roadway centre increased. Similarly, using both an instrumented vehicle and a fixed base driving simulator, Reeves and Stevens (1982) also found that drivers glanced less frequently at an IVNS display when traffic density increased.

Walker et al (1991) mentioned above, controlled task difficulty by varying road width, strength of wind and monitoring task difficulty. Although they did not specifically examine glance behaviour, they also found that as driving complexity increased, attention to the monitoring task decreased, suggesting that here also, participants tailored their visual attention to the prevailing workload. They also found that driving speed decreased as task complexity increased.

Itoh et al. (2005) found that age affected glances towards the IVNS display. Their research suggested that IVNS be placed in the central field of view to minimize disruption to elderly drivers' eye movements and reaction times. Dingus et al. (1997) found that experienced IVNS users made fewer lane departures than novices. They also found that older drivers made more lane departures and had greater difficulty navigating concurrently than their younger counterparts. Liu (2001) found that older drivers made more navigational errors, reported higher psychological stress and workload and controlled their vehicles more poorly.

Allen et al (1991) also found when examining diversion behaviour that older drivers were more hesitant to divert than younger drivers. However, Green, Fleming and Katz (1998) reported no age (or gender) effects on navigational errors, but did find age effects on driving performance measures such as throttle, speed and lateral position. They suggested based on these results that age effects probably shouldn't be considered in future work on navigational performance. According to Hartley, Hartley and Johnson (1983) empirical studies should provide older drivers with adequate practice at using innovative driving technology before behavioural and performance measures are taken as this could significantly improve their driving performance.

2.6 Methodology issues

Clearly there is much diversity in the present research that has compared IVNS equipped driving behaviour with traditional navigational methods. Several other authors (e.g. Nilsson, Harms and Peters 2002; Saad, 2004) have also noted the wide diversity in findings, designs and methodologies of studies which have examined behavioural adaptation to in-vehicle systems. Table 2.1 shows the main design characteristics, and direction of findings (in terms of safety and navigational efficiency) of most of the studies reported above for purposes of comparison. For the sake of simplicity, the table does not capture the extensive variation that exists between studies in relation to methodology, performance measures and findings. They are instead meant as a brief indication of the direction of some of the research findings thus far, and some important differences that presently exist between studies. However, even in such an incomprehensive review, a number of methodological and classification issues arise.

Table 2.1 : comparison of studies which have compared driving and navigating using an IVNS with traditional navigational methods, showing basic study design characteristics and direction of findings in terms of safety (unshaded rows) and navigational efficiency (shaded rows)

Author(s)	Method of investigation	Relevant area(s) of investigation	Driver behaviour level addressed	Findings	Direction of findings
Antin, Dingus Hulse and Wierwille (1990)	Instrumented vehicle on-road	Glance behaviour	Control	Increased glances to IVNS relative to paper maps	-
		Lane deviation	Control	No change	n
		Brake usage	Control	No change	n
		Travel/driving time	Strategic	No change	n
		Trip preparation time	Strategic	Less than paper map users	+
Forzy (1999)	On-road. Observers recorded behaviour	Navigation performance	Tactical	No effect	n
		Engagement in unsafe driving behaviours	Tactical	Less than paper map users	+
Inman et al (1995)	On-road. Observers recorded behaviour	Near-crash involvement	Tactical	Less than paper map users	+
Fairclough and Parkes (1990)	Instrumented vehicle on-road	Visual attention to the road ahead	Control	Greater than paper map users	+
Kostynuik et al (1997)	Qualitative participant reports following naturalistic study	Attention to in-vehicle and roadway stimuli	Control/tactical	IVNS had no effect on attention to stimuli	n
Privilege insurance (2006)	IVNS users survey	Self-reported distraction	Control/tactical	Respondents thought IVNS were slightly more distracting than paper maps	-
Dingus et al (1995)	Instrumented vehicle on-road and observers recorded behaviour	Glance frequency	Control	Participants made more glances to the IVNS display than paper maps	-
		Driving performance measures (e.g. lane deviations, braking errors)	Control	IVNS users made more safety-related errors than paper map users or those using written directions	-
		Navigational performance	Tactical/strategic	IVNS users performance was better than paper map users	+
Parkes et al (1991)	Instrumented vehicle on-road	Attentional demand of navigational aids	Control/strategic	Paper maps entailed greater attentional demand than IVNS	+

Author(s)	Method of investigation	Relevant area(s) of investigation	Driver behaviour level addressed	Findings	Direction of findings
Pohlmann and Traenkle (1993)	On-road. Observers recorded behaviour	Driving speed	Tactical	IVNS users drove more slowly than paper map users, with less consideration for other road users	-
		Lane departures	Control	IVNS users made more lane departures than paper map users	-
		Navigational performance (finding shortest route)	Strategic	No difference between IVNS and paper map users	n
Galsterer et al (1990)	Instrumented vehicle on-road and observers recorded behaviour	Lane departures	Control	IVNS users made more lane departures than those using conventional navigational aid	-
TNO (2007)	On-road. Observers recorded behaviour	Unsuitable driving behaviour	Control/tactical	IVNS users engaged in less unsuitable driving behaviour than those using conventional navigational aids	+
		Journey distance/time in unfamiliar areas	Strategic	IVNS users journeys were shorter and quicker than those using conventional navigational aids	+
		Navigational performance (number of times stopping or turning around)	Strategic	IVNS users made fewer stops, stopped for less time when they stopped and turned around less frequently than those using conventional navigational aids	+
	User survey	Self-reported distraction	Control/tactical	Most IVNS users didn't agree they were more distracted using IVNS compared to conventional navigational methods	+

Author(s)	Method of investigation	Relevant area(s) of investigation	Driver behaviour level addressed	Findings	Direction of findings
Walker et al (1991)	Fixed base driving simulator	In-vehicle hazard detection	Tactical	Paper map users performed more poorly than other groups using different IVNS modalities	+
		Lateral placement and lane position	Control	No effect of navigational aid	n
		Driving speed	Tactical	Paper map users drove more slowly than those using different IVNS modalities	-
Lee and Cheng (2008)	Instrumented vehicle on-road	Pre-trip planning time	Strategic	Paper map users took longer than PND users	+
		Journey time/distance	Strategic	Paper map users took longer to complete journeys and drove further than PND users	+
		Navigational errors (distance travelled exceeding planned routes)	Tactical	Paper map users made more errors than PND users	+
		Yaw rate and standard deviation of yaw rate	Control	PND users had lower yaw rate and SD of yaw rate suggesting safer vehicle control	+
Allen et al (1991)	Laboratory experiment presenting slides representing driving scenes at 5 second intervals	Ability to anticipate congestion and divert	Strategic	Dynamic map and IVNS users anticipated congestion and diverted much quicker than static map users	+

Key

- Negative
+ Positive
n Neutral

Please note: Direction of findings for strategic and tactical level navigational tasks (i.e. not driving tasks) are assessed in terms of navigational efficiency not safety. These rows are shaded for the readers' convenience

2.6.1 Classification issues

In table 2.1 research findings have been classified as either positive (having a positive effect on driving performance/navigational efficiency measures), negative (having a negative effect on driving performance measures/navigational efficiency) or neutral (having no discernable effect on driving performance measures/navigational efficiency). However, forcing classification of findings in this way ignores a range of other pertinent issues, such as, the relative strength of the effect, the validity of the driving performance measures or the power of statistical methods used. Complications also arose in classifying some driving behaviours according to Michon`s (1985) three levels. Some topics (e.g. glance behaviour) may fall into more than one category. In these cases, behaviours were classified according to the timescales proposed by Lee and Strayer (2004).

Perspective can further affect classification of results. Walker et al (1991) found that attention to a hazard detection task decreased as driving complexity increased. From a hazard detection perspective, this is negative driving behaviour. However, from a distraction perspective, this shows that drivers diverted their attention from a secondary task, in favour of the primary driving task, and this is positive driving behavioural adaptation.

2.6.2 System variation

A major difficulty in making meaningful comparisons between these studies and in drawing conclusions from them about behavioural adaptation to contemporary IVNS is the extensive variation in systems that have been used across studies and over time.

Many of the studies conducted during similar time periods employed different IVNS for their research. For example, Antin et al (1990) used the ETAK navigator whereas Fastenmeir and Gstalter (1990) and Bonsall (1991) used the LISB system and Pohlmann and Traenkle (1993) used the Travelpilot. Similarly, Inman et al (1996) used the Travtek system whereas Kostynuik et al (1997) used the Tetrastar.

A further difficulty is that many of these studies were conducted during the 1990`s either before or soon after IVNS first became available to drivers as luxury options integrated in expensive new vehicles. While illustrating the evolution of IVNS, chapter 1 described how the first IVNS on the market were static systems that were not informed by GPS (instead they used dead reckoning to determine vehicle position), that simply displayed a visual map detailing a start point and a destination point. Dynamic systems followed and over time many of the features most contemporary users are familiar with (e.g. turn by turn guidance, route re-calculations, points of interest etc.) became standard. This system evolution is also ongoing (e.g. it is likely that in the near future, features such as traffic information and photo-realistic road views will also become standard). Due to the extensive variation in features and functions that exists between early models and contemporary models, it is particularly difficult to generalize findings from these early studies to present day drivers who use contemporary IVNS. For example, Antin et al (1990) found IVNS users glanced more at the system display, than users of paper maps did at their maps. However, relative to contemporary IVNS, Antin et al`s (1990) findings may be over-estimations due to technical limitations of the early system they used. They reported that the ETAK navigator could only provide general route information beyond approximately half a mile radius of the current vehicle, and as such, drivers could only use the navigator effectively by repetitively glancing at the display to acquire important information as it was updated and presented. Furthermore the digital maps and operating system were stored on tapes. Due to the limited memory capacity of these tapes, maps for some cities were spread across several tapes, so when drivers reached map boundaries they had to change tapes to continue receiving route guidance support. Also the ETAK navigator presented route guidance information to drivers using green vector maps only. Modern IVNS are much more effective and efficient at presenting route information, and typically use visual displays with much higher graphical fidelity so effective navigational performance may entail fewer glances (e.g. TNO, 2007). Although IVNS user research is still ongoing in traffic psychology (e.g. TNO, 2007; Lee and Cheng, 2008; Varden, 2008), the majority of studies relevant to behavioural adaptation were conducted during the 1990`s, so this thesis makes an important contribution to the literature by examining a range of behavioural adaptation issues affecting drivers today, using contemporary systems.

2.6.3 The Novelty effect

Additionally, the novelty effect may exert a significant influence on driving performance measures. Antin et al (1988) found a substantial novelty effect when performing on-road testing of the ETAK navigator. Drivers initially appeared to devote significant spare attentional resources to the IVNS. They suggested that this effect makes assessment of driver behaviour while using these systems difficult, once system experience is gained. Dingus et al (1997) collected data on IVNS users over the course of two runs. The first when they were novice users, and the second when they had used the system regularly for 6 weeks. They found that experienced IVNS users made fewer glances of shorter durations to the IVNS than novices. They suggest this illustrates the novelty effect wearing off, and that experienced users may have better strategies for extracting relevant navigation information from the NS display. The novelty effect is a particularly salient issue in behavioural adaptation research because many forms of behavioural adaptation to in-vehicle systems may not appear immediately, but will only become apparent after a familiarization period (Saad et al., 2004).

2.7 Strategic level behavioural adaptation to IVNS

Although aspects of strategic level behavioural adaptation have been considered above, several other studies have also reported aspects of strategic level behavioural adaptation to IVNS (and other advanced non-conventional navigational aids), without directly comparing aided driving with traditional navigational methods. IVNS are primarily purported by designers and manufacturers to positively influence driving behaviour in terms of departure times and route choice to improve individual mobility and wider societal traffic congestion (Dia, 2002), so behavioural adaptation at the strategic level is a particularly important consideration.

Although a range of methodologies have been used in studies that have reported strategic level adaptation, surveys have proved particularly appropriate for this area of investigation. As shown above, some study results may be unreliable due to the novelty effect. Additionally many authors have shown/hypothesized that some forms of behavioural adaptation may sometimes take some time to occur. Longitudinal experimental research is often time consuming and very expensive, but surveys enable researchers to understand behavioural adaptation (and other issues) of an established user population.

Smiley (2000) notes the relative lack of research that has considered strategic level behavioural adaptation to IVNS specifically. Therefore, this part of the literature review will cast a broader net to include studies which have reported changes in strategic level driving behaviour in response to a wider range of advanced navigational aids including advanced traveler and information systems (ATIS), pre-trip route planning, variable message signs (VMS) displaying traffic information and radio/television traffic/travel information broadcasts. Basically any situations in which drivers have been provided with navigational information except using conventional methods (e.g. paper map, memorized route).

The first section considers strategic decisions to use IVNS, and also explores how they are used as well as the effects of individual difference or situational variables on usage. It will go on to consider the effect of travel/traffic information on route choice. Other forms of strategic-level adaptation (e.g. mode of transport, etc) will also be examined.

2.7.1 Acceptance

An important strategic behaviour in terms of IVNS concerns drivers' decisions to use their system, and if used how they are used. Decisions to use IVNS are part of system acceptance. Acceptance is an important issue when considering behavioural adaptation to any in-vehicle system. Low acceptance will mean that drivers do not use the system, only with moderate to high system acceptance can researchers hope to study the effects of IVNS on driving behaviour.

Nearly half of all the participants who purchased a vehicle with a factory installed IVNS in the J.D. Power and Associates (2003) survey reported high levels of satisfaction, and most suggested that they would recommend their systems to a friend. Indeed many participants indicated that if an IVNS wasn't offered with a vehicle they were purchasing, that this would negatively affect their purchase decision. Similarly, The J.D. Power (2008) survey revealed that nearly 60% of consumers wanted an IVNS in the next vehicle they purchased.

The J.D. Power (2004) usage and satisfaction study found that IVNS satisfaction comprised several key factors, including appearance (13%), ease of use (35%), system speed (12%), routing capabilities (19%), screen information (12%) and voice prompts (9%). Svahn (2004) asked participants to rate the value of key system features. The majority of participants rated route planning capabilities (75.9%,), guidance (98.3%), destination search (96.6%) and traffic information (70.1%) as "valuable" or "of great value". GFK (2008) surveyed German consumers about the most important criteria in purchasing a portable

IVNS. They found that 25% of respondents considered routing reliability to be the most important factor, followed by price (19%), price/performance ratio (17%), user friendliness (11%) and good equipment test results (7%).

Svahn (2004) also attempted to gauge the perceived utility of auditory guidance compared to visual guidance. He found that most participants (50%), preferred display information or mainly display information and that a significant proportion (47%) considered voice and display to be equally important. Svahn (2004) also assessed how satisfied participants were with their systems' routing capabilities. Given that IVNS users could reliably assess their systems' routing capabilities when they have the benefit of local knowledge, Svahn (2004) asked participants to rate the degree of correspondence between their systems' routing advice and their own individual preference when travelling in familiar areas. He found that 65% of participants rated the correspondence as reasonable or significant; while only a minority (12%) rated it as relatively low or insignificant. Svahn (2004) acknowledged that this measure is very subjective, but suggested that it does indicate that users are fairly satisfied with their systems' routing capabilities.

The J.D. Power and Associates (2008) survey also demonstrated that consumers expect greater functionality in future IVNS models. For example, 66% of consumers wanted the ability to play mp3 audio files. Similarly, the GfK (2008) survey revealed high growth in demand for more technologically advanced models. For example, demand was particularly high for systems with larger screens. Consumers also stressed considerable interest in software innovations such as speed limit indications, photo-realistic depictions of junctions and advanced point of interest information.

GfK (2008) conducted a study, asking German consumers about the most important criteria for buying a PND. According to the study, 25% of those asked said that route reliability was the most important factor, followed by price (19%), the price/performance ratio (17%), user friendliness (11%) and good test results for the equipment (7%). In terms of route reliability, Hook (1998) reviewed several aspects of human route choice behaviour, and suggested that if IVNS fail to take human route choice behaviour into account in route planning algorithms, this could also affect system acceptance .

These statistics concerning the popularity of IVNS and user satisfaction cited generally indicate high acceptance of IVNS among most drivers. For example, in a recent survey (N=10,000), 88% of drivers using an integrated IVNS said they would want the technology installed in future vehicles they purchase (AAA foundation, 2005). In an Australian survey (N=1200) drivers were asked about the effectiveness and usefulness of four in-vehicle technologies: IVNS, forward collision warning systems and two types of intelligent speed adaptation systems. Between 75% and 85% of drivers thought the technologies would be effective with IVNS judged as most effective (Gray, 2001). Mankinnen et al. (2001) were interested in drivers' preferences for three in-vehicle systems: ACC, ISA and IVNS. They surveyed 911 European car and heavy vehicle users about their preferences and expectations. Car drivers judged IVNS to be the most important system, whereas heavy vehicle drivers also judged IVNS as most important except on motorways and rural roads.

Svahn (2004) conducted a survey of IVNS users who used the Volvo RTI (road and traffic information) system only. He was primarily interested in levels of active (drivers actively use the system for route guidance purposes) and more passive (the system is turned on and used mainly for situation awareness) system usage in familiar and unfamiliar areas. He found that approximately 90% of participants reported basic system usage always or often, and that when driving in unfamiliar areas, the system is frequently used, and mostly in an active manner. He also found that about two thirds of participants hardly ever used their system while travelling in familiar areas, but that about a third did at least have their system switched on in this travel context.

Svahn (2004) also reported individual differences in usage patterns. Two variables that were particularly salient were annual mileage and self-reported level of computing skill. Participants with a high annual mileage used their systems in a passive manner more than average. Those who had good computing skills use their system actively in familiar environments more than average. They also reported greater attention to surrounding traffic than average.

Using an online survey, Franken (2007) explored the usage and acceptance of a much wider variety of IVNS users. She found that most drivers (42%) use their IVNS often, and nearly 20% use them during nearly every trip. She found a significant positive correlation between frequency of car (equipped with IVNS) use and frequency of IVNS use, as well as between annual mileage (in kilometres) and frequency of IVNS use. She found that most people use them nearly all the time on holidays (long distance trips) and business trips. She also found that a high proportion of users (42%) use their systems in familiar areas. A similar proportion (44%) reported feeling very insecure in unfamiliar areas without an IVNS.

2.7.2 Route choice and departure time

In an early survey of Israeli and Swedish commuters, Stern (1993) found that nearly two thirds of the sample would change their travel behaviour due to traffic information, and about 43% would change their habitual route if they received information about possible traffic problems (e.g. congestion). Emmerink et al. (1996) analysed drivers' route choices in response to VMS and radio information. They proposed that some people have a natural tendency to trust travel information regardless of its type or source. However, an early Japanese study following the introduction of a VMS system that predicted travel times showed that on a tactical level most commuters were reluctant to leave their habitual route and on a strategic level they were also reluctant to change their habitual route, even when the VMS showed it was inferior to other routes.

In a survey of drivers using ATIS, more than half the respondents reported that they had made changes to their route on the basis of radio, telephone or television mediated pre-trip information (Khattak et al., 1999). However, Lappin and Bottom (2001) point out that the nature of the guidance information can significantly affect drivers' route choice behaviour. For example Kantowitz, Hanowski and Kantowitz (1997) showed that drivers will only accept ATIS information if the systems' reliability exceeds a certain threshold (this study is reviewed in greater detail later in this chapter). Khattak, Schofer and Koppelman (1995) suggested that drivers have a preference for traffic – related information (descriptive) more than route recommendations (prescriptive). However several studies have shown that prescriptive information can also influence route choice. Polydoropoulou and Ben-Akvia (1998) found that participants switched routes more often when guidance information increased in detail. Other studies have also indicated superior route choices in response to prescriptive compared to descriptive information (e.g. Owen, 1980; Llaneras and Lerner, 2000). Interestingly some studies have indicated that participants have a bias for motorways, so that drivers switch routes when they receive messages which suggest switching from a non-motorway road to a motorway more often than those receiving the opposite message (Hato, Taniguichi and Sugie, 1995; Kitamura et al., 1999). Other factors which appear to affect route choice include habit and inertia (Uchida et al., 1994; Hato et al. 1995; Srvinvasan and Mahmassani, 2000).

After surveying (N=3972) commuters in Seattle, Washington, about their route choices in response to a computerized traffic information system, Gray et al (1990) distinguished four distinct groups of drivers that differed in terms of their route choices and departure times. 96 drivers representing each group were interviewed further. Overall the interviews found that commuters rarely changed routes in response to traffic information and felt more stressed when they did (relative to their normal route). Commuters also stressed the importance of actually seeing congestion for themselves before changing routes based on information. This has implications for trust in automation. Hook (1998) also points out that acceptance of route choice information from automated sources and route choices in response to this will also depend on the type of driver. For example commuters may have very different motivation for route choices than taxi drivers or holiday makers. Other authors (e.g. Burnett, Summerskill and Porter, 2004) have also stressed the importance of individual driver differences and driving styles in terms of resulting behaviour.

In Franken`s (2007) survey about a third of drivers reported that they often used different routes since possessing an IVNS. In the Washington state department of transportation (WSDOT) survey Haselkorn, Spyridakis, Barfield (1991) examined the effects of several ATIS systems including radio traffic reports, VMS, and highway advisory radio, on route choice behaviour. A cluster analysis revealed four distinct groups of drivers: those who change route (20.6%), those who change route and departure time (40.1%), those who change route before starting a trip (15.9%) and those who don't change route (23.4). 75% of drivers were prepared to change their normal route to work, and 60% were prepared to change commuting route before their trip or en-route on the basis on ATIS information. Interestingly, when the latter group was shown experimental ATIS screens, 55% of them indicated they would be prepared to change their route.

As part of the Berlin LISB trial Bonsall (1991) surveyed drivers equipped with a route guidance system, they were asked about their system usage and journey characteristics. He examined drivers' responses to both static and dynamic route guidance. About a fifth of those using the static system had changed their normal route to work due to the guidance they had received. Nearly half the participants (47%) expected to save time on their journey to work using the dynamic system. Interestingly, based on participants' subjective comments, Bonsall reported that the guidance they had received motivated them to try out new routes even without navigational assistance. Additionally, the system had become the most frequently used method of navigating to unfamiliar destinations. In a survey of Japanese IVNS users, Kubota et al (1995) found that IVNS users tended to worry less about the consequences of getting lost, and drove through unfamiliar streets more frequently to avoid congested ones. The AAA foundation (2005) survey also reported that 84% of participants strongly agreed that using an IVNS has lowered their risk of getting lost.

In a series of surveys aimed at commuters who received radio traffic broadcasts, the majority (64%) reported that pre-trip information had rarely affected their departure time (Barfield et al., 1989; Haselkorn and Barfield, 1990; Mannering and Kim, 1994). According to some authors, perceived accuracy of the information is the key factor in the decision process (Khattak, et al., 1991; Khattak et al., 1999; Polydoropoulou and Ben-Akiva, 1999). Using a travel choice simulator Srinivasan and Mahmassani (2001) investigated the decision making process concerning departure time, once drivers have received ATIS information. They found that in addition to perceived accuracy of information, its nature and type were also important.

2.7.3 Mode choice and decision to travel

Very few studies could be found which have examined the effect of travel information on mode choice or decision to travel. The previous section showed that prescriptive information can affect route choice; there is also evidence to suggest that prescriptive recommendations favourable to public transport can also affect mode choice. Yim and Miller (2000) reported that after hearing information about bad traffic conditions, less than 1% of callers to a San Francisco travel information service asked to be re-routed to the transit menu, but over time as drivers' experience with the system increased, the number of callers asking to be re-routed also significantly increased up to 5%. There is also evidence that information concerning bad conditions can affect drivers' decision to travel (Khattak et al., 1999).

2.8 Automation-related behavioural adaptation

Some types of behavioural adaptation to in-vehicle systems have been proposed and empirically tested that can only be understood in the wider automation context. These are discussed in terms of their implications for behavioural adaptation, below.

2.8.1 Automation issues

Several automation issues must be explained in order to illustrate examples and predictions throughout the literature concerning automation-related behavioural adaptation to IVNS. As each issue is described, instances or predictions of behavioural adaptation to IVNS (and in some cases other vehicle systems) will be cited.

2.8.2 Advantages of automation

Similar advantages are often suggested concerning the introduction of automation. It is widely perceived to increase safety, efficiency and to provide economic benefits when implemented in a wide variety of domains, such as driving (Walker, Stanton and Young, 2001), manufacturing (Bessant et al. 1992), medicine (Thompson, 1994), robotics (Sherdian, 1992), aviation (Spitzer, 1987) and shipping (Grabowski and Wallace, 1993) to name but a few.

It is widely considered that these benefits mainly arise due to the exceptionally high degree of precision that automation can offer relative to human operators, who are prone to human error. Drawing on Reason`s (1990) taxonomy of error, humans are prone to make several different types of mistakes/errors even when performing routine, well practiced tasks (e.g. driving). According to Singh, Molloy and Parasuraman (1997), it is widely assumed that automation will bring an end to such errors in task performance and that as well as increasing efficiency and cost effectiveness, it will also quantitatively improve safety, and reduce fatigue and workload (Singh, Molloy and Parasuraman, 1997).

2.8.3 Supervisory control paradigm

There is little doubt that widespread implementation of automation has delivered some of the expected benefits – namely those related to increased precision and economy (Sarter, Woods and Billings, 1997). However, engineers and system designers have been criticised in the literature for only considering the technical issues and failing to consider the human element. Given that even in the most highly automated systems there is still a degree of human involvement; the human-automation interaction is therefore an important consideration.

When automation takes over tasks previously performed by humans (e.g. vehicle control, navigation) the role of the human fundamentally changes from one of active control to one of supervisory control (also referred to as human meta-control – Sheridan, 1960). During supervisory control the operators role is to monitor automation to ensure it is performing tasks correctly (in relation to prevailing environmental and situational circumstances) and to intervene (i.e. resume manual control) if the system fails or a situation is encountered which automation is unequipped to deal with, for example certain vehicles (e.g. those on a curve or in a different lane) are outside the detection range of adaptive cruise control (ACC), and the system will not respond to a stationary vehicle ahead. In this case drivers are expected to regain vehicle control. Similarly IVNS can only be as good as the maps that are driving them. An IVNS could deliver unreliable guidance if drivers use outdated maps in newly developed environments.

However, a wealth of research has shown that changing the operators task in this way produces mainly qualitative rather than quantitative changes. For example task demands (or workload) and errors are not necessarily reduced, but are qualitatively different to those that generally occur during manual control. Other problems include incomplete mental models of system function, lack of effective communication between the automated system and the operator, loss of situational awareness, trust and reliance issues, complacency (or over-reliance) and deskilling of operators due to decreased opportunities to practice manual control.

2.8.4 Deskilling

Sheridan and Parasuraman (2006) highlight a wide range of ways in which the shift from active control to supervisory control may alienate operators (e.g. abandonment of responsibility, desocialisation, technological illiteracy etc.). One of the most important aspects in terms of safety is deskilling. Early psychological research concerning memory emphasised the importance of rehearsal in retaining information (e.g. Atkinson and Shiffrin, 1968; Baddely and Hitch, 1974). Operators only become skilled at tasks if they are given the opportunity to practice. For example, novice drivers must devote significant attentional resources to use of controls such as gear shifting in manual cars, lane keeping, visual scanning etc. but over time, with practice, these skills become largely automatic, where the driver barely has to think about them. If automation takes over control from operators, it is conceivable that when faced with emergencies, system failure or situations automation is unequipped to deal with, that operators will have insufficient skills to resume manual control. According to Bainbridge (1983, p.775)

"a formerly experienced operator who has been monitoring an automated process may now be an in- experienced one. If he takes over, he may set the process into oscillation. He may have to wait for feedback, rather than controlling by open—loop, and it will be difficult for him to interpret whether the feedback shows that there is something wrong with the system or more simply that he has misjudged his control action. He will need to make actions to counteract his ineffective control, which will add to his workload"

The effects of deskilling have been documented across a range of professional groups whose task has changed from active control of processes to passive supervisory control of automation, such as pilots (Dreyfus and Dreyfus, 1986) and power plant operatives (Sharit, Chang and Salvendy, 1987; Sheridan, 1987). According to Gstalter and Fastenmeir (1990), deskilling is unlikely to affect IVNS users because they replace no driving skills. However, drawing on Michons' (1985) taxonomy, the strategic and tactical tasks of way finding are replaced or strongly supported by IVNS. Therefore it is feasible that over time, automated way finding may diminish non-automated navigational skills.

Navigation research shows that drivers learn to drive in unfamiliar areas by developing a cognitive map. Neisser (1976) defined cognitive maps as orienting schema within which spatial information can be encoded and organised. Byrne (1979) identified two stages in the development of cognitive maps. There are vector maps which deal with vectors, distances and angles between nodes and network-maps which concern the ways the nodes are linked together topologically. Before the introduction of IVNS drivers would supplement inaccurate and/or incomplete cognitive maps of unfamiliar environments with paper maps. However, Antin et al (1990) pointed out that there are subtle differences between paper maps and electronic maps that could affect their development. They suspected IVNS could improve cognitive map development due to various system/display characteristics (e.g. moving map, high level of detail, scaleable map, system positioning within view of driver). They found that electronic moving-map displays provided some information for vector maps. Citing Borgman (1989), Hook (1998) also explained that IVNS are typically designed by engineers, who as a group, tend to have fairly good spatial and map reading skills, most likely, better than the general driving public. Hook (1998) suggests this is why abstracted maps on small electronic displays have become the dominant interface characteristic on the majority of models. They could be too complex to adequately aid cognitive map development in drivers with poor spatial skills. In a simulator study comparing IVNS with paper maps, Adler (2001) observed that during the final five routes when participants that had been using the IVNS received no navigational assistance, they performed more poorly. Similarly, using a fixed base driving simulator, Burnett and Lee (2005) found that participants using an IVNS had worse memory for the area they were driving in than those using paper maps. Although poor development of cognitive maps can obviously affect navigational behaviour, the effects of IVNS on their development should however, probably be discussed in the context of cognitive rather than behavioural adaptation. For a review of early research which contributed to present understanding of cognitive maps and their relation to route guidance issues in particular, see Hook (1998).

2.8.5 Workload

In many cases automation undoubtedly relieves some of the burdens of physical workload. It can also reduce aspects of mental workload. This is analogous to physical workload, and it refers to the attentional demands created during performance of cognitive tasks (O`Donnell and Eggemeier, 1986) and subjective experiences of cognitive task performance as effortful and fatiguing (Mulder, 1986). IVNS are primarily purported to eliminate the need for route planning both before and during trips, so they too are expected to reduce these aspects of driver workload.

However, a number of studies have shown that contrary to initial designer expectations, automation can also significantly increase mental workload (e.g. Weiner, 1985, 1989; Weiner and Curry, 1980; Parasuraman and Riley, 1997). This is largely due to the relatively high cognitive demands associated with sustained and divided attention[1]. For example, in the driving automation domain, drivers are expected to supervise and interact with or use automation, in addition to completing the primary driving task. Depending on the prevailing driving situation, significant demands can be placed on the attentional system, particularly in terms of sustained and divided attention, fortunately In Psychology; these fields have been studied extensively.

Sustained attention involves maintaining attentional focus over a prolonged period of time. Although it was studied before (e.g. Billings, 1914), interest in the subject peaked during and after the Second World War as operational reports highlighted the high incidences of radar operator failures in detecting military targets (e.g. German submarines). Over the next few years Mackworth (1948, 1950, 1957) devised a series of tests to examine vigilance performance. One of the main tasks he used was called the clock test, in which a second hand moved a specified distance in discrete one-second intervals on a clock face. However, very occasionally it would move twice the distance it usually moved. Participants were required to detect these infrequent movements. He found that after only a short time on the task, detection performance significantly deteriorated. This deterioration is commonly referred to as the vigilance decrement. A number of studies since have replicated this effect in a wide range of contexts (e.g. Jerison, 1977; Craig, Davies and Matthews, 1987).

Many automated systems provide output/feedback on multiple displays (e.g. modern aeroplane cockpits) and others are used while operators are also engaged in other non-automation related tasks (e.g. driving). Divided attention refers to a person`s ability to perform two or more tasks simultaneously. It is typically studied using discrete-trial tasks or continuous performance tasks. Continuous performance tasks are typically most complex, and are considered to be more representative of real-world tasks such as driving (Matthews et al. 2000). Participants must continually focus attention on two separate tasks such as a tracking task (in which participants may use a cursor to continually track an

[1] Workload has also been associated with selective attention (Trick, 2004), but only sustained and divided attention are outlined here to describe workload.

erratically moving stimulus) and some other task (e.g. signal detection or short term memory task). Typically divided attention research has shown that performance on either task is affected by task difficulty, operator skill and task similarity.

Resource theories typically view attention as a sort of internal reservoir, which can become depleted while performing complex tasks. Multiple resource theory (Wickens, 1980, 1984, 1991) is often invoked to explain the reasons why task similarity can affect task interference. Wickens (1980) noted that in some dual task situations difficulty-sensitivity tradeoffs rarely occurred and task performance could often be improved by changing the response format of the other task (i.e. reducing task similarity). He proposed that attentional resources were divided according to processing stages (i.e. whether tasks required central processing or response selection/execution), processing codes (verbal or spatial) and processing modality (auditory or visual). He suggested that dual task interference was most pronounced when dual tasks competed for similar processing resources (e.g. two visual tasks or two tasks requiring spatial processing) and least pronounced when tasks require different resource pools (e.g. one auditory task and one visual task). Both the vigilance decrement and dual task interference occur because excessive demands are placed on the cognitive system. The cognitive effort required to maintain vigilance or complete tasks requiring the same resources is often referred to as workload.

Although some attempts to measure workload have faced criticism (e.g. Kramer, 1991; Aretz, Johanssen and Obser, 1996), many studies have employed both objective physiological indicators such as pupil diameter (Kahneman, 1973) and event-related potential (ERP) components (Kramer, 1991; Rosler, Heil and Roder, 1997); and subjective measures (Eggemeier, Crabtree and LaPointe, 1983). The most widely used subjective measure is the NASA task load index (TLX) scale (Hart and Staveland, 1988). Subjective measures were developed based largely on the premise that people know how effortful certain tasks are to perform, so the best way to determine workload is simply to ask them using a standardised scale.

In addition to increasing operator mental workload, there is also some evidence from aviation that automation unevenly distributes workload over time. Weiner (1989) points out that in modern aircraft, automated systems typically support pilots during ordinary, mundane low workload portions of flight, but are of little use and may even be an obstacle during time-critical dynamic situations such as descent and approach. Some automated systems require substantial input from pilots regarding prevailing situational circumstances so that they can make appropriate decisions. During descent, air traffic controllers may make several demands of pilots to alter trajectory, and since air traffic controllers are not directly linked to the autopilot, human pilots must convey these demands to the automated system. Therefore the pilot must act as a translator and mediator. It is during these times that pilots report excessive workload (Sarter, Woods and Billings, 1997).

Similarly, driving difficulty changes over time. Transitions from straight roads to curved roads or quiet country roads to busy urban roads are usually associated with increased driver workload (Hancock et al. 1990, Noy 1990, Harms 1991). Monitoring in-vehicle devices has also been shown to further increase perceived workload (Noy 1990, Beh and Hirst 1999, Verwey 2000). So while following an electronic map display while driving along quiet rural roads may be a low workload exercise, performing a similar task in a busy urban environment could place considerable cognitive demands on the driver.

Several studies have investigated the effects of IVNS on driver workload. This can be a complicated issue as a range of tasks can be included when considering IVNS usage. A later section of this literature review will show that drivers can develop trust for IVNS. The research will show that increased system trust is associated with decreased system monitoring for errors. This can (deceptively) relieve some driving workload, as drivers believe strategic and tactical navigational tasks are truly automated and reliable so (s)he monitors the automation less frequently. Several studies have reported that in comparison with traditional navigational methods (e.g. paper maps), IVNS reduce drivers workload (e.g. Burnett and Joyner, 1993; Daimon, Masuno and Kawishima, 1994; Dingus et al., 1995).

Until workload could be discussed in detail, an important type of tactical level behavioural adaptation has remained unaddressed. Several authors have suggested drivers may take advantage of perceived reductions in workload, by engaging in secondary tasks while driving (Rudin-Brown and Parker, 2004). According to Smiley (2000), the prevalence with which drivers engage in speeding and other unsafe driving practices suggests that they often trade safety for mobility (i.e. more frequent driving in more difficult conditions and at higher speeds). She suggests this is hardly surprising because the payoffs for increased mobility are immediate and apparent to drivers, but since accidents are such infrequent events, it may take much longer for the benefits of increased safety to become obvious to drivers. Smiley interprets the tendency to engage in secondary tasks while driving due to reduced perceived workload as a safety-utility tradeoff. (see Hoyes et al., 1996; Janssen and Tenkink, 1988 for utility-maximization model of behavioural adaptation).

Drivers equipped with IVNS might also try to take advantage of reduced perceived workload by interacting with their system while driving. As shown in the introduction, several earlier models restricted many aspects of system interaction while driving, but with the increasing sales of nomadic and portable IVNS, manufacturers have been increasingly less able to limit this form of system interaction. Although manufacturers clearly have no interest in being sued because of accidents resulting from IVNS use, due to market forces and customer demands for increased functionality and driver control, Burnett, Summerskill and Porter (2004) point out that they will increasingly try to add this function to their devices.

Although drivers may engage in several different interactive tasks while driving (e.g. point of interest search, menu navigation), destination entry tasks have received the greatest research attention due to their relative complexity compared to other interactive tasks. Before the introduction of IVNS, when drivers relied solely on paper maps, some drivers would have pulled over to plot the route to their next destination, while others may have done so while driving. Whichever method they previously used, IVNS destination entry while driving is a form of safety-negative, tactical level, behavioural adaptation to IVNS, as drivers engage in interactive tasks (via voice command or touching buttons/screen), they previously would not have. Even route planning while driving using traditional methods requires qualitatively different forms of interaction with the navigational aid (i.e. it is a purely visual task; there are no buttons to push or menus to navigate). Therefore, if drivers enter destinations (or perform other interactive tasks) while driving, this is clearly a form of tactical level behavioural adaptation to IVNS.

Due to the hierarchical nature of driving tasks, driver propensity to enter destinations while driving can also affect other types of control and tactical level driving behaviour. In other words, this form of behavioural adaptation might encourage/discourage behavioural adaptation at other levels of driving behaviour (e.g. eye glances, vehicle speed, lateral deviation etc.). Over the past twenty years several studies have examined the effects of a wide range of secondary tasks on driving performance such as use of mobile phones, radios and PDA while driving. Some have also examined the effects of IVNS destination entry tasks on a range of driving performance measures such as longitudinal and lateral control tasks, hazard detection tasks and glances to and from the roadway. This research has stemmed from earlier dual-task laboratory studies concerning the effects of secondary tasks on tracking performance, as the driving task has central tracking components (i.e. lateral control tasks). Many of these studies informed the design of Wicken`s (1992) multiple resource theory described above, which proposed that when two tasks draw from similar perceptual (visual vs auditory), cognitive (verbal vs spatial) or motor (vocal vs manual) processing resources, task interference can occur, which could result in degraded performance in one or both tasks. Since driving is a primarily visual-spatial-motor task, any secondary task drawing on these processing resources could theoretically cause task interference.

There are two main methods of interaction with current commercially available IVNS (i.e. manual or vocal). Although manual destination entry draws on verbal rather than spatial cognitive processing resources, this method requires motor responses (e.g. typing, scrolling, tapping) to visual information (e.g. location of characters on a keyboard, scrolling through lists), so according to the theory it should cause some task interference. However, the theory implies that vocal destination entry may cause less task interference, as although it may also rely on the visual modality to some extent (e.g. vocally navigating through menus, confirming speech recognition accuracy), the response format is vocal not manual. Evidence from dual task studies in which participants have had to complete a tracking task and a signal detection task requiring either manual or vocal response, has demonstrated that vocal responses produce significantly less task interference than manual responses (e.g. Mcleod, 1977; Wickens et al., 1983; Sarno and Wickens, 1995). However, dual task studies have also shown that vocal responses can cause some interference, even it is not as pronounced as it is for manual tasks (e.g. Van Hoof and Van Strien, 1997; Bardy and Laurent, 1991), and several studies have shown that mobile phone conversations can cause significant task interference (e.g. Brookhuis, de Vries, & de Waard, 1991; Strayer & Johnston, 2001). Tijerina et al (2000) argue that the vocal response should not be considered as a separate modality, but instead as a complex motor response that could potentially interfere with other motor responses.

Since the purpose of entering destinations is to obtain route guidance information, manual or vocal destination entry also might occasionally draw on spatial cognitive resources, for instance, drivers in partially familiar areas might enter destinations or interact with their IVNS to “fill in the gaps” in their route knowledge, in these situations choices of destinations or other navigation-related decision-making processes, could to some extent also draw on spatial processing resources. Research concerning the effects of both forms of destination entry on driving performance is considered in more detail below.

2.8.5.1 Manual destination entry

Over the years, manufacturers have introduced several methods for drivers to manually enter destinations while driving, most of which have been described elsewhere (e.g. Burnett, Summerskill and Porter, 2004; Tijerina et al., 2000). These primarily include:

- Manually typing in alphanumeric address data using keyboards or touchscreen interfaces
- Scrolling through system-generated choices and menu options using touchscreen interfaces, rotary wheels, toggle switches etc.

Section 2.5.1 described Green`s (2000) analysis of accident data collected by the National Police Agency of Japan, it showed how 74% of IVNS-related traffic accidents during 1999 could be attributed to looking tasks. However, the study also showed that 24% of accidents could be attributed to operating tasks, even though destination entry while driving is prohibited by law in Japan. Although the difficulties of relying on accident data have already been discussed (see also Stevens and Minton, 2001), this provides further evidence of the potential for manual destination entry to degrade driving task performance. Several studies have shown that mobile phone dialling tasks can negatively affect driving performance (Briem and Hedman, 1995; Broohuis, DeVries and DeWaard, 1991). Some studies have evaluated different types of manual IVNS destination entry methods (e.g. Marics, 1990; Sears et al., 1993; Paelke, 1993; Monty, 1984). Based on reviews of many of these studies, Steinfeld et al. (1996) suggested that keyboard mediated manual address entry should always be facilitated by arranging keys (or touchscreen representations of keys) in a standard QWERTY format.

The most common driving performance measures that have been evaluated in the literature concern longitudinal (e.g. Srinivasan and Jovanis, 1997) and lateral (e.g. Dingus et al., 1995; Tijerina et al., 1998) vehicle control tasks, glance behaviour/eyes off road time (e.g. Tijerina et al., 1998 Dingus et al., 1989) and reaction time (e.g. Srinivasan and Jovanis, 1997). The majority of studies have also examined destination entry time, but although it is a measure of secondary task performance, it is neglected in the present discussion in favour of more direct driving performance measures like eyes-off-road time. Destination entry time is an important consideration though in its own right. In their test-track study, Tijerina et al (2000) examined the visual demand of entering destinations into four different commercially available IVNS (see below). An important finding in this research was the particularly low correlation between static (i.e. when the vehicle is stationary) destination entry time and destination entry time while driving. This research led to the development of the 15-seocnd rule, which has been adopted by the Society of Automotive Engineers (SAE). The rule states:

"All navigation functions that are accessible by the driver while the vehicle is in motion, shall have a statically measured total task time of less than 15 seconds" (Farber, Foley and Scott, 2000, p.7).

There are some problems with this rule. According to Tijerina et al (2000), a 15-second rule is not necessarily any more or less appropriate than a 30-second rule. Young, Regan and Hammer (2003) discussed some issues which have been raised in the literature. For example, it fails to address speed maintenance during interactive tasks (see below), and does not address the possibility the task has been chunked (i.e. split into several discrete attempts or chunks, to minimise distraction). Despite these objections, it is generally believed to achieve its primary purpose of providing design guidelines to industry about reasonable task completion times while the vehicle is in motion (Farber et al., 2000; NHTSA, 2000). According to Ranney and Mazzae (as part of NHTSA 2000), future revisions of the rule should make it applicable to more than one type of system. They also suggest that as it presently stands it is confusing and open to misinterpretation (i.e. drivers could interpret the rule as suggesting it is safe to take eyes of the road for 15 seconds at a time), but they do acknowledge some difficulties in developing revisions. These include:

1. The rule must be agreeable to the majority of those charged with the development of recommended practice
2. There is presently insufficient direct empirical evidence justifying a revision of the rule.

The primary reason why destination entry time is not considered in detail as a performance measure is due to the scope for this particular measure to change significantly over time as better and more ergonomic interfaces are designed and implemented. For example, many early studies reported destination entry times ranging from 1-4 minutes and Farber, Foley and Scott (2000) reported destination entry times of up to 9 minutes. However, in a more recent study Chiang, Brooks and Wier (2004) found that on average, drivers took just 34 seconds to enter destinations while driving and individual average entry times ranged from just 27 seconds to a maximum of 49 seconds. As user interfaces improve over time, it is likely that entry times will also decrease significantly, making it particularly difficult to compare studies over time based on performance on this particular measure.

Although interface characteristics have also been shown to affect other driving performance measures (e.g. Kamp et al., 2001; Antin et al., 1990), these are considered with caution below as they are direct indicators of driving behaviour (i.e. the main focus of the thesis). In terms of lateral performance, the evidence suggests that drivers make more lane departures and deviations when manually entering destinations while driving (e.g. Nowakowski et al., 2000; Dingus et al., 1995; Tijerina, Palmer and Goodman, 1998; Zwahlen, Adams and DeBald, 1988). In their comparison of four commercially available IVNS, Tijerina, Palmer and Goodman (1998) found that drivers made almost one lane departure on every destination trial (the interface method that required drivers to scroll through lists caused the most lane departures), this was 14 times higher than the number of lane departures in a baseline task (dialling a mobile phone). Tsimhoni, Smith and Green, (2002) found that most lane departures occurred within the first minute of destination entry time, and that the standard deviation of lane position increased with elapsed destination entry time. However based on the number of lane departures observed during destination entry tasks relative to non-interactive IVNS use, Chiang, Brooks and Weir, (2001) concluded that lane keeping performance was acceptable.

Although there are mixed findings about the effects of manual destination entry on lane keeping, poor lateral performance could be explained by high frequencies and long durations of glances toward system displays, and therefore away from the roadway (i.e. eyes off road time). For example, Zwahlen, Adams and DeBald (1988) examined driving performance when participants completed touchscreen data entry tasks while driving on a test track. They reported a significant positive correlation between the number of lane deviations and eyes off road time. In an early study, Dingus et al. (1989) investigated attentional issues associated with using the ETAK IVNS, a paper map and memorized route instructions. Participants drove an instrumented vehicle along public roads. The researchers were particularly interested in the direction and duration of glances to both the IVNS and the roadway. They found that when performing IVNS tasks, participants glanced significantly longer at the IVNS display than when performing conventional tasks using dashboard instrumentation. Burnett and Joyner (1993) also reported that participants' use of an IVNS was "associated with large amounts of eyes off road time". Tijerina, Parmer and Goodman (1998) found that manual destination entry methods entailed the greatest amount of eyes off road time. They showed that for destination entry tasks which took around one minute to complete, drivers spent three quarters of this time with their eyes off the road and Tijerina et al (2000) reported an average total eyes-off-road time of 60 seconds for one particular system. However, in a more recent study, Chiang, Brooks and Wier (2004) found average total duration of glances to an IVNS display of only 20 seconds, even though participants were instructed to take their time, and not to rush destination entry tasks. The author`s note that this duration of eyes-off-road time, conforms with generally accepted safety standards suggested elsewhere (e.g. Green, 1999; Tijerina, 1999; Farber et al., 2000; Greenberg, 2000).

In terms of longitudinal driving performance, there is evidence that manual destination entry causes reductions in driving speed and speed variation (e.g. Srinivasan and Jovanis, 1997, Chiang et al., 2001; Zylstra et al., 2003). As Young, Regan and Hammer (2003) point out in reference to observed reductions in speed when drivers used mobile phones, what is unclear is whether drivers reduce speed because they pay less attention to it or as a compensatory response to reduce accident risk or workload due to engagement in a distracting activity (i.e. a form of behavioural adaptation). Zylstra et al (2003) found that throttle position was the best predictor of in-vehicle task performance, as 13 out of 16 participants in their study could not perform in-vehicle tasks, maintain lateral position and constantly fine tune their speed, so occasionally they stopped adjusting speed during destination entry tasks.

2.8.5.2 Vocal destination entry

Due to the increasing accuracy of speech recognition technology over the past few years, a continually expanding range of IVNS models are being released to drivers with vocal interfaces, to replace some key IVNS interactive tasks including aspects of destination entry. Tijerina et al (2000) describe a range of tasks that could be controlled vocally including destination entry, mobile phone dialling, answering and hanging up and creating voice memos. Manufacturers are generally keen to point out that vocal IVNS interaction is a solution to distraction issues caused by manual destination entry, and in an early paper Leiser (1993) suggested that vocal interaction would provide a non-manual and non-visual means of accessing system functionality. However, a substantial volume of research has shown that conducting mobile phone mediated conversations while driving can seriously degrade driving performance (e.g. Brookhuis, de Vries, & de Waard, 1991; Strayer & Johnston, 2001). In one study, Redelmeir and Tibshirani (1997) examined phone records of 699 people who had been involved in traffic accidents and found that almost a quarter of these had been using a mobile phone in the ten minutes leading up to the accident. According to Redelmeir and Tibshirani (1997) the task interference caused by mobile phones was caused by attentional issues. There are similarities between these tasks and vocal IVNS destination entry tasks, but there are also some important differences. In papers concerning mobile phone use while driving, researchers often point out that a phone call is qualitatively different from a conversation with passengers, similarly issuing instructions to an automated system that may provide little or no response is qualitatively different to a phone conversation as it is a predominantly one-sided interaction. Although a review of the literature concerning driving performance while using a mobile phone is outside the scope of the present discussion, the reader is directed to Goodman et al. (1997, 1999), Young, Regan and Hammer (2003) and Horrey and Wickens (2006) for comprehensive reviews of the literature.

Contrary to Leiser`s (1993) proposal, research tends to suggest that speech recognition systems will also entail some visual demand. For example, drivers may require IVNS to provide visual confirmation of spoken instructions (Dewar, 2002). Graham and Carter (1998) reported that some drivers have a tendency to look at a microphone when speaking to a system, and Burnett, Summerskill and Porter (2004) pointed out that without some form of manual interaction to confirm that the driver wished to interact with the IVNS, it could mistake unrelated conversations unfolding in the vehicles from passengers or the radio, for interactive tasks. There is some evidence that speech-based interfaces decrease workload. In an early study using a helicopter navigation task, Malkin and Christ (1985) compared keyboard data entry with vocal data entry. The majority of participants indicated that they preferred vocal data entry and the results showed it entailed less perceived workload, although destination entry time was fastest when participants used the keyboard.

In a study comparing four commercially available IVNS interfaces, of which, one was vocal, Tijerina, Parmer and Goodman (1998) examined several driving performance measures during destination entry tasks, while participants drove an instrumented vehicle on a test track. The results showed that although all IVNS destination entry tasks took significantly longer to complete than the baseline task of dialling a phone, when participants used the vocal interface they completed destination entry tasks in less time, had reduced eyes off road time, and glanced less frequently at the IVNS display. They also found that participants made no lane departures over ten trials when they vocally entered destinations while driving (compared to less than one per ten trials for dialling a phone and 2-8 per ten trials for manually entering destinations). Although they also found that participants glanced away from the road scene more frequently and for longer durations, Tijerina et al. (1998) suggested this was most likely due to the increased need to spell the information correctly using the vocal interface. The authors concluded that IVNS that employ voice recognition technology are a safer and more viable alternative to visual-manual interfaces.

In a driving simulator study where speech recognition accuracy was controlled at 92%, Tsimhoni et al (2002) found that drivers entered destinations faster using vocal interaction than using keyboards. The vocal entry method in which participants recited whole words also resulted in faster destination entry time than the method in which participants had to recite characters. In contrast, Gartner et al (2001) found that vocal destination entry took longer to execute than visual-manual tasks, although in this study, speech recognition accuracy was much lower.

2.8.5.3 Age differences

Some of these studies have also revealed age differences in both destination entry task performance and driving performance while entering destinations. Tijerina, Parman and Goodman (1998) found that older participants (> 55 years) took twice as long as younger participants to complete the same manual destination entry tasks, and that over ten destination entry trials, older drivers made 8 lane departures when using the manual entry method and younger drivers made only 2. Importantly, there were no associations between age and lane keeping performance when participants vocally entered destinations while driving. Zylstra et al (2004) also found that older participants took longer to complete destination entry tasks than middle aged participants; they reported that older women took longest to enter destinations.

According to Mourant et al (2001) these age differences are caused by diminished perceptual and cognitive abilities. Using a driving simulator, they found that younger participants (23-46 years) displayed better lane keeping performance than older participants (58 to 76 years), although both groups made lane positional errors. In this study participants were also required to read four digit strings (the divided attention component) projected onto either the roadway or different positions to the right of the drivers' straight ahead visual plane. Younger drivers consistently correctly identified more stimuli than the older group.

2.8.5.4 Prevalence of destination entry while driving

Although many studies have examined the behavioural and driving performance effects of destination entry while driving, the extent to which drivers engage in this safety-critical form of behavioural adaptation are much less well understood. Green (1997) identified several real world scenarios, in which drivers might attempt to enter destinations while driving (e.g. in a hurry, need to change destinations on route due to congestion, finding out final destination during a trip). Some IVNS users may be unaware of the dangers of system interaction while driving. In such a case, perhaps they don't trade safety for utility, but rather do not view system interaction while driving as an inappropriate behaviour. Some research has begun to investigate this issue. The privilege (2006) survey mentioned above found that one in ten drivers admitted to using system controls while driving and more than half of these respondents thought that in doing so their eyes had been taken off the road. In the AAA foundation (2005) survey, 47% of respondents thought it was unacceptable to restrict drivers from manually entering destinations while driving. Svahn (2004) asked drivers to rate how distracting they found ordinary IVNS usage (defined as simply following route guidance) and system interaction while driving. More than 90% of respondents thought that ordinary usage caused only moderate or minor reduction of attention to surrounding traffic, but 65% thought their attention was clearly or significantly reduced during system interaction.

2.8.5.5 Willingness to engage

According to Lerner (2005), unlike distractions drivers are most often exposed to (e.g. a loud bang or sudden shock), distraction from an in-vehicle task occurs due to a user-choice to engage in a secondary task that might draw their attention away from the primary driving task. In his paper, Lerner (2005, p.499) used the phrase "deciding to be distracted", but it is more commonly referred to as "willingness to engage". Ranney et al (2000 p.2) defined willingness to engage as "conscious or unconscious decision processes involved in electing to carry out secondary tasks while driving". They cite a range of factors that influence willingness to engage including:

1. The driver (e.g. experience, trust, confidence)

2. The vehicle (e.g. display design)

3. Environmental (e.g. weather)

4. Task characteristics (e.g. ease of use)

Although the above factors undoubtedly affect willingness to engage, Ranney (2008) explained that it was also related to the benefits drivers associate with the secondary tasks. Ranney lists several ways in which performing in-vehicle secondary tasks while driving could be perceived as beneficial. These include:

1. They provide entertainment

2. They counteract the effects of boredom or fatigue

3. They allow the driver to accomplish “work”, such as making business calls or scheduling appointments while driving

The final point is particularly interesting in terms of behavioural adaptation. System interaction while driving is a form of behavioural adaptation to IVNS. Section 2.3.2 showed that various attempts have been made to model behavioural adaptation. Although risk models have been prevalent for many years, they have limitations. Other authors have suggested that behavioural adaptation might be linked to a need to increase utility or mobility (Smiley, 2000; Hoyes et al., 1996; Janssen and Tenkink, 1988), and Eost and Flyte (1998) even showed that some drivers use their car as a mobile office. For IVNS users, entering destinations while driving would negate the need to pull over to enter them (i.e. mobility) and those particularly pressed for time, such as working drivers may view it as a more efficient use of their limited time (i.e. utility).

Lerner (2005) conducted two related studies concerning drivers’ willingness to engage in distracting activities while driving. The first used a focus group which discussed various reasons for drivers’ behavioural choices. The second study was an on-road study, in which an experimenter accompanied participants on actual roads and at pre-designated times, asked them to rate their willingness to engage in a range of potentially distracting activities (though for purposes of safety participants never actually engaged in these activities). Lerner (2005) was interested in factors affecting willingness to engage in distracting activities while driving, so in the on-road component he asked for willingness ratings in various traffic situations and on different types of road (e.g. motorways, arterial roads and minor roads). Participants considered interacting with PDA and IVNS while driving to be considerably more distracting than performing basic phone tasks such dialing, answering and conversing while driving. Participants were also more willing to enter destinations by stored location while driving than to enter a whole address. There were only slight differences in willingness to engage in terms of road type, but for IVNS destination entry tasks (by address and stored location) participants were most willing to engage on minor roads.

Participants rated mobile phone tasks performed while driving as more risky than several other distracting activities such as conversation with passengers or using temperature controls. Of particular relevance to the present discussion, the mobile phone tasks rated as most distracting were keying in calls, using voicemail and looking up a number, there are obvious similarities between these tasks and destination entry features. Lerner (2005) also reported significant associations between subjective ratings of risk and age, with teen drivers rating in-vehicle activities as least risky and older participants rating them as more risky.

2.8.6 Mental models, error and communication

Mental models are internal representations that users adopt to guide their actions and help interpret system behaviour. Norman (1983) suggests they usually have vague boundaries, are incomplete, and unscientific. According to Goodrich and Boer (2003) they subsume important elements of decision making, by providing the context to meaningfully assess sensory information and to generate purposeful behaviour.

Drawing on Goodrich and Boer`s classification of automation in chapter 1, operators may have a poor understanding of an automated systems skill execution and skill termination because they have inaccurate and/or incomplete mental models concerning system operation. Sherry and Polson (1999) suggested that problems occur because of a mismatch between the operator’s mental model and automated system behaviour as programmed by designers.

Closely related to mental models is the issue of mode awareness. According to Degani (2003) a wide spectrum of automated systems ranging from simple alarm clocks to complex flight management systems involve internal transitions between different modes of operation that may be hidden from the user, such that they think it is one mode when it is actually in another. In safety non-critical applications mode errors may merely cause frustration but in safety-critical applications they may be catastrophic (Norman, 1990; Sheridan and Parasuraman, 2006).

2.8.7 Situation awareness

Breakdowns of communication between the system and operator, lack of feedback concerning mode of operation or system state and inaccurate or incomplete mental models of system functioning may also reduce an operators situation awareness. Endsley (1995, p.36) described situation awareness as "*the perception of elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the future".* Clearly therefore an adequate mental model must be a pre-requisite of situation awareness (Sarter and Woods, 1991).

Stanton and Marsden (1996) show that in the cockpit, automation of low workload tasks (e.g. relating to flight operations) tends to result in operator boredom, whereas automation of high workload tasks (e.g. take-off and landing) demands considerable cognitive strain due to reduced situation awareness. This occurs because operators (flightcrew) are left "out of the loop" for certain procedures, as such, they have insufficient information regarding system state and actions taken. A great deal of research (e.g. Endsley et al 1995; Hopkin and Wise 1996) highlights the importance of keeping operators in active control of processes as it allows them to accurately gauge their present and future circumstances. Poor situation awareness has been implicated in a wide range of aviation accidents, particularly in aircraft containing highly automated systems (e.g. Endsley, 1996; Hardy and Parasuraman, 1997; Jones and endsley, 1995). Gugerty (1997) also suggested that it plays a key role in driving accidents.

2.8.8 Trust, reliance and self-confidence

In "out of the loop" scenarios, the partnership between the human and the automation can be of critical importance. Flawed partnerships may result in automation misuse (where operators inappropriately rely on automation) or disuse (where operators reject the capabilities of automation) (Parasuraman and Riley 1997). An important variable that has increasingly been implicated in affecting misuse and disuse of automation is trust (Lee and See, 2004). While a fully comprehensive review of the trust literature is out of the scope of this thesis, it will be discussed in moderate detail below (see Lee and See, 2004 for a review of trust literature).

As a concept, trust has received considerable research interest. Trust is a purely Psychological state that can be measured subjectively (Wickens and Xu, 2002; Jian, Bisantz and Drury, 2000). Lee and See (2004) attempted to identify commonalities across the diverse range of potential definitions in the literature. They show that trust may be viewed as an attitude or expectation concerning future outcomes (Rotter, 1967; Barber, 1983; Rempel, Holmes and Zanna, 1985), an intention or willingness to act (Moorman, Deshpande and Zaltman, 1993; Mayer, Davies and Schoorman, 1995; Johns, 1996), or as a behavioural result or state of vulnerability or risk (Deutsch, 1960; Kramer, 1999; Meyer, 2001). In a framework reconciling these conflicting definitions, Azjen and Fishbein (1980) showed that intentions (a function of attitudes) result in behaviours, and that attitudes are based on beliefs and perceptions. Therefore while trust is the attitude, reliance is the actual behaviour. Based on this work, Lee and See (2004, p.54) referred to trust as *"the attitude that an agent will help achieve an individual`s goals in a situation characterized by uncertainty and vulnerability"*.

Trust research has taken place in three main areas:

1. Social psychology (emphasis on human-human interactions)
2. Systems engineering (emphasis on human-machine interactions)
3. Information technology and the internet (emphasis on machine mediated human-human interaction)

The first two will be discussed below as much of the systems engineering trust research stems from interpersonal research, and there are certain similarities (and differences) between the two types of trust, but research concerning trust in internet and computer based interaction (e.g. Muller, 1996; Kim and Moon, 1998; Lee and Turban, 2001) will be excluded from the present discussion.

2.8.8.1 Social Psychological trust research

Research investigating trust in interpersonal interactions has primarily focused on romantic relationships (Rempel et al., 1985) and organisational contexts between superiors and subordinates (Kramer, 1999; Tan and Tan, 2000). Several authors (e.g. Stack, 1978; Gaines et al., 1997) show that individual differences exist in propensity to trust, as some people appear to be more inclined to trust than others.

In line with social learning theory, Rotter (1967) referred to trust as a stable personality trait that can be measured (Rotter, 1980), where expectations for a particular situation are determined by previous experience of situations perceived to be similar. Additionally, Kikuchi, Wantanabe and Yamasishi (1997) showed that individuals with a high propensity to trust were better than those with a low propensity to trust at predicting trustworthiness in others.

Rempel, Holmes and Zanna (1985) developed a hierarchical model of trust in close personal relationships which consisted of three components: predictability, dependability and faith. Predictability and dependability are related to past experience and reliability of the trustee. Predictability concerns fixed, specific behaviours, whereas dependability concerns the qualities and characteristics of the trustee. However, faith goes beyond the available evidence to generalise trust in future, novel situations. Therefore it is concerned not with specific behaviours but beliefs and convictions about future events. Luhman (1980) suggested that in social relationships, people may initially be biased towards trust as it requires less mental effort than distrust.

2.8.8.2 Systems engineering trust research

Muir (1994) presented participants with complex automated process control scenarios, where researchers manipulated the reliability of the automated procedures. She found that the Rempel et al. (1985) model can usefully be extended to include human-machine interactions. Specifically they found that human operators will trust automation to the point at which it falls below some threshold. Only at this point will they attempt to override the system. Muir and Moray (1996) also found that development of trust in automation can follow the reverse pattern where faith is most important early on, followed by dependability and then by predictability. Using a similar process control paradigm as above, Lee and Moray (1992, 1994) also found that in addition to trust, an operators reliance on automation also depends on self-confidence (i.e. belief in their ability to perform the task themselves). When self-confidence was high, operators preferred to perform tasks themselves, but when it was low they were prepared to delegate responsibility to automation.

Since the early trust in automation research using the process control paradigm, a considerable amount of research has further investigated trust in automation in a wide variety of contexts including driving

(Kantowitz, Hanowski and Kantowitz, 1997; Fox and Boehm Davis, 1998; Lee, Gore and Campbell, 1999), aviation (Tenney, Rogers and Pew, 1998; Mosier, Skitka and Korte, 1994), robotics (Dassonville, Jolly and Desodt, 1996) and manufacturing (Trentesaux, Moray and Tahon, 1998).

However, there may sometimes be difficulties in generalizing trust in interpersonal interaction to trust in automation. There are distinct qualitative differences between the two situations. For example, contrary to Luhman`s (1980) claim concerning initial biases in interpersonal interactions, Sheridan and Hennessey (1984) suggested that operators in supervisory control environments, particularly novices, may initially be biased towards distrust. This is because automated systems are usually designed to perform complex tasks involving some element of risk (e.g. replacing vehicle control tasks), and initially trusting an incompetent machine could have catastrophic consequences. Lee and See (2004) also list several fundamental differences between trust in humans and trust in automation. For example, automation lacks intentionality. While interpersonal trust depends on trustee characteristics like loyalty, benevolence and value congruence, automated systems do not (presently) embody these characteristics, although as Rasmussen, Pejterson and Goodstein (1994) point out it may to some extent embody intentionality of designers. Additionally, interpersonal trust is often part of a social exchange relationship where for example a person may be trustworthy in order to elicit a favorable response from others (Mayer et al., 1995). Lee and See (2004) refer to a symmetry in interpersonal relationships where the way one person is perceived by another influences behaviour, however this symmetry does not exist in human-machine interactions.

Trust (the attitude) is strongly related to reliance (the behaviour). Automation reliance may be appropriate (where operators trust automation that is either reliable or more reliable than manual operation) or inappropriate (where operators trust automation that is either unreliable or less reliable than manual operation). Inappropriate reliance on automation may lead to a form of automation misuse commonly referred to as automation-induced complacency (Parasuraman, Molloy and Singh, 1993). Lee and See (2004) suggest that good calibration of trust (a high degree of correspondence between trust and automation capabilities), high resolution (trust can discriminate between levels of automation capability) and high specificity (trust reflects the capabilities of discrete elements of the system rather than the system as a whole) can lessen misuse and disuse of automation.

2.8.9 Automation-induced complacency

Skitka, Mosier and Burdick (1999) coined the term automation-bias to refer to situations when operators trust automated systems even when visual cues give contradictory information. Over-reliance on automation is referred to as automation-induced complacency (also known simply as complacency). It has been defined as "*a Psychological state characterised by a low index of suspicion*" (Weiner, 1981, p.117). Parasuraman (2000) has shown that complacency can be linked to failures in detecting automation failure, unreliability or inaccuracy.

Sheridan and Parasuraman (2006, p.99) illustrated a "classic case" of complacency by citing a naval accident in which a cruise ship ran aground because the GPS system had malfunctioned by switching to dead reckoning mode (i.e. it didn't account for tides, weather, etc.). An accident report showed the crew were over-reliant on the (malfunctioning) automated position display, and failed to utilise other navigation aids or environmental information for navigation. Sampaio and Guerra (2000) also provide a fascinating detailed case study concerning the impact of over-trust and complacency issues on a Portuguese aircraft accident, in their paper titled "the day 'God' failed or over-trust in automation".

Complacency has been associated with excessive trust (Parasuraman and Riley, 1997), low self confidence (Lee and Moray, 1994), sub-optimal system monitoring (sampling) for malfunctions (Parasuraman et al., 1993) and a poor mental model of the automated system functioning (Lee and Moray, 1992). It is often inferred using objective, behavioural or performance measures, and there have also been some attempts to measure it subjectively. For instance, Singh, Molloy and Parasuraman, (1993) developed the complacency potential rating scale, which purports to measure an individuals' tendency to over-rely on automation.

However, some objective measurement approaches have been criticized. Moray and Inagaki (2001) proposed that many previous studies which have inferred complacency on the basis that operators used a sub-optimal sampling strategy are flawed because they failed to define the parameters of an optimal sampling strategy. They proposed that the extent to which an operator monitors an automated system depends upon the objective failure rate of automation, so it is appropriate that reliable systems are monitored infrequently. Sheridan and Parasuraman (2006) acknowledge these criticisms, but claimed that in many situations, particularly those where operators use a range of complex automated systems and have additional manual tasks; it would be difficult to identify an optimal sampling strategy. Moreover designing an appropriate sampling strategy for a particular automated system, would also require an operator to specify an appropriate sampling strategy for all other tasks.

Complacency as a concept has also faced criticism. Dekker and Hollnagel (2004) suggested that complacency (and some other human factors phenomena such as situations awareness) should be likened to folk models rather than scientific theory. They suggest, like folk models, the theory of automation-induced complacency cannot be falsified (in Popper`s 1972 sense), are attributed causal power without any specification of the mechanisms involved, where explanations and general constructs are defined by substitution instead of by decomposition or reduction. They also suggested that complacency, like folk models is prone to overgeneralization, where findings from narrow and specific laboratory studies are broadly and uncritically applied to a much wider range of situations. However, in a recent response, Parasuraman, Sheridan and Wickens (2008) criticized Dekker and Hollnagel`s (2004) selective review of the complacency literature and misunderstanding of certain key issues. They showed that complacency has a strong empirical research base within the wider trust in automation literature. [2] They cited numerous studies which have clearly demonstrated the importance of trust in human use of automation. They also highlight neuro-ergonomic research investigating brain regions involved in trust. They say that complacency has been operationalized in terms of human performance, and that the wealth of literature concerning human performance and trust does provide a strong basis for operationalisation. They accept the view that consumers (e.g. accident investigators, program managers) may sometimes overgeneralise, but insist that the scientific community, backed up by scientific publications are more thorough and do not support overgeneralization.

Complacency has been empirically investigated in a range of contexts, including driving with adaptive cruise control, aviation, process control and use of automated decision aids. Recently researchers have begun to investigate individual differences in propensity to trust (and over-trust) automation. Ho et al. (2005) suggested that there are many reasons why elderly adults might respond differently to

[2] Parasuraman, Sheridan and Wickens (2008) also refuted claims that other human factors constructs such as mental workload and situation awareness are unscientific and may be likened to folk models

automation and fluctuations in automation reliability than their younger counterparts, for example, older adults have greater difficulty learning to use computers (Czaja and Lee, 2001). They may also be less familiar with automation and therefore less aware of potential unreliability. They suggested that age-related cognitive deficits in attention-allocation, working memory, mental workload, decision-making and interpreting stochastic information may make older adults more prone to complacency, as these cognitive changes may reduce self-confidence in manual performance. Using a flight simulation task, Vincenzi and Mouloua (1999) showed that older adults were less likely to notice automation errors and correct for them when they occurred. A range of driving research using advanced traveller information systems (Fox and Davies, 1998) and gauge warning monitoring tasks (Sanchez, Fisk and Rogers, 2004) has also indicated that older drivers trust automated vehicle systems more than their younger counterparts. In their study, Ho. Wheatley and Schiafa, (2005) found that older adults placed greater trust in an automated medical management system, and made more errors because they relied on the system too much. In an early study concerning user experiences of the LISB system (see section 2.7.2), Fairclough et al (1991) noted that elderly drivers sometimes felt paced by the system, such that they would sometimes feel obliged to immediately follow it.

Some authors have also linked trust to behavioural adaptation. In their descriptive model of driver behavioural adaptation to adaptive cruise control, Rudin-Brown and Parker (2004) proposed that adaptation was influenced by interaction between mental models, system feedback, system trust and the individual difference variables locus of control and sensation seeking. Although they did find some evidence for this relationship, their findings lacked statistical power due to the small size of their sample. As shown above, system trust is strongly related to reliance. Seppelt et al (2005) found that ACC users demonstrated inappropriate patterns of system reliance. Failure to regain vehicle control in the situations outlined above could also be associated with over-reliance on automation (i.e. automation-induced complacency).

Several authors (e.g. Fancher and Branchet, 1998; Smiley, 2000) have predicted that behavioural adaptation to ACC could manifest itself in terms of increased attention to secondary tasks, due to the decreased perceived workload offered by ordinary non-eventful ACC equipped driving.[3] ACC equipped driving has been associated with improved secondary task performance in simulator research (Stanton et al., 1997) and using an instrumented test-track vehicle (Rudin, Brown and Parker, 2004). In the latter study, participants were given a stock-market task completely unrelated to driving. Smiley (2000) suggests that behavioural adaptation as secondary task engagement may result from a safety-utility trade-off, where drivers attempt to engage resources freed during ACC equipped driving, to increase productivity.

2.9 Automation-related behavioural adaptation to IVNS

Trust, mental models and situation awareness may also be associated with IVNS usage. These concepts might also explain aspects of behavioural adaptation to IVNS. Due to the relative lack of research in this area, this section will also include authors' predictions as well as secondary sources (e.g. press reports) to outline some other potential manifestations of behavioural adaptation to IVNS.

Some studies (e.g. DeVries, 2004; Bonsall and Joint, 1991, Kantowitz, Kantowitz and Hanowskil, 1994) have shown that the accuracy of route guidance information affects trust in IVNS, such that decreases in reliability lead to decreases in trust. Of particularly relevance to the present thesis, DeVries (2004) conducted several investigations concerning the performance of participants who completed real-time route guidance tasks from a map overview perspective. In most of the studies, their task was to reach various destinations, by using the automated route planner, or planning the route manually. They obtained extra "credits" when they reached destinations within a specified time. DeVries (2004) controlled a range of factors (e.g. system reliability, indirect information) to examine the contexts in which they elected for automated or manual route planning. In one study he showed that motivation could also affect trust. Altogether his research demonstrated that both direct and indirect sources or reliability information as well as motivation and self-confidence can affect trust in automation.

Kantowitz, Hanowski and Kantowitz (1996) used three reliability conditions (100%, 71% and 43%). They found that presenting drivers with unreliable information did negatively affect their trust, but that trust

[3] Assuming that over-trusting drivers would feel less compulsion to monitor ACC, so would avoid the extra workload demands that monitoring typically entails.

did recover when reliable information was subsequently presented. Kantowitz, Hanowski and Kantowitz (1997) also found that when drivers were familiar with the area, self confidence exceeded trust. In these cases, drivers may be more critical of automated route guidance information.

Kantowitz et al (1996) suggest that 71% reliability was acceptable and useful to drivers. With such a low threshold of reliability it is conceivable that some drivers may become over reliant on IVNS because they trust the system too much. In ACC research some authors have considered this type of behavioural adaptation in terms of delegation of responsibility to automated control. Risser and Lehner (1997) found that some ACC equipped drivers left system settings unchanged for as long as possible to prevent system deactivation. Citing Michon et al (1990) and Reason (1990), Gstalter and Fastenmeier (1992) likened over reliance to the command effect (Kramer and Reichart, 1989); where a tendency to obey automation is increased due to a confirming bias (i.e. people tend to look for information that supports their actions and ignore information that contradicts them). Gstalter and Fastenmeier (1992 p.46) described how over-reliance might affect IVNS user behaviour:

"*The driver has made a destination input into the navigation system in an unknown traffic environment. When he looks at the display later on, he sees that his destination is at a right angle to the left of his car`s position and he approaches a junction. That arrangement may influence him to try to turn left at the intersection. If his reliance on the system is very strong he may attempt to turn left even if it is prohibited at that junction*"

Although as shown above, some practitioners have a tendency to overgeneralise complacency to a wide range of situations, some authors have suggested that drivers may become over reliant on IVNS (e.g. Stevens et al., 2001; Katz et al., 1996). Stevens et al (2001) suggested that this type of behavioural adaptation to IVNS can only be studied using long term trials. Katz et al (1996) proposed that over-trust in IVNS could lead drivers to view route guidance instructions as commands. Presently very little literature concerning over-reliance on IVNS exists. If drivers were to become over-reliant on IVNS, this would be a major safety concern and would indicate negative behavioural adaptation. Chapter 1 showed that IVNS sales have escalated over the past few years. During this time, several articles have been released in the press reporting situations in which IVNS users may have been over-reliant on their systems:

An 80-year-old German motorist has obediently followed his navigation system all the way into a huge pile of sand…"The driver was following the orders from his navigation system and even though there was a sufficient number of warnings and barricades, he continued his journey into the construction site," a police spokeswoman has said… Source: http://www.news.com.au/story/0,23599,20555319-13762,00.html

(accessed 24th May, 2007)

…student's car was wrecked by a train after she followed her sat nav system onto a railway track…she was trying to cross the line in the dark when she heard a train horn, realised she was on the track, and the train smashed into her car…"I put my complete trust in the sat nav and it led me right into the path of a speeding train" she said…"the crossing wasn't shown on the sat nav"…"I was using the sat nav completely dependent on it"…Source:

http://news.bbc.co.uk/1/hi/wales/south_west/6646331.stm

(accessed 24th May, 2007)

…satellite navigation systems have caused so many problems in one corner of the country that road signs have been put up to tell drivers they are heading for trouble. The bright yellow signs have gone up in the village of Exton, near Winchester in Hampshire, after lorries repeatedly got stuck in a narrow lane hardly wide enough for one car… Source: http://www.metro.co.uk/news/article.html?in_article_id=37839&in_page_id=34 (accessed 24th May, 2007)

An ambulance crew transferring a patient to hospital were sent 200 miles in the wrong direction by a faulty satellite navigation system...The crew had been tasked with taking the male patient 12 miles across Essex from King George Hospital in Ilford to Mascalls Park Hospital near Brentwood - a 12 mile journey which should have taken about 30 minutes. But a fault in the ambulance's on-board satellite navigation system sent the London Ambulance Service crew on an eight-hour round trip to Manchester….. the crew hadn't been to Mascalls Park before and only realised they were heading in the wrong direction when they reached the outskirts of Manchester. Source:http://www.manchestereveningnews.co.uk/news/s/229/229783_sat_nav_ambulance_sent_the_wrong_way.html (accessed 24th Sept, 2008)

A man and woman accused in a spree of Newmarket vehicle burglaries are in custody after blundering into a U.S. border crossing in a stolen SUV while blindly following GPS dashboard directions to Alberta…guards detained the couple March 3 at the Port Huron, Mich., international bridge after checking the licence plate of a Toyota Highlander and discovering it was stolen.The Toyota's GPS device apparently pointed the vehicle to Western Canada via Michigan and Wisconsin, rather than by the Trans-Canada Highway looping north of Lake Superior." Unfortunately the GPS doesn't differentiate between highways and bridges and before (the suspects) knew it, they were crossing the Bluewater Bridge from Sarnia to Port Huron," Det. Duncan MacIntyre of York Region police said. Source: http://www.thestar.com/printArticle/193790 (accessed 24th Sept, 2008)

In a recent study Varden (2008) investigated driver misuse of IVNS. He surveyed 210 IVNS users and examined system trust, perceived distraction risk and self confidence. He found that participants reported high levels of trust in their IVNS, perceiving them as accurate and reliable. He did find that 45.8% of participants had followed IVNS when it was contradicted by advice from another person, and 31.9% of participants had followed IVNS when it was contradicted by road signs. Varden (2008) claimed that participants' accompanying descriptions of these situations provided acceptable justification for these situations. He stressed that the evidence suggested participants hadn't blindly followed the instructions and were aware that IVNS route guidance functions were not infallible. However, the privilege (2006) survey revealed that nearly one in eight drivers did not check a route they were unfamiliar with in advance, and simply relied on their IVNS to help them to reach their destinations. Additionally, In an IVNS user survey, Franken (2007) found that 79% of respondents (almost) always followed IVNS instructions when travelling through unknown regions. Respondents were also asked to respond to a hypothetical scenario in which they were driving to a fictitious city called "Korlin". They were asked how they would have reacted if they had passed a road sign which clearly contradicted IVNS instructions, 68% of participants reported that they would have followed the IVNS instructions.

In order to explain why some drivers might follow inaccurate guidance instructions, it would be important to consider the extent to which drivers actually process road signs when presented with consistent and contradictory IVNS instructions. If road signs are sufficiently processed, this would imply inappropriate reliance, but if they are not sufficiently processed then an attention-based explanation may be more appropriate. Following inaccurate instructions could represent a failure to focus on relevant information such as road signs or a failure in driving task performance (i.e. inappropriately responding to road signs) or a failure to respond appropriately to system errors.

Despite other evidence associating trust with IVNS use, Schmidt-Belz (2005) suggests that it can be problematic for users to develop trust in adaptive systems. IVNS are adaptive systems because, if a driver does not follow system-generated routing advice, the system will recalculate and suggest an alternative. Schmidt-Belz (2005) suggests this lack of transparency can make it harder for users to understand the system and predict its "behaviour".

However, If IVNS users develop appropriate mental models they should be able to understand the system and predict its behaviour, and as shown above this should also increase system-related situation awareness. An important starting point in understanding drivers' mental models of IVNS could be to examine their understanding of different aspects of how their system works, and the learning processes that lead to this understanding. In particular, in light of potential concerns about over-trust and complacency, research should examine their understanding of the accuracy of maps, frequency of updating etc. Some research has investigated aspects of drivers' understanding of system functioning. The AAA foundation (2005) survey showed that most drivers (65%) learned to use their system by reading the manual (as will be shown below, manufacturer manuals always state warnings concerning aspects of negative behavioural adaptation to IVNS), but a significant proportion (55%) learned by on-road experience. However, 63% of respondents didn't know about warnings from manufacturers or system limitations.

Recent surveys have shown that some drivers do experience map/route related problems with their IVNS. In Svahn (2004) about a third of respondents thought there was only moderate, low or insignificant correspondence between IVNS advice and their individual preference when travelling through unfamiliar areas. In the J.D. Power and associates (2006) usage and satisfaction survey, route or map related issues accounted for over 50% of all problems cited by IVNS owners. The authors suggested dissatisfaction will only diminish as the time between map production and delivery to customers decreases.

2.10 Summary

Clearly as a topic in traffic psychology, behavioural adaptation has received a great deal of attention. It has been empirically elaborated on extensively, using a plethora of methodologies and study designs since it was first operationally defined by an OECD expert panel in 1990. The hierarchical driving behaviour models outlined at the beginning of this chapter provide a useful framework for understanding the varied ways in which it affects different aspects of driving behaviour from vehicle control tasks to navigational effectiveness, and for measuring it when it occurs.

As shown, the vast majority of behavioural adaptation research and discussion has focused solely on the effects of safety-enhancing measures on driving behaviour, but behavioural adaptation as a general concept has much wider scope than this. The OECD expert panel explained that behavioural adaptation can occur in response to any transportation interventions, and clearly the above research shows that it is just as important a consideration in relation to IVNS as to any other in-vehicle system or more general transportation intervention. Although behavioural adaptation models have received relatively little attention in this review, clearly the wealth of available evidence concerning behavioural adaptation to a wide variety of transportation interventions shows that any attempts to explain it must move far beyond basic concepts of risk compensation, to include various other elements such as safety-mobility tradeoffs and utility maximization.

Table 2.1 clearly shows that studies which have directly compared the behavioural and performance effects of IVNS and more traditional navigational methods (e.g. paper maps, memorized route instructions) have produced a very mixed array of findings that are positive, negative and neutral in terms of safety and navigational efficiency/effectiveness. This makes it difficult to arrive at any firm conclusions from these results. Further difficulties in comparing these studies also arise due to the wide range of methodologies, study designs, behavioural/performance measures and IVNS used in this research both across studies and throughout time. The novelty effect is a particularly salient drawback of many studies when considering behavioural adaptation as the general consensus from researchers is that many aspects only appear after a familiarization period with in-vehicle systems.

Individual differences in behavioural adaptation to IVNS further complicate comparing these studies and drawing any firm conclusions from them. Although research has begun investigating these, clearly much more work needs to identify individual difference variants in behavioural adaptation to IVNS. This line of research has proved particularly fruitful in research concerning behavioural adaptation to ACC. Rudin-Brown and Parker (2004) identified the key influence of sensation seeking (SS) and locus of control (LoC) and incorporated them into their descriptive model. Since they authored their model, many more studies have further investigated the role of these individual difference variables in behavioural adaptation to ACC.

There are also many potential manifestations of strategic level behavioural adaptation to IVNS. Unfortunately however, there is a significant lack of research that has specifically investigated the effects of IVNS on strategic level behavioural adaptation. As such, this section of the literature review had to include a much wider range of studies that had considered the effects of a whole range of advanced travel/traffic information delivery methods on strategic level driving behaviour. It is expected that strategic level behavioural adaptation to IVNS could be as rich and diverse as it is to these other methods, but unfortunately with only limited empirical evidence, as yet this prediction remains largely untested.

There is also a relative lack of empirical research that has investigated behavioural adaptation to IVNS in the wider automation context. A key issue is drivers' response to the reduced perceived workload offered by in-vehicle systems. IVNS users may take advantage of this and interact with their IVNS while driving. Some studies have illustrated the performance effects of system interaction (destination entry in particular) while driving, but as shown; there is considerable variation among findings, most likely due to variations in systems used over time. However, much less research has examined the extent to which drivers behave this way, and any reasons why they may choose to do so, which would be important considerations in the design of any interventions implemented to reduce the extent to which drivers behave this way.

Clearly there are also a wide range of implications to introducing automation across domains, driving and otherwise. Fortunately, a wealth of research into these issues in the aviation and process control domains provides a good base from which IVNS behavioural adaptation research could stem. Particular automation-related concerns for IVNS relate to system trust and reliance, mental models and situation awareness. Presently, only very little empirical research have considered these issues. Their importance and relevance has already been identified by manufacturers, therefore researching them should be an urgent consideration given the popularity and market penetration of IVNS.

2.11 Conclusion

Based on an extensive literature search, this literature review is the first (in the author's opinion) to tie together all the different topics required to understand behavioural adaptation to IVNS. However, much more research in this area is urgently needed. The main conclusions from this literature review are:

1. Although a wealth of research has considered behavioural adaptation to other in-vehicle systems (particularly ACC and other ADAS), much less research has focused on IVNS specifically, and therefore this research topic requires much greater explanation and elaboration.

2. A wide range of both quantitative and qualitative study methodologies and designs have investigated behavioural adaptation to IVNS so far. This approach should continue in order to provide the widest possible understanding of the research topic.

3. With the exception of user surveys, in many of the studies reported in this literature review participants were not experienced IVNS users. Due to the novelty effect, and since some forms of behavioural adaptation only occur after a familiarization period, it is particularly urgent that focused IVNS behavioural adaptation research that includes long-term IVNS users is conducted as soon as possible.

4. Much more research is needed to examine individual difference variants in behavioural adaptation to IVNS. By understanding how behavioural adaptation effects IVNS users differentially, can attempts be made to support and enhance positive behavioural adaptations (in terms of both safety and navigational efficiency/effectiveness) and control or reduce negative behavioural adaptations.

5. Further IVNS user research should also explore drivers' understanding of their IVNS, particularly in relation to the accuracy and reliability of system maps.

Chapter 3 – Online driver survey

3.1 Introduction

The first study in the thesis was an online driver survey which was designed to highlight some of the characteristics of contemporary IVNS users and in particular, to identify any differences in the characteristics and self-reported driving behaviour of drivers who use and do not use IVNS. It was expected that comparing responses of IVNS users and non-users in this way would reveal initial evidence of positive, negative and neutral behavioural adaptations to IVNS in terms of both safety and navigational efficiency to address the first aim of the thesis. It was further expected that focusing on IVNS user and non-user characteristics would also partially address the second aim of the thesis by highlighting salient individual difference variates in drivers' experiences of behavioural adaptation to IVNS.

An online survey was considered more appropriate than traditional pen and paper methods (e.g. postal survey) because an A-priori power analysis indicated the need to recruit at least 105 respondents for each group (i.e. drivers who use and do not use IVNS) to achieve sufficient statistical power (see appendix AL). Although few difficulties could be anticipated in recruiting 105 ordinary drivers, it may have been much more problematic sampling this many IVNS users using traditional methods. However, several researchers (e.g. Reips, 2000, 2002; Krantz and Dalal, 2000; Fraley, 2004) have shown that the internet can provide a valuable new medium for research. More recently Li (2006) showed that internet mediated research (IMR) can also be an effective tool for IVNS user research. In their survey of researchers who used the web for the work, Musch and Reips (2000) reported that 70% certainly intended to use the method again. Respondents cited the potential for larger numbers of respondents and high statistical power as the most important reasons for conducting research online. Other advantages include their low cost (in terms of cost, efficiency and time) and the ease of collecting both quantitative and qualitative data in a format immediately ready for analysis. The three main disadvantages of IMR are increased dropout rates, population biases introduced by self-selection (Andrews, Nonnecke and Preece, 2003) and lack of experimenter control. Some authors (e.g. Matsuo et al, 2004) have also expressed concerns about the external validity of online research, but while there may still be some socio-economic biases, several studies have shown that the internet is getting increasingly representative of the general population (Krantz and Dalal, 2000; Reips, 2000, 2002;

Gosling, Vazier, Srivastava and John, 2004; Kraut, Olson Banaji, Brukman, Cohen and Couper, 2004). Some authors also point out that external validity is just as significant an issue for ordinary research using traditional methodologies. For example, Reips and Bachtiger (1999) suggested that while 80% of psychology studies are conducted with students, only 3% of the population is students. According to Gosling et al (2004), while samples in IMR may not yet be completely representative of the general population, most study findings are similar to those in published research in terms or socioeconomic status, gender, age, location and race. They compared sample demographics of respondents in a large scale internet survey with over 100,000 respondents and traditional studies published over the course of one year in the Journal of Personality and Social Psychology (a respected peer-reviewed journal). Their paper also debunked several myths about online research such as inability to generalize findings and inability to generalize across response formats. Also the focus of the present study was self-reported driving behaviour and the first aim of the thesis is to investigate positive and negative behavioural adaptations to IVNS, it was therefore important that respondents were honest about their driving behaviour. By conducting this survey online, respondents could be assured their responses were completely anonymous.

As this initial survey was a largely exploratory exercise, it was important to use an established scale to examine driving behaviour. Several self-report measures of driving behaviour were available. These included:

- The driver behaviour questionnaire (DBQ - Reason et al., 1990; Parker et al., 1995) which concerns the relative frequency with which drivers engage in aberrant driving behaviours.
- The driver behaviour inventory (DBI - Gulian, et al., 1989; Glendon et al., 1993) which is concerned with dimensions of driver stress.
- The driver mobility questionnaire (DMQ - Baldock, Thompson and Mathias, 2008) which concerns driver behaviour and health
- The behaviours in traffic questionnaire (BIT – Synodinos and Papacostas, 1985) which is related to self-reported driving behaviour in various traffic situations.
- The driving ability and confidence scales (Parker, Macdonald, Sutcliffe and Rabbitt, 2001) which concern self-rated driving ability and confidence in various traffic situations.
- The positive driving behaviour scale (Ozkan and Lajunen, 2005) which concerns the relative frequency with which drivers engage in a range of positive driving behaviours.

It was important that the scale was robust, short (to minimise the risk of dropout due to conducting the survey online), and included a range of driving behaviours concerning both safety and navigational efficiency at the strategic, tactical and control levels of driving behaviour. Following a review of each scale, the DBI, DMQ and driving confidence and ability scales were rejected because they contained a far too narrow range of items for investigating behavioural adaptation to IVNS[1]. The DBQ was selected instead of the BIT due to the range of driving behaviours examined and the high volume of previous studies that have replicated the factor structure (Parker et al., 1995; Westerman and Haigney, 2000), using culturally distinct sampling frames (e.g. Blockley and Hartley 1995; Aberg and Rimmo 1998; Xie et al 2000). This latter point was particularly important as a more culturally diverse sample was expected since the survey was conducted online.

Since the DBQ only includes items related to aberrant (i.e. negative) driving behaviours[2] and the first aim of the thesis was to identify positive, negative and neutral manifestations of behavioural adaptation to IVNS in terms of safety and navigational efficiency, this study also included relevant items from the positive driving behaviour scale which has previously been shown to correlate negatively with the DBQ (Ozkan and Lajunen, 2005).

3.2 Main objectives

The main objectives of this study were to:

1. Find out about IVNS and PND user demographics and characteristics
2. Examine usage patterns of IVNS and PND users, relative to normal unequipped drivers and compare other relevant driver characteristics (e.g. age, mileage).
3. Identify self-reported behavioural differences in terms of both safety and navigational efficiency between drivers who use IVNS and PND, and those who do not.

3.3 Method

The survey was piloted before being published for the study (see appendix A).

[1] The online survey would have taken too long to complete if these scales had been used in combination.
[2] Some irrelevant items were not included (e.g. those concerned with parking).

3.3.1 Respondents

Table 3.1 below illustrates some of the main respondent characteristics. 450 respondents (328 male, 122 female) took part in this study. All respondents were self selecting having responded to an online advertisement placed on driving related internet forums, bulletin boards and mailing lists (see appendix B).The sample was drawn mainly from Europe and North America.

Table 3.1: showing main characteristics of the online driver survey respondents (N=450)

Item	Categories	No. of participants/descriptive statistics	Percentage of participants
Gender	Male	328	72.9
	Female	122	27.9
Country of residence[3]	UK	354	78.9
	Rest of Europe	17	3.6
	USA/Canada	66	14.9
	Australia	13	3.1
	Israel	1	0.2
Age	<20 years	21	4.7
	21-30 years	168	37.3
	31-40 years	103	22.9
	41-50 years	80	17.8
	51-60 years	60	13.3
	>60 years	18	4
No. years with full driving license	<5 years	71	15.8
	5-10 years	81	18
	11-15 years	74	16.4
	16-20 years	60	13.3
	21-25 years	52	11.6
	>25 years	112	24.9
Approx. mileage past 12 months	Mean	17.1 thousand miles	n/a
	Median	12 thousand miles	n/a
	SD	16.1 thousand miles	n/a
	Range	0-210 thousand miles	n/a
IVNS user	Yes	157[4]	34.9
	No	293	65.1

[3] Responses added up to >100% because 3 participants indicated that they lived in two countries
[4] See appendix AM for a list of IVNS manufacturers used by respondents in this survey

3.3.2 Design

An online survey was considered the most appropriate design for this study. The survey was defined by 47 items (see appendix B for list of items, variable types and item responses), and three types of variable were used: nominal, ordinal and ratio (respondents were also asked to provide qualitative responses to some items). The questionnaire was split into two sections, the first section contained 22 items concerning driver characteristics and IVNS usage and the second section contained self-report items from the published behavioural scales outlined above. In the first section, the nominal level variables concerned gender, owning/using an IVNS, whether respondents were first-time IVNS users, type of system, IVNS user satisfaction, trust and navigational confidence and other in-vehicle systems used. The ordinal level variables concerned respondent age, driving experience and frequency of unfamiliar journeys since acquiring an IVNS. The ratio level variables concerned annual mileage, commuting mileage, length of time their present system has been installed and number of times respondents have used their system and made unfamiliar journeys in the past month[5]. Variables which required respondents to provide qualitative information concerned occupation, country of residence, IVNS make and model, and other unspecified in-vehicle systems that respondents used.

The second section contained 25 items taken from the DBQ[6] (Reason et al., 1990), positive driving behaviour scale (Ozkan and Lajunen, 2005), and from a previous survey in which Kubota et al (1995) investigated Japanese IVNS users' navigational behaviour. These were all ordinal level variables. Respondents were asked to rate the relative frequency with which they engaged in each behaviour on a 6-point scale, with the following response format:

1. Never
2. Hardly ever
3. Occasionally
4. Quite often
5. Frequently
6. Nearly all the time

[5] Two nominal variables were also associated with these last 2 items to find out if the past month was typical or atypical.

[6] One item on the Reason et al (1990) DBQ scale was altered from "drive with only half-an-eye- on the road, while looking at a map" to "drive with only half-an-eye on the road, while looking at a map **or navigation system display**" *(Bold text only used here).*

3.3.3 Materials

Respondents used their own computers to complete the questionnaire from remote locations. The questionnaire was designed using Microsoft Excel and html authoring software, and was stored on web space provided by the University of Nottingham.

3.3.4 Procedure

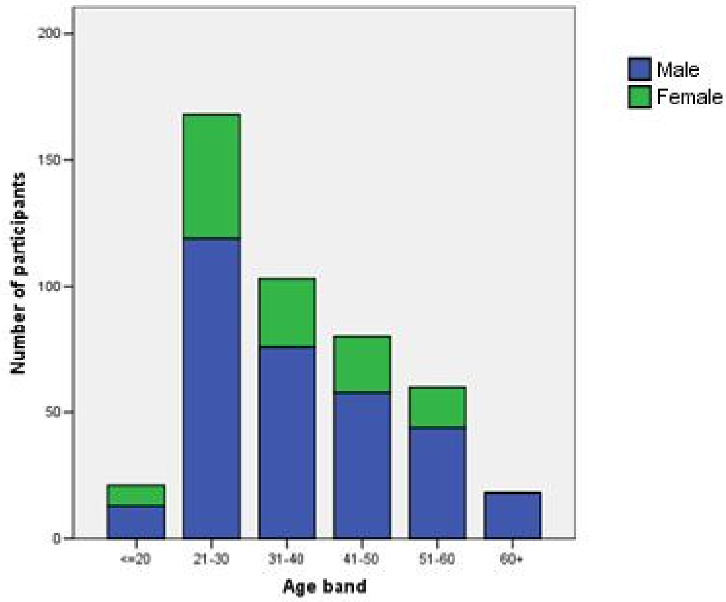
Respondents responded to online advertisements placed on driving related internet forums, bulletin boards and mailing lists. They were directed to follow a link to the questionnaire, provided that they had held a full driving license for at least 6 months. They were asked to read the instructions (see appendix D), in which they were told to answer the questions truthfully, and were reminded that their responses were completely anonymous. They were told that the questionnaire would only take five to ten minutes to complete, and that a summary of the results would be made available to them in due course, in return for their participation. They were also told to contact the researcher by email, if they had any questions or were unclear about the nature of the research. Once they had completed the questionnaire, respondents were thanked for their participation and directed to submit the form, which saved the results in a text format ready for analysis.

3.4 Results

3.4.1 Whole sample and IVNS user demographics

Figure 3.1 shows that all driver age bands except those under 21 years and those over 60 were fairly well represented in the sample. Most respondents were aged between 21 and 40 years, and more males than females participated, although females were represented in almost every age band. 157 respondents (35%) reported using an IVNS. Figure 3.2 shows that the age distribution of IVNS users closely resembled that of ordinary drivers surveyed. However, far fewer female drivers reported using an IVNS.

Figure 3.1: graph showing age distribution and gender of respondents (N=450)



The sample varied extensively in terms of driving experience (indicated by annual mileage and number of years with a full driving license). Just over two thirds had been driving for over ten years. On average, respondents had driven about 17,000 miles (SD=16.08 miles) in the past 12 months. Figure 3.3 shows that the majority of respondents had driven between 5 and 20 thousand miles during this period. Although it suggests a slight tendency for IVNS users to have driven further than non-users during this period, a t-test showed that this difference was not significant[7], even when respondents who had an IVNS installed for less than 12 months and hadn't used other systems previously were excluded from the analysis.

[7] Only significant results are reported here and throughout this thesis

Figure 3.2: graph showing age distribution and gender of IVNS users (N=157)

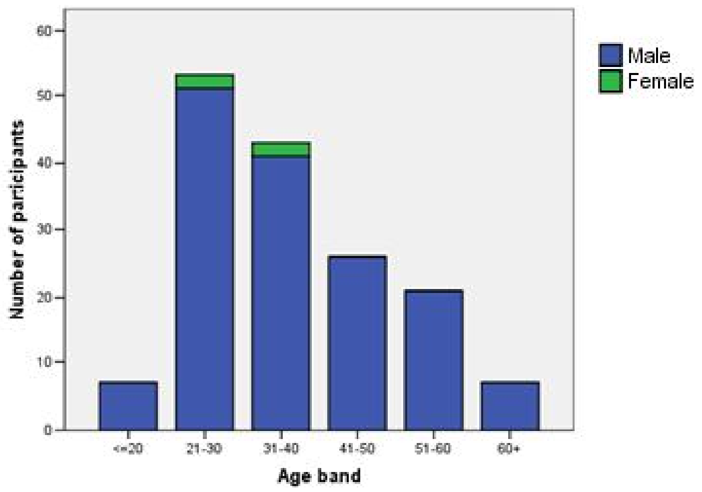


Figure 3.3: graph showing approximate mileage of IVNS users (N=157) and non-users (N=293) over the past 12 months

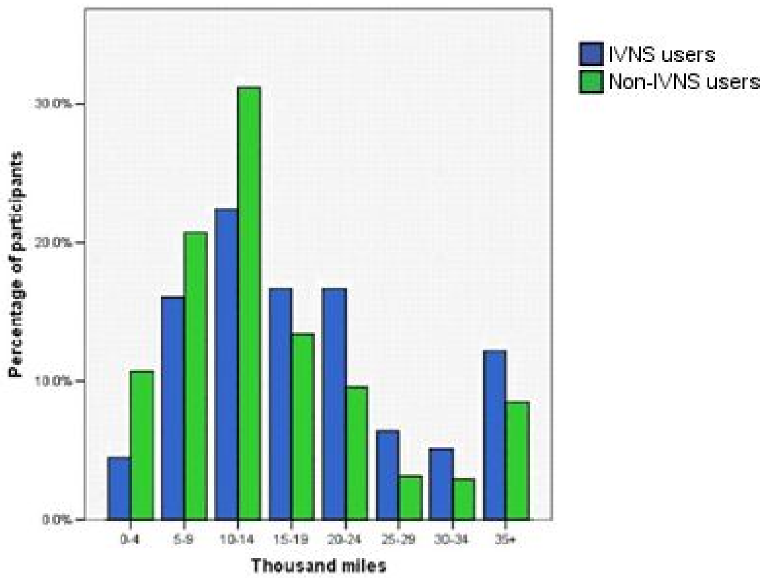
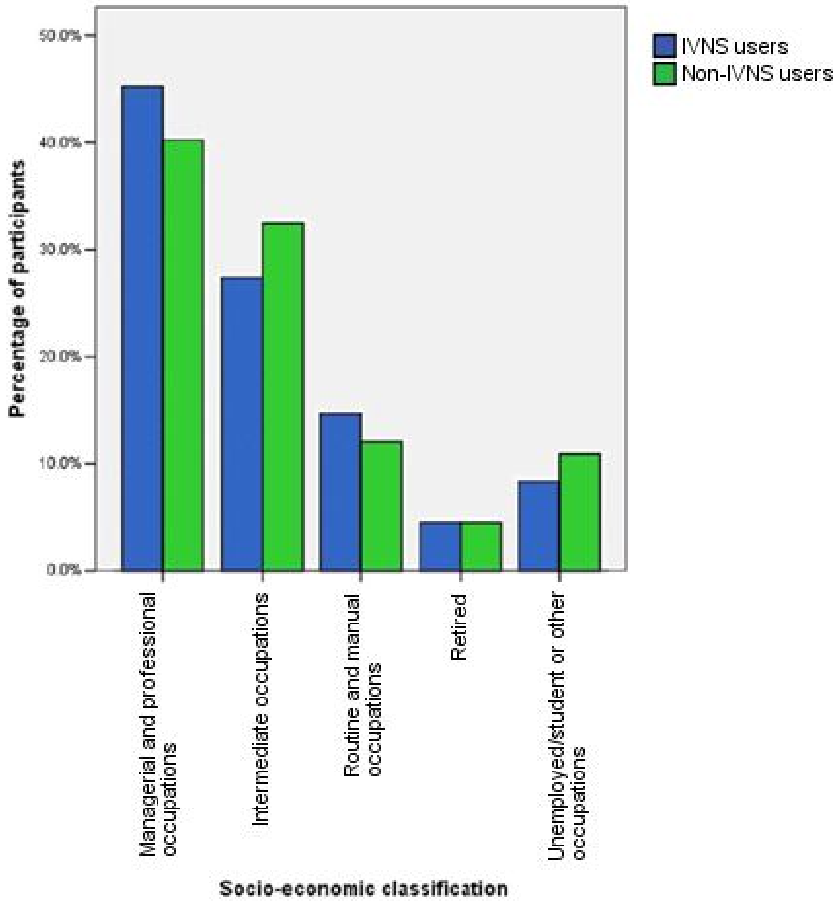


Figure 3.4 shows the socio-economic status of IVNS users and non-users surveyed. It shows that respondents with routine and manual occupations were under-represented in the sample population. Although there are slight differences (e.g. 5% more IVNS users held managerial and professional

occupation), the socio-economic status of IVNS users appears to be broadly similar to that of drivers who do not use IVNS.

Figure 3.4: graph showing socio-economic status of IVNS users (N=157) and non-users (N=293)



3.4.2 IVNS usage, satisfaction and trust

Most IVNS users were fairly experienced, having had their current system installed for an average of 16 months, although there was a wide range (1 month to nearly 6 ½ years). Only a quarter of respondents had used an IVNS previously. On average, they reported having used their systems approximately 33 times over the past month, and for most respondents (86%), this represented typical monthly usage. The majority of IVNS users (71%) reported making unfamiliar journeys about as frequently as they did before they used an IVNS, but over a quarter (26%) reported making more unfamiliar journeys than they used to. Most respondents (92%) use aftermarket IVNS and PND, and just over a fifth (22%) reported using other "intelligent" in-vehicle equipment (e.g. adaptive cruise control, collision avoidance systems).

Most respondents (88%) reported that they were satisfied with their IVNS, and just over half (54%) reported that since they started using an IVNS, they felt more confident driving in unfamiliar areas than they did before. Most IVNS users reported that they trusted their systems to provide accurate route guidance instructions (79%), although it is noteworthy that nearly a fifth of them did not, or were unsure.

3.4.3 Self-reported driving behaviour

A Mann Whitney U test was used to compare ordinal level responses of IVNS users and non-users in section 2. For just over half of the items there were no significant differences between each groups' responses suggesting that self-reported driving of each group was broadly similar in terms of these lapses, errors, violations and positive driving behaviours. However there were significant differences between the groups for some items. These are shown in table 3.2. Mean group responses are also reported to give an indication of the direction of these differences.

3.4.4 Associations between driver characteristics and self-reported driving behaviour

An analysis using Spearman`s rho test also revealed some significant correlations between section 2 items and driver characteristics[8] (see table 3.3 below). The strongest correlation was between the frequency with which participants use their IVNS each month and the relative frequency with which they make the strategic decision to use unfamiliar routes when faced with congestion. For some items table 3.2 shows that the results may not be attributed solely to use of IVNS. For example, mileage was significantly associated with IVNS users and non-users responses to the item *"worry about the consequences of getting lost".* In other cases, demographic variables were associated with non-users' responses, but not IVNS users' responses (e.g. *"misread the signs and exit from a roundabout on the wrong road").*

[8] Due to the lack of female IVNS users sampled, gender was excluded from analyses concerning associations between driver characteristics and section 2 items

Table 3.2: showing significant differences between IVNS users (N=157) and non-users (N=293) in responses to section 2 items[9] (df=448)

Error type	Item origin	Item	IVNS-users group mean	Non-IVNS users group mean	Mann-Whitney U	Z	Sig. level
n/a	Kubota et al (1995)	*Worry about the consequences of getting lost*	1.77	2.21	17631.5	-4.29	p<0.01
n/a	Kubota et al (1995)	*Use unfamiliar routes to avoid congested ones*	3.22	2.93	19293	-2.99	p<0.05
n/a	Self-added navigational item	*You are able to navigate regularly travelled routes entirely from memory*	5.46	5.22	20420.5	-2.22	P<0.05
n/a	Self-added navigational item	*Lose your way and have to ask someone for directions*	1.73	2.25	14704.5	-6.77	p<0.01
lapse	Reason et al (1990)	*Get into the wrong lane approaching a roundabout or junction*	2.22	2.54	18196	-3.91	P<0.01
lapse	Reason et al (1990)	*Misread the signs and exit from a roundabout on the wrong road*	1.93	2.3	17810	-4.18	p<0.01
lapse	Reason et al (1990)	*Realise that you have no clear recollection of the road along which you have been travelling*	2.55	2.77	20419.5	-2.05	p<0.05
error	Reason et al (1990	*Misjudge your crossing interval when turning right and narrowly miss a collision*	1.45	1.59	20736.5	-1.95	p<0.05
error	Reason et al (1990)	*Fail to notice someone stepping out from behind a bus or parked vehicle until it is nearly too late*	1.44	1.57	20612.5	-2.06	p<0.05
violation	Reason et al (1990)	*Drive with only half-an-eye on the road while looking at a map or navigation system display*	2.45	1.89	14987	-6.41	p<0.01

[9] High group mean value indicates more frequent engagement in behaviour
Low group mean value indicates less frequent engagement in behaviour

Table 3.3 showing significant correlations between IVNS user (N=157) / non-user (N=293) characteristics and section 2 items in table 1 above

Item	Mileage past 12 months		No. times used IVNS past month	No. Months IVNS has been installed	Driver age		No. years driving	
	IVNS user	Non-user	IVNS user	IVNS user	IVNS user	Non-user	IVNS user	Non-user
Worry about the consequences of being lost	-0.21 (df=156, p<0.01)	-0.21 (df=292, p<0.01)	-0.187 (df=156, p<0.01)	ns	ns	ns	ns	ns
Get into the wrong lane approaching a roundabout or junction	ns	ns	ns	-0.185 (df=156, p<0.05)	ns	ns	ns	ns
Your are able to navigate regularly travelled routes from memory	ns	0.236 (df=292, p<0.01)	ns	ns	ns	ns	ns	ns
Misread the signs and exit from a roundabout on wrong road	ns	-0.139 (df=292, p<0.05)	ns	-0.163 (df=156, p<0.05)	0.169 (df=156, p<0.05)	ns	ns	ns
Lose your way and have to ask someone for directions	ns	-0.122 (df=292, p<0.05)	-0.181 (df=156, p<0.05)	ns	0.232 (df=156, p<0.01)	0.218 (df=292, p<0.01)	0.182 (df=156, p<0.05)	0.236 (df=292, p<0.01)

Item	Mileage past 12 months		No. times used IVNS past month	No. Months IVNS has been installed	Driver age		No. years driving	
	IVNS user	Non-user	IVNS user	IVNS user	IVNS user	Non-user	IVNS user	Non-user
Use unfamiliar routes to avoid congested ones	0.198 (df=156, p<0.05)	0.214 (df=292, p<0.01)	0.355 (df=156, p<0.01)	ns	ns	ns	ns	ns
Miss give way signs and narrowly avoid colliding with traffic having the right of way	ns	-0.156 (df=292, p<0.01)	ns	ns	ns	ns	ns	ns
Intending to drive to dest A you drive to dest B perhaps because the latter is your more usual dest	ns	ns	-0.164 (df=156, p<0.05)	ns	ns	ns	ns	ns
Drive with only half-an-eye on the road while looking at a map or navigation system display	0.192 (df=156, p<0.05)	ns	ns	ns	ns	ns	ns	ns

ns = non-significant

3.5 Discussion

3.5.1 IMR validity and IVNS user characteristics

While 21-30 years was the most popular age band, respondents between 21 and 60 years were well represented in the sample. Junior drivers (those under 20) were under-represented relative to most of the other age bands but this largely reflects previous census findings. For example, in the UK the office of national statistics (ONS, 2001) national travel survey showed that just 36% of UK citizens aged 17-20 held a car driving license, compared to 73.5% of those aged 21-30 years, and 84% of those aged 41-50 years. Although seniors (those over 60 years) were also under-represented in the sample, Selwyn, Gorad, Furlong and Madden (2003) argue that older adults are less likely to adopt new technology. Additionally, Green (2001) has noted the difficulties in recruiting older drivers in traditional IVNS research.

Although drivers with managerial/professional and intermediate occupations were well represented in the sample, clearly those with routine and manual occupations were relatively under-represented. This may be an artifact of the IMR methodology as other online surveys have also reported fewer respondents from lower socio-economic cohorts (e.g. Kaye and Johnson, 1999). However, in their comparative analysis of traditional surveys and internet surveys, Gosling et al (2004) showed that socio-economic status of respondents is also a significant issue in traditional methodologies too due for example to their greater tendency to use university students who by definition are more educated than the general population (for example they showed that while 85% of traditional samples used students, only 27% of the US population were college graduates). Their survey of more than 116,000 internet respondents observed wide dispersion in socio-economic status. According to Lebo (2002, p.11):

"The Internet is far from being a bastion of highly educated, well-paid users. While the vast majority of high education/high income people use the Internet, those with less education and lower incomes log on in impressive numbers"

Figure 3.4 suggests a slightly greater tendency for IVNS users to hold managerial and professional positions. The ONS (2005) survey examined the availability of IVNS in UK cars/vans. It showed that 10% of respondents in managerial/professional occupations, 9% in intermediate occupations and 5% in routine/manual occupations reported having an IVNS. Svahn (2004) also reported similar findings. The present study was conducted three years later than Svahn (2004) and two years later than ONS (2005) and already suggests a smaller socio-economic difference between IVNS users and unequipped drivers. The statistics outlined in chapter 1 concerning the market penetration of IVNS suggest that from the perspective of ordinary drivers, these systems are beginning to shift from a luxury item to a convenience item. As their popularity continues to increase, their price continues to fall and the range of portable devices capable of providing electronic route guidance functions continues to expand, it is conceivable that in a few years this socio-economic divide will largely disappear.

The ONS (2005) survey showed that the highest IVNS using age bands were 26-44 years and 26-54 years. They were similar in the present study (21-30, 31-40 and 41-50). The highest using age band was 21-30 years (34% of respondents); while in Svahn (2004) it was 45-49 years. In addition to the later date of the present study, methodological differences between it and Svahn (2004) may somewhat explain this discrepancy. In Svahn (2004) respondents used the Volvo RTI IVNS only. As shown previously, this is an integrated IVNS which respondents would have acquired only after purchasing a new relatively expensive vehicle.

It was particularly surprising that just 2.5% of IVNS users in this sample were female. The ONS (2005) survey showed that an equal proportion of males and females used an IVNS, and although the majority of respondents in Svahn (2004) were male, just under a quarter were female. It is unlikely that this could be completely attributed to gender biases in the internet sample as more than a quarter of drivers surveyed were female. However, the present study only achieved a modest sample size and there may have been difficulties related to self-selection as it is likely that a higher proportion of respondents were IVNS and driving enthusiasts, since the sampling frame included internet forums, bulletin boards and mailing lists specifically related to driving and IVNS. Two recent online IVNS user surveys using a similar sampling frame have also encountered problems in attracting female respondents. In Varden (2008) over 90% of the sample was male, and in Li (2006) 97% was male. Although in recent years the gender disparity of internet users has significantly reduced (Ono and Zavondy, 2007), there is some evidence that there are still a higher proportion of males than females who use specialist websites (Joiner et al., 2005).

3.5.2 IVNS users vs non-users

3.5.2.1 DBQ items

Although some of the DBQ items obviously include a dimension of navigational efficiency, they are mainly concerned with driver safety, which is why many studies have linked DBQ responses to error and violation items in particular, with crash/accident involvement (Parker et al., 1995; Meadows, Stradling, & Lawson, 1998; Mesken et al., 2002; Sullman et al., 2002). With the exception of the violation item[10] *"drive with only half-an-eye on the road...",* the results suggest that in general IVNS users believe they

[10] All driving errors/violations reported in this chapter were classified following Reason et al. (1990).

commit fewer safety-related driving errors than non-users do. In terms of statistical significance, the strongest differences between IVNS users and non-users were for tactical-level lapses.

It was particularly surprising that there were no significant differences between IVNS users and non-users in terms of the frequency with which they reported planning their routes badly, so they meet traffic congestion they could have avoided. It was expected that that non-users would report doing this much more frequently than IVNS users due to the extra strategic (route guidance) and tactical (turn-by-turn guidance, and diversions in the case of congestion) assistance the systems provide.

Given the extensive body of research that has covered the distraction potential of IVNS, it was particularly interesting that IVNS users reported that they "*fail to notice pedestrians stepping out from behind buses or parked vehicles"* significantly less frequently than non users. Chapter 2 outlined how some drivers have been shown to tailor their glance behaviour to the prevailing driving workload. Perhaps IVNS users have strategies to minimize glances to the IVNS display when driving through urban streets where pedestrians and other hazards may appear suddenly. Piechulla et al (2003) suggested that most drivers are aware of the of the potential risks of glancing away from the roadway, so they keep any glances made to a minimum duration, typically about 1.6 seconds (Rockwell, 1988; Wikman et al., 1998).

Alternatively these questionnaire respondents may have been prone to overconfidence bias. They may have been aware of the potential risks of distracted driving (i.e. reduced ability to detect hazards such as pedestrians that suddenly appear from nowhere in the roadway) but overestimated their own ability to cope. Several studies have implicated overconfidence bias in risky behaviour and decision making in aviation (Goh & Wiegmann, 2001) and in the driving domain (Fox, 1989; Matsuura, Ishida & Ishimatsu, 2002; Kramer et al., 2003). However, there is no reason to believe that overconfidence bias would affect IVNS users only, particularly as non-users still have plenty of other opportunities to engage in other forms of distracted driving (e.g. map-reading, grooming, using in-car/stereo controls, talking to passengers etc.), similarly there is no particular reason to believe that IVNS non-users would not also be less vigilant in relation to the distraction item from the DBQ discussed above. Much more IVNS user and non-user information would need to be collected before discussing or speculating about this issue further. Nevertheless, in future studies in this thesis it would be useful to find out more about the perceived risk that drivers associate with various IVNS tasks, it may then be possible to examine the potential impact of overconfidence bias on results.

The main negative finding (in terms of safety) was that IVNS users reported that they "*drive with only half-an-eye on the road while looking at a map or navigation system display*" significantly more frequently than non-users. Given the significant difference between groups in the frequency with which they commit this violation, it would have been particularly useful when designing the present study to have added an extra item in section 2 to examine the extent to which IVNS users and non-users actually physically interacted with various in-vehicle equipment (including IVNS) while driving. Clearly, system interaction while driving needs to be comprehensively addressed before a complete understanding of behavioural adaptation to IVNS can be achieved.

3.5.2.2 Other section 2 items

There were no significant differences between groups regarding the relative frequency with which they engaged in positive driving behaviours (Ozkan and Lajunen, 2005), but there were significant differences in responses to items concerning other pertinent navigational behaviours and IVNS user attitudes, that have arisen in the literature. One item was included in a brief attempt to examine any associations between IVNS use and cognitive map development. To find out whether IVNS use could potentially hinder drivers' ability to learn unfamiliar routes suggested by their system over time, respondents were asked the frequency with which they are able to navigate regularly travelled routes entirely from memory. Contrary to other evidence (e.g. Burnett and Lee, 2005), in the present study IVNS users reported that they were able to do this significantly more frequently than non-users. However, this is just a single questionnaire item, and there were also problems with its wording and perceived context. Respondents might have associated "regularly travelled routes" with familiar journeys in familiar areas rather than unfamiliar routes that are regularly travelled over time.

Kubota et al (1995) claimed that Japanese IVNS users engaged in greater exploration of unfamiliar areas since acquiring an IVNS. The present study aimed to examine these claims using a between-groups design and a culturally distinct sampling frame comprising mainly European and North American drivers. It has also shown that IVNS users explore unfamiliar areas when faced with congestion significantly more frequently than non-users. These results would be particularly useful to IVNS manufacturers, marketers and designers as IVNS are often purported to provide users with extra security when travelling in unfamiliar areas and to encourage more efficient route planning. Several authors have reported that large-scale implementation of IVNS technology (as well as automated highway systems and ATIS) in the vast majority of road vehicles could also offer environmental benefits (Nissan motor co.

2008) due to the provision of efficient route planning and guidance information/support. These findings generally indicate that the IVNS users sampled do appear to have exploited some of the intended benefits of these systems. This is also reflected in the finding that IVNS users lose their way, to the extent that they need to ask for directions; significantly less frequently than non-users, although closer examination of IVNS user responses to this particular item did show that a small minority (12%) of IVNS users did still lose their way and have to ask directions occasionally or more frequently.

Further research should consider reasons why IVNS users still sometimes lost their way completely like this. Salient issues might include reliability and perceived reliability of IVNS-mediated route guidance information. It would also be particularly useful to find out about drivers' understanding of IVNS, particularly in relation to map updates, as some users may get lost because they use outdated or inaccurate maps. The present study used a between-groups design to examine differences in the self-reported driving behaviour of drivers who use and do not use IVNS, but it would also be interesting for future research employing culturally diverse sampling frames to use within-subjects designs to examine specific changes in the strategic and tactical level driving behaviour of individual drivers who use IVNS over time.

3.5.3 Driver and IVNS user characteristics

Table 3.3 shows significant correlations between responses to section 2 items and some general driver characteristics (i.e. annual mileage, age, driving experience) as well as IVNS user characteristics (e.g. no. of months using, frequency of use). Several studies have highlighted gender effects in DBQ responses, particularly concerning their association with violations, but the effects of gender were excluded from the present analysis due to the lack of female IVNS users who participated.

It has already been shown that IVNS users worry significantly less frequently than non-users about the consequences of getting lost. Table 3.3 shows there was also a significant negative correlation for both groups between annual mileage and the frequency with which they worried about this, suggesting that it's not merely the presence of IVNS that affected responses to this item but a possible interaction between IVNS usage and annual mileage. Similarly, annual mileage also appeared to be associated with the extent to which IVNS users reported using unfamiliar routes when faced with congestion.

As shown above, IVNS users committed the lapse error "*misread the signs and exit from a roundabout on the wrong road*" significantly less frequently than non-users. They also "*lose their way and have to* *ask for directions*" significantly less frequently than non-users. The data reported in table 3.3 suggests that the frequency with which non-users encounter these navigational problems is negatively associated with mileage. This may suggest that with driving experience they too can avoid some of these problems. However, merely using an IVNS was associated with reductions in the frequency with which respondents encountered these navigational problems, without the need to have also achieved a high annual mileage[11]. Similarly, table 3.3 suggests that infrequent IVNS users committed the lapse error "*get into the wrong lane approaching a roundabout or junction"* more often, and frequent IVNS users were likely to "*use unfamiliar routes to avoid congested ones"* more frequently.

Driver age was significantly positively associated with responses to the above DBQ lapse item for IVNS users only. There was also a strong positive correlation between driver age/number of years driving and the frequency with which they lose their way and have to ask for directions. Some authors (e.g. Salthouse, 1991) have proposed that age should be associated with engagement in lapses, but according to Westerman et al (2000) these links have yet to be proven. However, these correlations could be associated with age-related cognitive decline, particularly since significant correlations were found for IVNS users and non-users alike. Age-related cognitive decline has been shown to affect other aspects of driving and behaviour and performance on dual-tasks that require substantial motor components (Riby, Perfect and Stollery, 2004; Ho et al, 2001; McPhee et al, 2004) so it may also affect navigational efficiency. For IVNS users age related cognitive decline may also occur in terms of difficulties faced in understanding, perceiving and appropriately acting upon route guidance information presented to them. For example, Ho (2005) suggests that older adults may have difficulty interpreting information presented using new technologies.

The data reported in table 3.3 also suggests that the further IVNS users had driven in the past 12 months, the more frequently they reported driving "*with only half-an-eye on the road while looking a map or navigation system display".* It is unusual that correlations between IVNS-user age and responses to this item were non-significant, as previous research shows strong negative associations between driver age and the frequency with which they commit driving violations in general (Aberg and Rimmo, 1998; Blockey and Hartley, 1995; Parker et al., 1995; Simon and Corbett, 1996).

[11] Although the data suggests that the frequency with which IVNS users encountered these navigational problems was also associated with system usage frequency and length of time since system installation.

3.5.4 Limitations

A major limitation of the present study was that it investigated self-reported driving behaviour only. Although the DBQ is a widely used (and validated) driver behavioural assessment tool, self-report measures will always be highly subjective, and prone to several biases not encountered in other types of investigation. Two of the most important biases are acquiescence and social desirability. Acquiescence refers to a tendency to agree/disagree or to mostly indicate either positive or negative connotations in response to questionnaire items (Couch and Keniston, 1960). Acquiescence is usually controlled by balancing the number of positively and negatively framed items in a questionnaire. Although navigational items unrelated to safety and items from the positive driving behaviours scale were also included in the present study, there were significantly more DBQ items, and as mentioned previously, the DBQ features only aberrant (i.e. negative) driving behaviours.

Social desirability refers to a tendency to "fake good" in questionnaires. According to Rust and Golombok (1999) it is unsurprising that this form of response bias is so widespread, as many people from a young age are often encouraged to "make the most of ourselves" in job interviews etc. Using factor analysis and structural equation modeling, several studies have demonstrated that social desirability is not a single construct, instead it comprises two distinct constructs: impression management and self-deception (Paulhus, 1982; 1984; 1989; Paulhus and Reid, 1991; Barrick and Mount, 1996). Barrick and Mount (1996, p.262) defined impression management as "*a deliberate attempt to distort one`s responses in order to create a favourable impression with others*" and self deception as "*a dispositional tendency to think of oneself in a favourable light*". According to Paulhus (1984), social desirability effects are ubiquitous and will always affect questionnaire items. Social desirability bias has most often been discussed in the context of personality and integrity testing. However, in light of their popularity among the research community, some authors have also expressed concerns about the effects of social desirability in responses to questionnaires assessing self-reported driving behaviour (Nederhof, 1985; Paulhus, 1991). The DBQ primarily includes negatively framed items many of which describe socially unacceptable forms of driving behaviour. However, Lajunen and Summala (2003) found only negligible effects of social desirability on DBQ responses. They were primarily interested in the effect of anonymity on socially desirable DBQ responses. Their results suggest that anonymity should further minimize any difficulties with socially desirable responding.

An advantage of the methodology used in the present study was that responses were completely anonymous. To ensure social desirability bias was minimized all respondents were explicitly reminded of this during the instructions phase of the questionnaire. Interestingly, considering the DBQ item "*drive with only half-an-eye on the road while looking at a map or navigation system display,* it doesn't appear that respondents were particularly biased towards socially desirable responses. This violation item might have been expected to have elicited the greatest social desirability bias of all those discussed so far as it involves deliberate execution of an increasingly socially unacceptable driving behaviour (especially in light of recent legislative decisions in the UK addressing issues such as smoking and using a mobile phone while driving) that could result in accidents. Violations more than any other form of driving error have been directly linked to accident and crash involvement (Parker et al., 1995, Reason et al. 1990; West, Elander, and French, 1991).

Another important limitation of the present study was that only very basic information was collected about IVNS users and non-users, which makes it difficult to draw any firm conclusions from any comparisons between them. For example, it is unclear whether non-users often used paper maps while driving or some other traditional navigational aid, there may also be a whole range of other important uncontrollable characteristics that might have affected their driving behaviour such as presence of passengers, engagement with other in-vehicle systems or driving unrelated tasks, mode of transport etc.

3.5.5 IVNS usage, satisfaction and trust

Similarly although IVNS user information was collected, it lacked sufficient detail. This was primarily because a key design consideration was the length of the online survey. According to Reips (2002) the probability of dropout in online research is much greater than it is in research using traditional methods due to a range of factors (e.g. lack of experimenter-participant interaction).

Methodological factors have been proposed to reduce the risk of dropout; these include use of a financial incentive in exchange for participation (Musch and Reips, 2000), minimizing study length (Reips, 2002[12]; Van Selm and Jankowski, 2006; Sheehan and Mcmillan, 1999) and asking participants to enter their email address (Oneil and Penrod, 2001). Concerning study length, according to Sheehan and

[12] Reips (2002) has also developed the high entrance barrier technique to reduce drop out in which participants are told that their IP address is traceable, and are reminded that good science needs high quality data.

Macmillan (1999) a good rule of thumb is that the longer an online survey is, the less likely that people will respond. As the present study aimed to attract a high number of respondents, it was not feasible to offer a financial incentive for participation[13], so to minimize the risk of dropout and maximize questionnaire attractiveness to potential respondents, a range of item combinations were piloted to ensure that sufficient self-reported behavioural data could be collected within a timeframe no longer than 10 minutes. Unfortunately this meant that other IVNS user information could only be briefly addressed.

Most respondents in J.D. Power and associates (2003) reported using their systems once or twice a week (33%) or once or twice a month (30%) with only a minority (22%) reporting that they used them daily. Varden (2008) found that 37% of respondents used their IVNS every month or less, 43% used them every week and 20% used them daily. In general, IVNS users in the present study reported even more frequent use of their systems. 45% reported that they had used their systems more than 12 times in the past month, just over a quarter had used them daily or more, and 11% had used them more than twice a day.

However, this is a fairly vague indication of IVNS usage frequency, and this value alone doesn't provide much useful information as there is no explanation of how they actually used their systems. Perhaps those who used them more than twice daily merely had them switched on, while those who used them less frequently engaged in significantly more system interaction. Understanding system usage in much greater detail will be necessary to determine the extent of behavioural adaptation to IVNS. Some studies have examined usage in much greater detail. For example, chapter 2 outlined Svahn`s (2004) IVNS end-user survey in which he explored the extent to which drivers used their systems both passively and actively when driving through unfamiliar areas. Although a useful indicator of IVNS usage, this survey only achieved a small sample size and only sampled German integrated IVNS users, so detailed and more culturally diverse usage patterns of a wider range of IVNS users are still in need of further investigation.

In the present study more than half of the IVNS users reported feeling more confident at driving in unfamiliar areas since acquiring their systems, and over a quarter appeared to be exploiting the efficiency benefits originally conceived for these systems by making more unfamiliar journeys than they

[13] Participants were instead told they would receive a summary of the results in exchange for participation if they provided their email address. This was a short document detailing main differences between IVNS users and non-users and showing demographic graphs. More than 100 participants emailed back in appreciation of receiving this summary.

used to. These findings suggest that these systems can provide a useful extra “safety net” to some users. However, the highest proportion of respondents reported no change in the number of unfamiliar journeys they have made since acquiring an IVNS. This is consistent with previous research. For example Bonsall and Parry (1990) showed that most drivers tend to make familiar journeys to familiar destinations most of the time.

In J.D. Power (2003) nearly half of the respondents reported high levels of satisfaction with their IVNS. Although respondents in the present study weren’t asked to rate the extent of their satisfaction, a much greater proportion (88%) reported being satisfied, and less than 10% were dis-satisfied. To further elaborate on this issue and to aid future system design, it would be advisable for future research to identify IVNS features and functions that contribute to user satisfaction/dis-satisfaction, especially since behavioural adaptation is so closely linked to user satisfaction and acceptance.

Although the highest proportion of respondents trusted their IVNS to provide accurate route guidance instructions, it is interesting that a fifth of respondents did not or was unsure. Further research is urgently required to investigate reasons why some drivers do not trust their IVNS and the associations between trust and perceived accuracy/reliability of route guidance instructions received. Unfortunately there was insufficient space in the present study to find out about key behavioural adaptation issues concerning over-trust and over-reliance. These will need to be addressed in order to gain a complete understanding of driver behavioural adaptation to IVNS.

3.6 Summary and implications for behavioural adaptation

This chapter described an online driver survey which examined a range of IVNS user responses and compared IVNS users with non-users in terms of the frequency with which they reported engagement in aberrant driving behaviours from the DBQ, positive driving behaviours as well as other items related to navigational efficiency.

The online survey methodology achieved reasonable external validity in terms of age, gender, socio-economic status and driving experience, although due to problems associated with self-selection, the sample probably contained more IVNS and driving enthusiasts than are typically found in the general driving population. The responses of IVNS users and non-users were compared for several items. The results suggested that the socio-economic divide between IVNS users and non-users has become increasingly smaller, and that most IVNS users are aged between 21 and 40 years.

Although the section 2 results must be interpreted with caution due to several limitations such as insufficient detail of non-user information collected, the potential influence for response biases and characteristics of the internet sample, there were some important differences found between IVNS users and non-users that have implications in terms of behavioural adaptation to IVNS.

The first aim of the thesis was to identify different types of behavioural adaptation to IVNS affecting contemporary drivers, including those which have a positive, negative and neutral impact on driving safety and navigational efficiency. Importantly the majority of respondents reported that they were satisfied with their IVNS indicating that acceptance (a pre-requisite of behavioural adaptation – see chapter 2) among the present sample was probably quite high.

Concerning the DBQ items specifically related to driving safety there were few significant differences in the relative frequency with which IVNS users and non-users reported engagement in a range of driving errors. The most notable exception was that IVNS users reported driving while distracted significantly more frequently than non-users, but this was a violation item (i.e. a deliberate action rather than an accidental one). For all other safety-related DBQ items, where differences were found they suggested that IVNS users behaved more safely than non-users.

In terms of navigational efficiency, responses largely indicated positive strategic level behavioural adaptation to IVNS, as IVNS users reported making fewer tactical level navigational errors (i.e. misreading signs on roundabouts and junctions) than non-users. Also more than a quarter of IVNS-using respondents reported that since acquiring their system they have made more unfamiliar journeys than they used to. However, the majority of respondents reported no change in their exploration of unfamiliar areas since acquiring an IVNS, although over half did report feeling more confident when driving through unfamiliar areas, which suggests that some users are receiving some of the intended benefits of IVNS in terms of navigational efficiency.

Part of the second aim of the thesis was to identify individual difference variates in drivers' experiences of behavioural adaptation to IVNS. The present study highlighted several interesting significant associations between responses to section 2 items and a range of driver and IVNS user characteristics, suggesting that in addition to IVNS usage, a whole range of other factors are also associated with the frequency with which IVNS users engage in the various driving behaviours reported. However, this section did not address the second thesis aim because that was concerned with identifying individual differences variates in drivers' experiences of safety-negative behavioural adaptation to IVNS, and as shown with the exception of the violation item "*drive with only half an eye on the road while looking at a map or navigation system display*" the driver survey indicated only positive IVNS user behavioural adaptation in terms of driving safety. Nevertheless the significant correlations that were identified highlight the added importance of individual difference variables in understanding driver behavioural adaptation to IVNS.

A major limitation of the present study was that due to constraints on the length of the online survey, the small amount of IVNS usage information collected lacked sufficient detail. Further research is urgently required to understand precisely how drivers use their IVNS and some of the contexts in which usage occurs. Usage will also need to be defined more rigorously so it is clear whether participants are referring to following system instructions, physically interacting with their IVNS while driving or some other user behaviour. Although driver trust in IVNS was briefly examined, issues related to over-reliance and components of trust in IVNS were also neglected. These issues are important aspects of behavioural adaptation to IVNS that have received limited attention in the literature so far.

In conclusion, although the present study highlighted some important differences between drivers who use and do not use IVNS and associations between driver/IVNS user characteristics and experiences of behavioural adaptation to IVNS, a number of issues (particularly aspects of safety-negative behavioural adaptation to IVNS) still require much more detailed investigation before the first two aims of the thesis can be considered fully addressed. To accomplish this, a second online survey was designed to target a much higher number of IVNS users only, and to investigate issues that went unexamined, or that were examined in insufficient detail in the present study (see chapter 4).

Chapter 4 – Online IVNS user survey

4.1 Introduction

This chapter describes a second survey, this time aimed solely at IVNS users. Due to the high volume and wide range of IVNS users recruited for the previous survey, as well as the other advantages cited in the previous chapter, this survey was also conducted online. As shown in chapter 3, to reduce dropout and increase questionnaire attractiveness to potential respondents, the length of the survey was constrained. Although there were some methodological limitations, the driver survey made a contribution to the first aim of the thesis by highlighting significant differences in the self-reported driving behaviour of IVNS users and non-users. However, there remain significant gaps specifically concerning IVNS user-behaviour and negative behavioural adaptation to IVNS (in terms of safety).

The present study aimed to further address the first aim of the thesis by identifying behavioural adaptations which can degrade driving safety, but have received little previous research attention and were insufficiently addressed in the previous study. By recruiting a large and culturally diverse sample of IVNS users, it also aimed to partially address the second aim of the thesis by identifying stable user trends within the sample population as well as any salient individual difference variates in drivers' experiences of behavioural adaptation to IVNS. No established scales were employed here because this study was intended to examine issues that have received little or no previous research attention, but all items were piloted before being included in the final survey (see appendix E).

As the previous study collected only limited IVNS usage information, the present study was also designed to investigate IVNS usage in much greater detail than before, as it is such an important aspect of behavioural adaptation. In particular the IVNS user survey aimed to find out how, and to what extent, drivers use their IVNS in familiar and unfamiliar areas. These items were not meant to examine system interaction[1], but more the level of navigational assistance that drivers wish to receive when driving in familiar and unfamiliar areas. Following Svahn (2004) respondents were asked to rate the relative frequency[2] with which they engage in passive and active system usage when driving in familiar and unfamiliar areas[3]. Svahn (2004, p.11) defined active system usage as "*a destination is configured. The*

[1] System interaction is addressed elsewhere in the questionnaire
[2] These items used the same ordinal scale as section 2 items in the previous study
[3] Svahn (2004) also distinguished basic system usage where the system is merely turned on, but this category was not included in the present study

navigation service will then include routing, turn by turn guidance and traffic information notification[4]*";* and passive system usage as "*the system is used, without an active route, and consequently no destination....this kind of system usage will mainly provide situation awareness and orientation".*

4.2 Main objectives

The main objectives of this study were to:

1. Address the first two aims of the thesis by exploring behavioural adaptation issues that were insufficiently addressed in the previous driver survey, particularly those which have the potential to degrade driving safety[5] such as over-reliance and manual system interaction while driving.
2. Further address the second aim of the thesis by identifying any individual difference variates in the extent to which drivers show behavioural adaptation to IVNS.

4.3 Method

4.3.1 Respondents

Table 4.1 below illustrates the main respondent characteristics. 872 respondents (844 male, 28 female, mean age = 45 years, range =17-79 years[6]) provided data for the survey. All respondents were self-selecting, having responded to an online advertisement placed at various locations across the internet (see section 4.3.4).

[4] In the present study this definition was extended to say "*The navigation service will then include routing, turn by turn guidance and traffic information* ***(if available)****..."* to include those IVNS users whose system does not have this feature.

[5] Previous research shows than manual and vocal destination entry while driving can degrade driving safety and performance (see chapter 2), and although there is little research concerning overreliance on IVNS, it is intuitive to assume that incorrect route guidance advice that conflicts with official traffic signs/regulations (e.g. one way streets) has the potential to degrade driving safety.

[6] Mean age and age range based on 710 respondents as some didn't enter any data for this item (see 4.4 below).

Table 4.1: showing main characteristics of respondents in the IVNS user survey (N=872)

Item	Categories	No. of participants/descriptive statistics	Percentage of participants
Gender (N=872)	Male	844	96.8
	Female	28	3.2
Country of residence[7] (N=710)	UK	428	60.3
	Rest of Europe	76	10.7
	USA/Canada	182	25.6
	Australia/New Zealand	23	3.2
	Other (inc. South Africa, Singapore, Turkey & Israel)	6	0.8
Age (N=710)	Mean	44.7 years	n/a
	Median	45 years	n/a
	SD	12.7 years	n/a
	Range	17-79 years	n/a
No. years with full driving license (N=710)	Mean	26	n/a
	Median	25	n/a
	SD	13.2	n/a
	Range	0.5-63 years	n/a
Approx. mileage past 12 months (N=710)	Mean	18	n/a
	Median	15	n/a
	Mode	12	n/a
	SD	15.9	n/a
	Range	0-200 thousand miles	n/a
Employment status (N=872)	Self-employed	140	16.1
	Employed (manager)	207	23.7
	Employed	370	42.4
	Retired	120	13.8
	Student	16	1.8
	Other	19	2.2
Self-rated computing skills (N=872)	Expert	307	35.2
	Considerable skills	378	43.3
	Moderate skills	158	18.1
	Some skills	22	2.5
	Insignificant skills	6	0.7
	No skills	1	0.1

[7] Please note countries of residence sum to greater than 100% because some participants reported living in two countries

Item	Categories	No. of participants/descriptive statistics	Percentage of participants
IVNS type (N=872)	Integrated	123	14.1
	Separate	453	51.9
	PDA	260	29.8
	Mobile phone	16	1.8
	Handmade	11	1.3
	Other (inc. laptop)	9	1

4.3.2 Design

An online survey was developed based on piloting to ensure that all questions/options had good clarity with a clear structure, and that it could be completed in about 5 minutes to increase its attractiveness to potential respondents and to minimize respondent dropout. The questionnaire was defined by 41 items (see appendix F for response format of each item). Age, number of years holding full driving license, annual mileage, mileage past five years, months using IVNS and months using current IVNS map were ratio level variables. Computing skill, map update frequency, perceptions of map update cost, usage in familiar and unfamiliar areas, correspondence between routing advice and individual preference, frequency of system interaction while driving and perceived distraction of IVNS were ordinal level variables. Gender, employment status, IVNS type, IVNS experience, map update purchases, *reasons for map update/non-update*, future map updates, map update importance, preferred source of route guidance information, route guidance reliability/efficiency, *inaccurate/dangerous/illegal route guidance instructions received and followed* and destination entry features/other IVNS functions that should be allowed while driving, were nominal variables. Nationality, system features particularly liked/disliked, and the "other, please specify" responses for variables in italics above required text entry.

4.3.3 Materials

Respondents used their own computers to complete the questionnaire from remote locations. The questionnaire was designed using Microsoft Excel and html authoring software.

4.3.4 Procedure

Respondents responded to online advertisements placed on IVNS and driving related internet forums (see appendix G), bulletin boards and mailing lists, as well as a range of other general interest internet forums, and those specializing in other topics unrelated to IVNS and driving. They were directed to follow a link to the questionnaire, provided that they had held a full driving license for at least 6 months. They were asked to read the instructions (see appendix D), in which they were told to answer the questions truthfully, and were reminded that their responses were completely anonymous. They were told that the questionnaire would only take five to ten minutes to complete, and that a summary of the results would be made available to them in due course, in return for their participation. They were also told to contact the researcher by email, if they had any questions or were unclear about the nature of the research. Once they had completed the questionnaire, respondents were thanked for their participation and directed to submit the form, which saved the results in a text format ready for analysis.

4.4 Results

A summary table showing descriptive statistics of results for each questionnaire item can be found in appendix F. Some of the most pertinent findings are reported in more detail below. In the previous survey some key driver demographic information such as age and driving experience was collected using ordinal level variables. In the present study this data was collected using ratio level variables so that more powerful statistical analyses could be used. Unfortunately however, 162 respondents failed to provide data for these items. It is unclear whether this was due to a technical error with the web-form itself or because respondents simply did not wish to enter this information. To avoid problems associated with missing data these respondents were excluded from analyses involving these variables, which include age, mileage, driving experience, IVNS experience and number of years with a full driving license. All respondents were included in analyses that didn't concern these variables. To avoid confusion, the number of respondents included is explicitly stated in each analysis in this section.

4.4.1 IVNS user demographics

Figure 4.1 shows that all age bands were well represented in the present study. In comparison with the previous study, it attracted much higher proportions of drivers over the age of 50 and under 20. The mean age of respondents was 44.7 years (SD=12.7 years). Clearly in the present study too, there were a much higher proportion of male respondents, although females were represented in every age band (except 35-39 years).

Most respondents were from the UK (60%), USA/Canada (26%) or the rest of Europe (11%). The majority (96%) were employed or retired, and most considered themselves as expert computer users (35%) or possessing considerable skills (43%).

Respondents had held their driving licenses for an average of 26 years (SD=13.2 years), and had driven an average of about 18,000 miles (SD=16,000 miles) in the previous year. Figure 4.2 shows the distribution of respondents' annual mileage. Following Rothengatter et al. (1993), driving experience was also calculated based on mileage over the past 12 months and 5 years, and the number of years respondents have held a full driving license. This classification scheme is illustrated in appendix AK. Figure 4.3 shows that despite the wide range in annual mileage, most respondents were experienced (35%) or very experienced (55%) drivers.

Respondents had been using their current system for an average of 12 months (median value reported) and 42% had used other systems previously. Most respondents used nomadic (52%), PDA-based (30%) or integrated (14%) systems.

Figure 4.1: graph showing age distribution and gender of survey respondents (N=710)

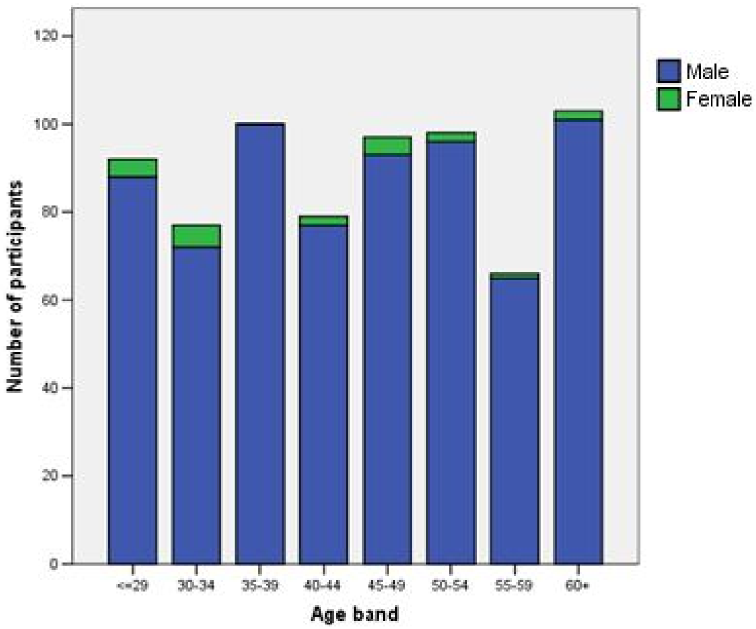


Figure 4.2: graph showing distribution of survey respondents' annual mileage (N=710)

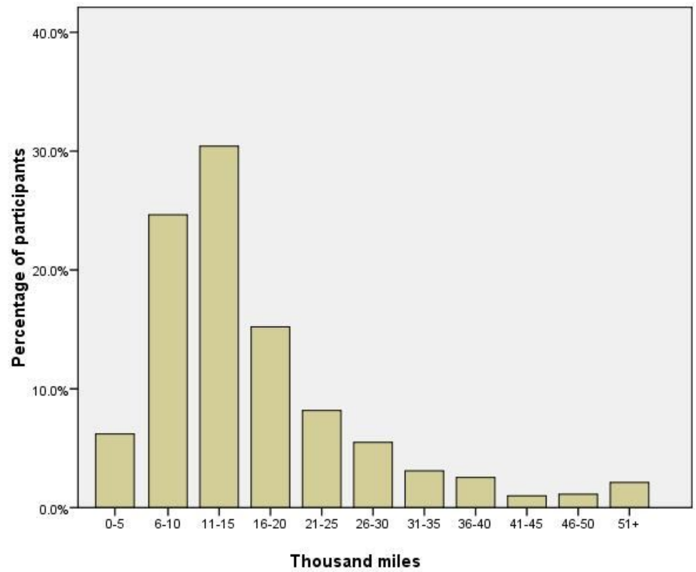
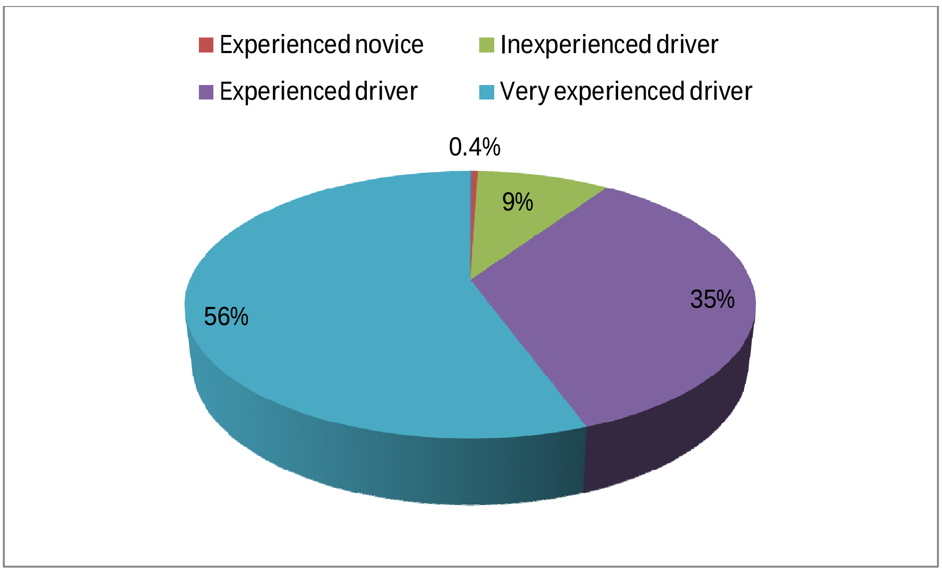


Figure 4.3: pie chart showing survey respondents' levels of driving experience (N=710), based on Rothengatter et al`s (1993) classification scheme



4.4.2 Online survey validity

Although female IVNS users were under-represented in the sample, for purposes of comparison, figure 4.4 compares the age distribution of the present sample with the age distribution of UK car license holders, it illustrates how the survey sample followed the same bell-shaped trend of UK car license holders, suggesting that in terms of age the sample was fairly representative of UK drivers. Table 4.2 compares the ages of IVNS users in the present sample with those of IVNS users in the office for national statistics (Department for Transport, 2005) driver survey. It shows that in both studies the majority of IVNS users were aged between 26 and 44 years, and that a much lower proportion of respondents aged 16-25[8] and 55-74 years were IVNS users, but the DfT (2005) survey did attract a much higher proportion of elderly respondents.

Table 4.3 shows a comparison between key demographics of the present sample and those of another IVNS user survey (Svahn, 2004) conducted using traditional methods (i.e. postal survey). Although the demographics are dis-similar in terms of gender and socio-economic status, they follow broadly similar patterns in terms of age, mileage and computing skill.

[8] The DfT (2005) survey used this age band. The youngest respondent in the present study was aged 17 years.

Figure 4.4: graph showing age distribution of UK licensed drivers[9] and of IVNS user survey respondents (N=710)

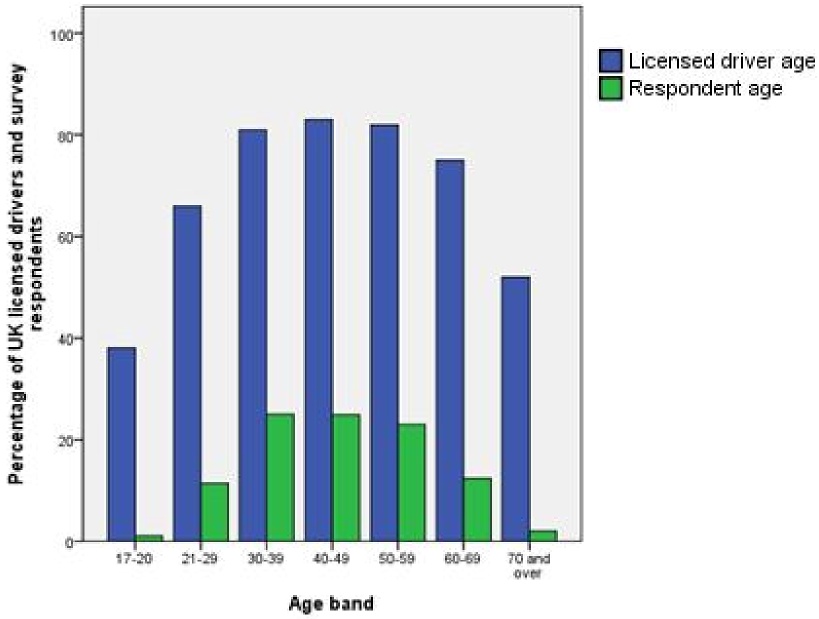


Table 4.2 comparing age distribution of respondents in the present study (N=710) and of IVNS using drivers in the DfT (2005) driver survey

	16-25	26-44	45-54	55-64	65-74	75+
Forbes (2006)	7%	41.9%	27.4%	18.3%	4.6%	0.8%
DfT (2005)[10]	5%	9%	9%	6%	3%	8%

9 UK licensed driver ages derived from UK department for transport, national travel survey 2007

10 Please note DfT (2005) data does not add up to 100% because this survey targeted IVNS using and non-using drivers only about a range of issues. Each percentage in table 4.2 denotes the percentage of drivers from each age band who used IVNS, for purposes of comparison with the present study.

Table 4.3 : comparing key demographics of respondents in the present study (N=872) and in Svahn (2004, N=58)

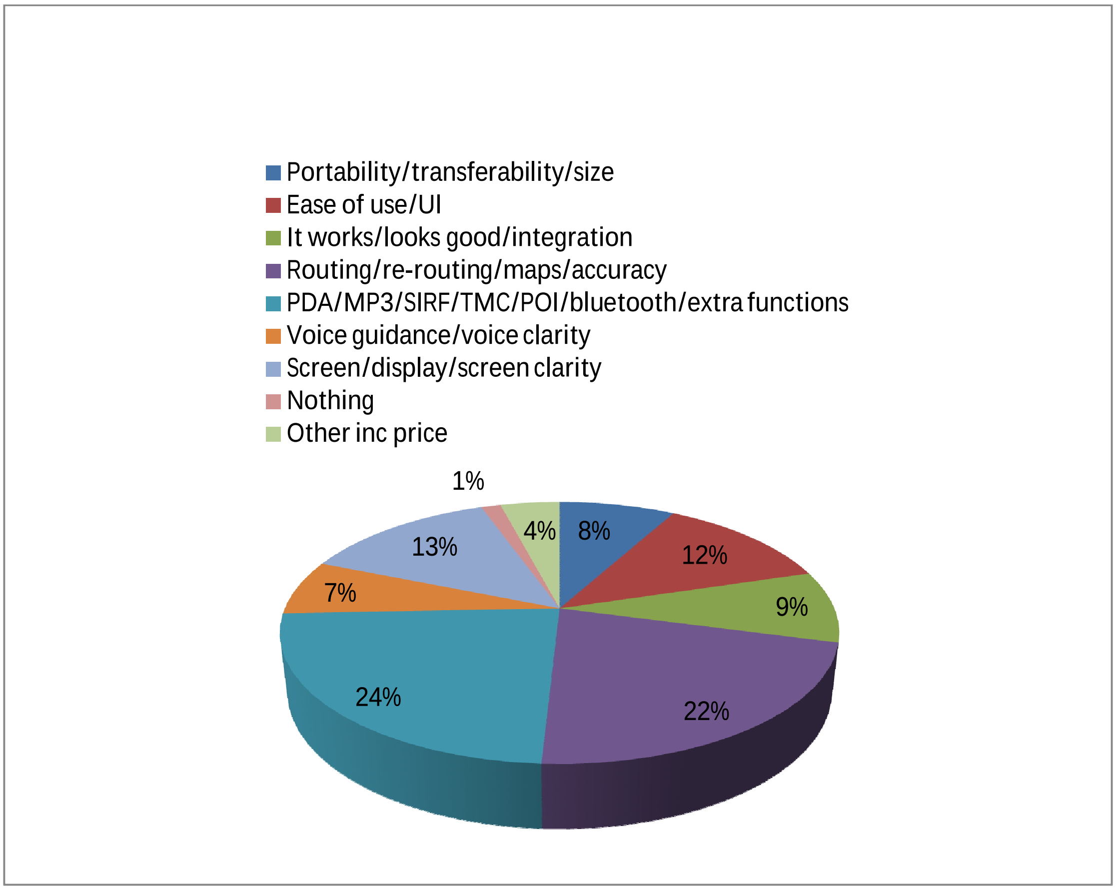
Variable	Study	Mean	SD	Percentage					
Age	Svahn	45.3	8.8						
	Forbes	44.7	12.7						
Annual mileage (km)	Svahn	34,300	10,300						
	Forbes	29,000	25,500						
Gender				Male	Female				
	Svahn			77.59%	22.41%				
	Forbes			96.8%	3.2%				
Computer skills				Expert	Considerable skills	Moderate skills	Some skills	Insignificant skills	None
	Svahn			5.17%	58.62%	31.03%	5.17%	0	0
	Forbes			35.2%	43.3%	18.1%	2.5%	0.7%	0.1%
Employment				Self employed	Employed (manager)	Employed	Retired	Other	
	Svahn			0	37.93%	62.07%	0	0	
	Forbes			16.1%	23.7%	42.4%	13.8%	4%	

4.4.3 Acceptance and user preferences

To identify some of the components of IVNS user satisfaction and dis-satisfaction, respondents' open ended responses concerning features they particularly liked and disliked about their IVNS were grouped together into 9 distinct categories. These are shown in figures 4.4 and 4.5 below[11].

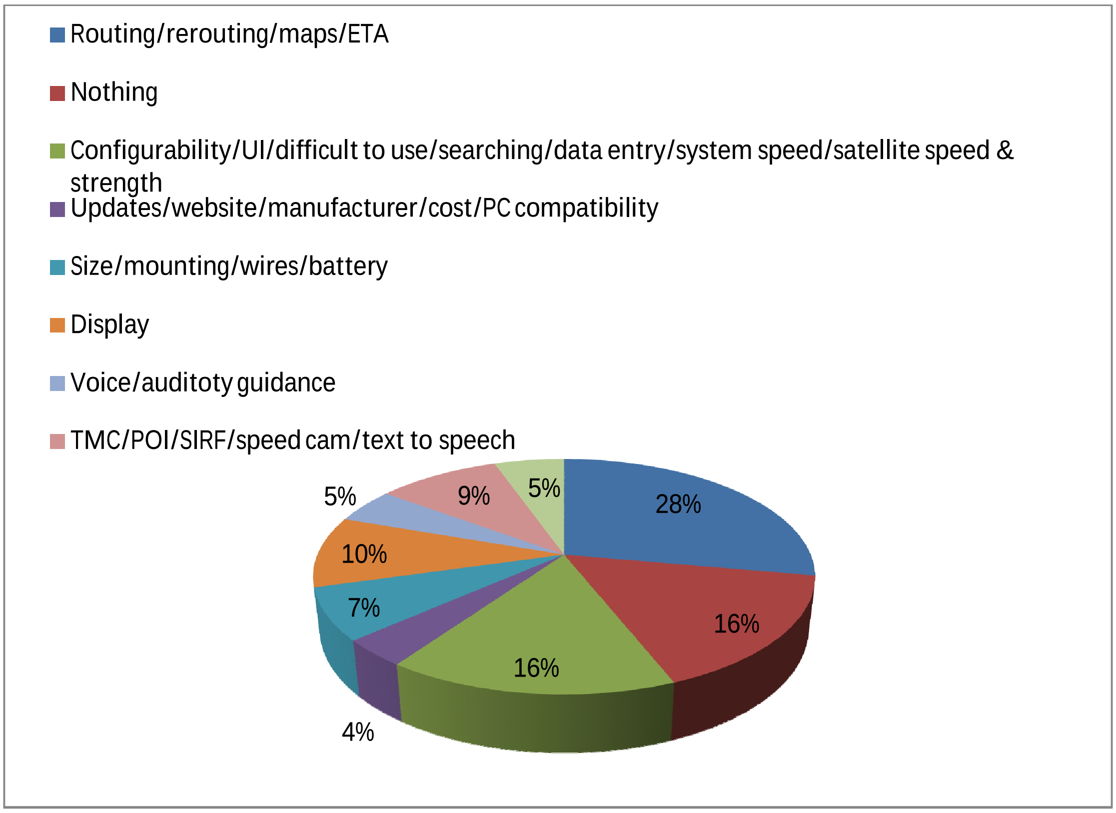
Nearly three quarters of respondents rated voice and display as equally important as sources of route guidance information. However, over a fifth of respondents rated display information of greatest importance compared to just under 10% who rated voice guidance as of greatest importance.

Figure 4.5: pie chart showing the components of IVNS user satisfaction (N=710)



[11] Please note components of user-satisfaction and dis-satisfaction add up to more than 100% because these were open ended items in which respondents could list as many features as they wished.

Figure 4.6: pie chart showing the components of IVNS user dis-satisfaction (N=710)



4.4.4 IVNS usage

Figures 4.6 and 4.7 below show the extent to which respondents reported engaging in passive and active system usage while travelling in familiar and unfamiliar areas. Further analyses investigated associations between IVNS experience and passive and active system usage. These terms were defined as follows:

Novice: IVNS user who has been using their system for less than 6 months, and for whom the featured system is their first

Expert: IVNS user who has been using their system for more than 6 months, or has used another IVNS previously

Experts engaged in passive system usage significantly more frequently than novices when driving in both familiar (Mann-Whitney U(708) = 29095, Z=-2.25, $p<0.05$) and unfamiliar areas (Mann-Whitney U(708) = 29526, Z=-2.02, $p<0.05$).

The majority of respondents (67%) indicated that acquiring an IVNS has not affected the extent to which they venture into unfamiliar areas, but a similar proportion (27%) have ventured into unfamiliar areas more frequently or much more frequently than they did before they started using an IVNS.

About half the sample (50.2%) also thought that using an IVNS had no effect on the amount of time it takes them to learn new routes, but while just under a fifth of respondents (18.3%) thought that this amount of time had increased or slightly increased, almost a third (31%) thought it had decreased or slightly decreased.

Relative to traditional navigational methods such as paper maps or memorised route instructions, most respondents (49.9%) thought that since acquiring an IVNS, their attention to surrounding traffic and road signs had increased or slightly increased, while only a minority thought it had decreased or slightly decreased (17.7%) and almost a third thought it was about the same (32.3%).

Figure 4.7 : showing the frequency of respondents' self-reported system usage when driving in familiar areas (N=872)

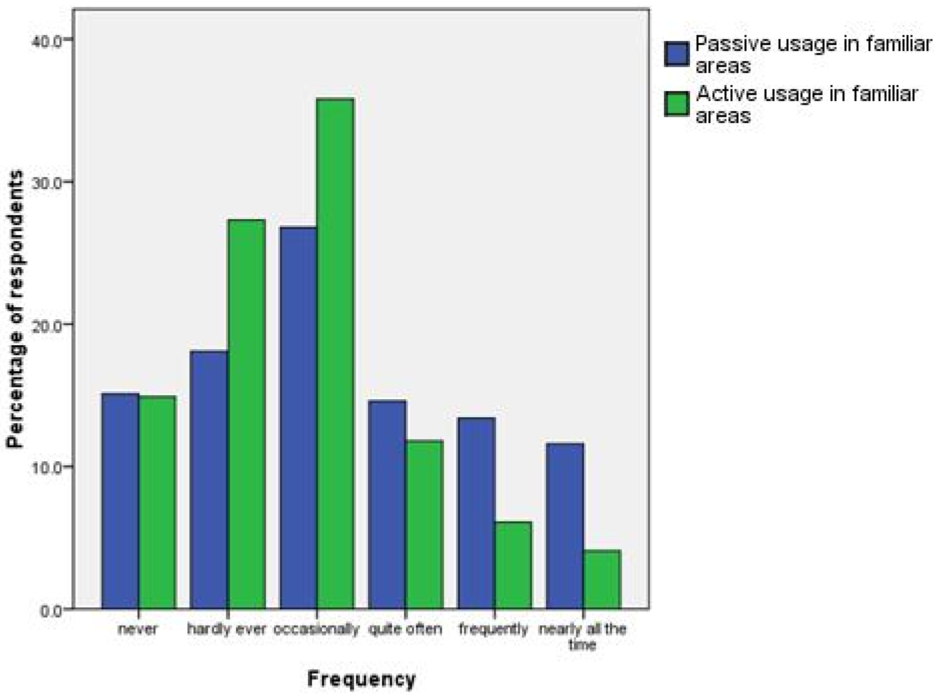
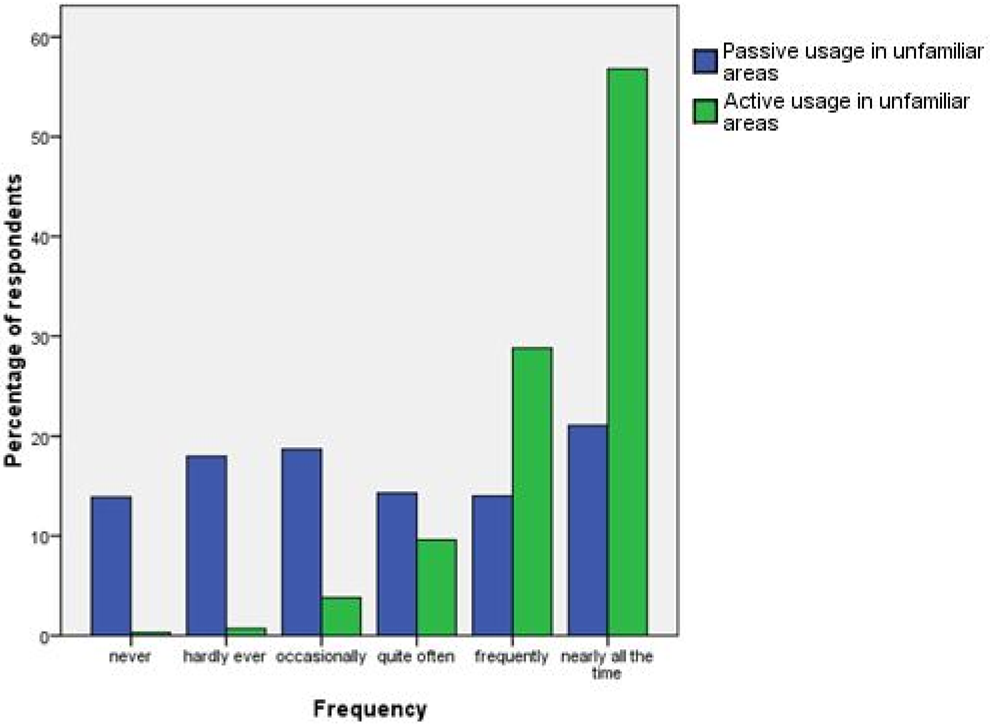


Figure 4.8: showing the frequency of respondents' self-reported system usage while driving in unfamiliar areas (N=872)

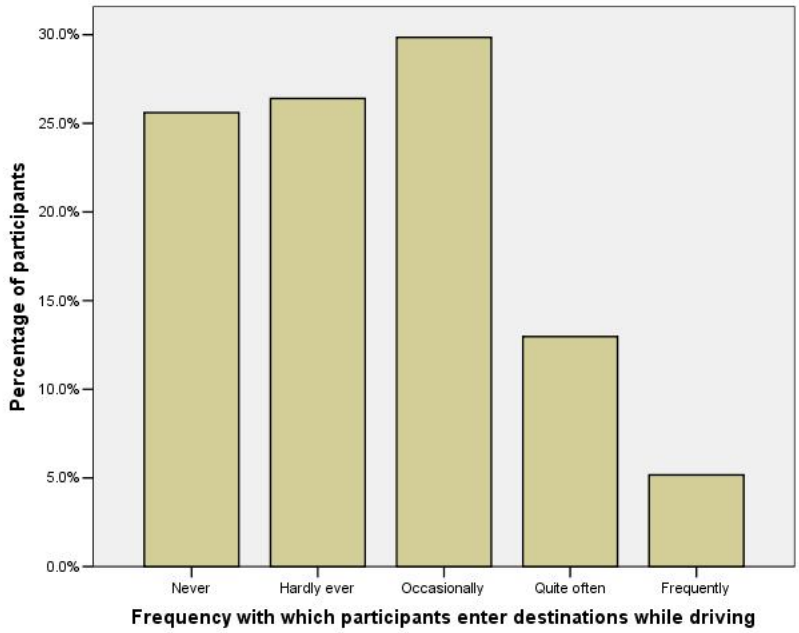


4.4.5 System interaction while driving

Figure 4.9 shows that only a quarter of respondents reported that they never enter destinations while driving. Nearly a fifth admitted to doing so a lot of the time, and over half of them reported that they do so at least occasionally.

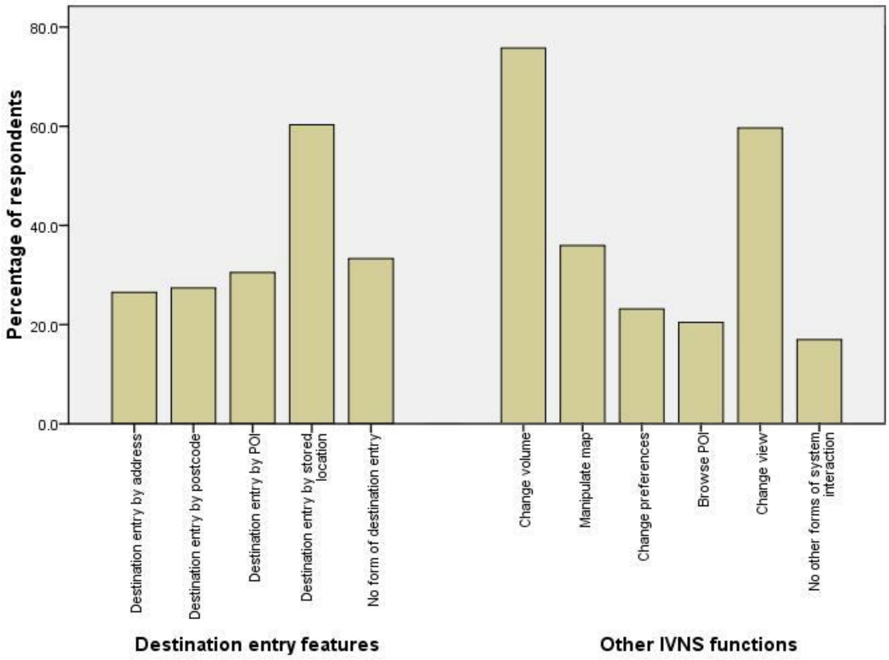
Interestingly, in light of these findings, figure 4.10 shows that a third thought that no form of destination entry **should** be allowed while driving. Of those respondents who think that some forms of destination entry should be allowed while driving, over 40% consider destination entry by previously stored location to be acceptable. Nearly a quarter of these respondents think that destination entry by POI is acceptable, and although far fewer consider destination entry by postcode (18%) and address (18%) to be acceptable, they still represent a significant proportion of respondents. Figure 4.10 also shows other IVNS functions that respondents thought should be allowed while driving. Clearly a much lower proportion of drivers consider any form of system interaction while driving to be unacceptable (16%), suggesting that some respondents were aware how much more intensive destination entry tasks are compared to other IVNS functions. It is clear from Figure 4.10 that the majority of respondents thought that access to quick and easily executed functions like changing volume and changing view should be allowed while driving, while allowing access to other attention-demanding functions (e.g. change preferences, browse POI`s) was much less popular[12].

Figure 4.9: Showing the frequency with which respondents reported entering destinations while driving (N=872)



[12] Please note the percentages discussed in this paragraph and illustrated in figure 4.9, add up to greater than 100% because respondents were allowed to pick multiple responses for these items.

Figure 4.10: showing destination entry features and other IVNS functions that respondents thought *should* be allowed while driving (N=872)



There were also some significant individual differences concerning the extent to which respondents entered destinations while driving and some of their views on this and other forms of system interaction while driving.

Compared to those respondents who had never entered destinations while driving, those who had:

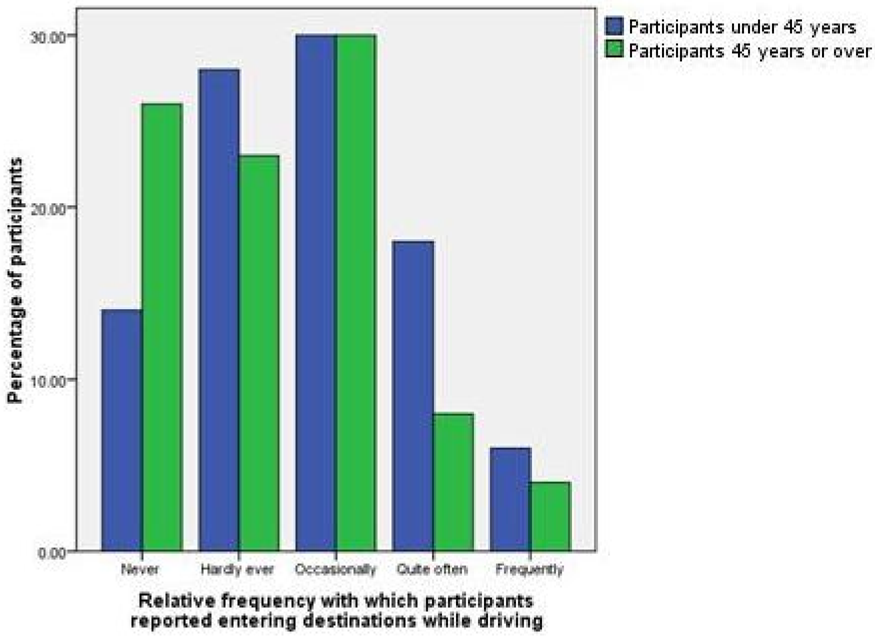
1. Were significantly younger ($t(708)=6.326$, $p<0.01$).
2. Were significantly more experienced drivers (Mann-Whitney $U(708)=40946$, $Z=-3.39$, $p<0.01$).
3. Considered themselves significantly more skilled at using computers (Mann-Whitney $U(870)=59081.5$, $Z=-4.36$, $p<0.01$).

There were also significant correlations between age ($r(708)=-0.237$, $p<0.01$), driving experience (spearmans-rho=0.159, df=708, $p<0.01$), and computing skills (spearmans-rho=-0.104, df=870, $p<0.01$)[13] and the frequency with which respondents reported entering

[13] Please note this correlation was negative because a reverse response format was used for computing skill which ranged from expert to no skills. See appendix F

destinations while driving. The association between age and the frequency with which respondents reported entering destinations while driving is also illustrated in figure 4.11.

<u>Figure 4.11: graph showing the relative frequency with which respondents under and over the age of 45 reported entering destinations while driving (N=710)</u>



Compared to those respondents, who thought that no destination entry features should be allowed while driving, those who thought that that some type of destination entry should be allowed:

1. Were significantly younger ($t(708)=-3.494$, $p<0.01$) and had held their driving licenses for significantly less time ($t(708)=-2.301$, $p<0.05$).
2. Were significantly more experienced drivers (Mann-Whitney $U(708)=48963$, $Z=-3.05$, $p<0.01$).
3. Used their systems actively in familiar areas significantly more frequently (Mann-Whitney $U(870)=70558.5$, $Z=-4.1$, $p<0.01$).
4. Considered themselves to be significantly more skilled at using computers (Mann-Whitney $U(870)=67163.5$, $Z=-5.274$, $p<0.01$).

Similarly, compared to those respondents who thought no other forms of system interaction should be allowed while driving, those who thought some should be allowed:

1. Were significantly younger ($t(708)=-4.694$, $p<0.01$) and had held their driving licenses for significantly less time ($t(708)=3.411$, $p<0.01$).

2. Were significantly more experienced drivers (Mann-Whitney U(708)=33573.5, Z=-1.971, p<0.05).
3. Used their systems passively in familiar areas significantly more frequently (Mann-Whitney U(870)=43383, Z=-3.526, p<0.01)
4. Considered themselves to be significantly more skilled at using computers (Mann-Whitney U(870)=38024.5, Z=-5.785, p<0.01)

Those respondents who thought drivers should be allowed to enter destinations by any method while driving had also driven significantly further in the past 12 months (t(472)=-2.127, p<0.05) and the past 5 years (t(472)=2.301, p<0.05) than those who thought drivers should only be allowed to enter destinations by stored location or POI while driving.

4.4.6 System reliability

4.4.6.1 Inaccurate route guidance received and followed

Only 15% of respondents thought that routing instructions generated by their navigation systems were always completely reliable. 82% reported that they had received route guidance instructions that were inefficient or wrong and 42% reported that they have received inaccurate instructions that were dangerous or illegal. Nearly a quarter of these respondents (23%) admitted to having followed dangerous/illegal instructions on at least one occasion. Dangerous or illegal route guidance instructions that respondents have both received and followed are illustrated generally in figure 4.12 and more specifically in table 4.4. Bold text in table 4.4 represents inaccurate instructions respondents have followed. Specific examples noted by respondents of inaccurate instructions they have both received and followed (also shown in bold) are highlighted in table 4.4.

Those who had followed them were significantly older (t(101.8)=2.35, p<0.05) and held their driving licenses for significantly longer (t(83.5)=2.784, p<0.01) than those who had not. 73% of them were over the age of forty. Following dangerous or illegal route guidance instructions was not significantly associated with navigation system type, navigation system experience, driving experience, computing skill or any other demographic variables.

More than a quarter of respondents (28.7%) have also received information from their IVNS, which has led to them travelling to an incorrect final destination, and this has happened to just over 40% of these respondents on more than one occasion. In the final questionnaire item, respondents who had experienced this either once or several times were asked to think about the last time it happened and attribute blame. The majority of respondents reported that the system was at fault (57.5%), about a fifth blamed themselves (18.9%) and about a quarter (23.6%) blamed both themselves and the system.

Figure 4.12 Tree diagram highlighting contexts in which drivers have followed inaccurate route guidance instructions (N=872)

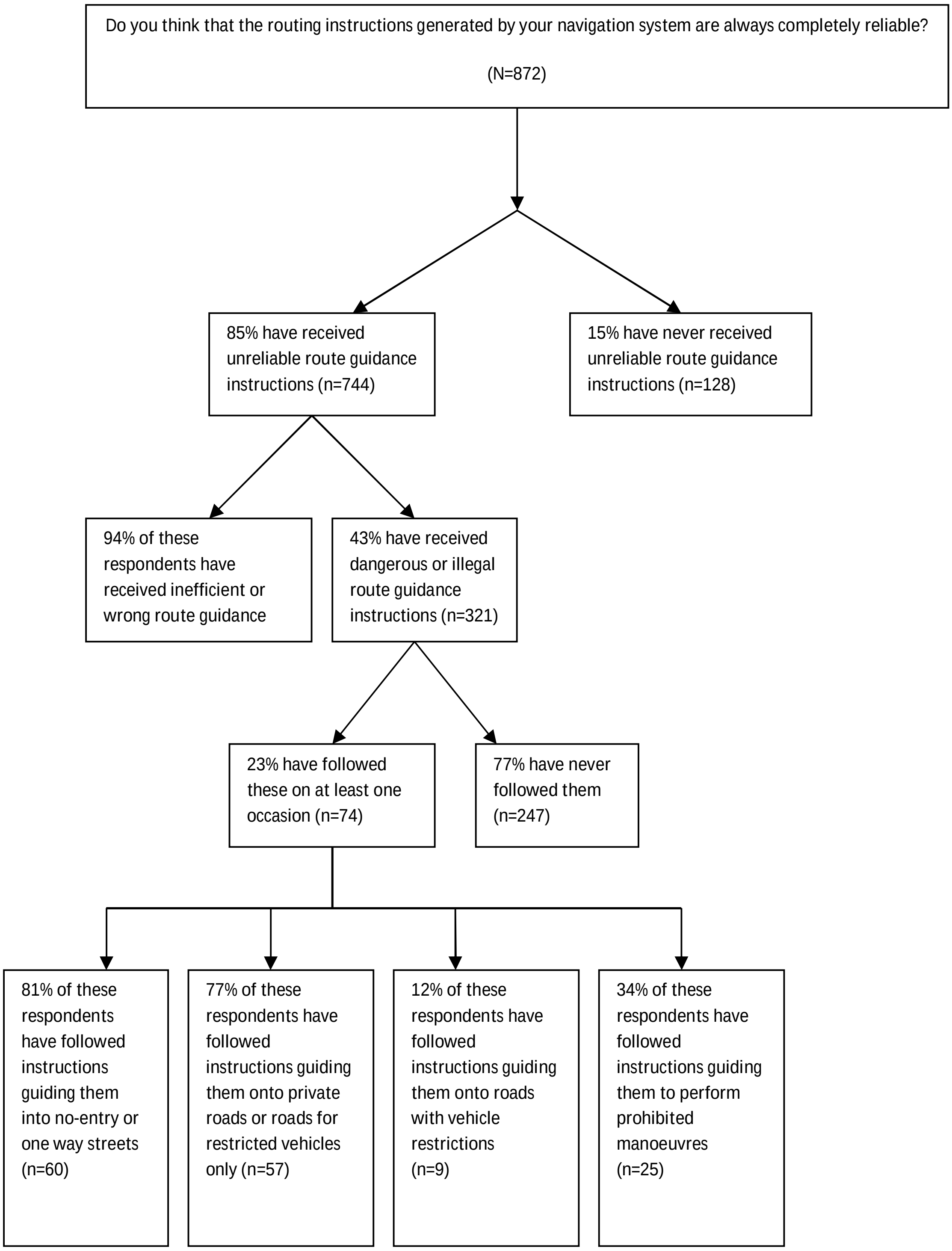


Table 4.4: showing specific contexts and participants' examples of occasions where they have received and followed inaccurate route guidance instructions (N=778)

Routing problem	Specific routing problems	Specific examples based on participants' comments
No entry/one way street *58% ** 22%	**Routed into streets signposted as no entry or no permitted turn (42%)**	Indicated turns where these are not permitted (the map is out of date!)
		tells me in my own neighbourhood to drive into streets that do not exist
		suggested taking a slip road on a motorway that has been blocked off for nearly a year
		drive where there are no roads
		it once told me to turn right while I was on a bridge
		Sent me down a street which had been bollarded off by the council.
		Turn where there is no road to turn into
	Routed into one way streets specifically (39%)	**turn at non-existent street drive to a dead-end**
Private road/ road for restricted vehicles 51% ** 19%	**Routed into Pedestrianised zones and other city areas cars are not permitted (20%)**	**Turn into a newly designated car free bus station**
		directed me into a cul de sac only forward exit was for pedestrians
		Drive on a non-road (it was an alley)
		the system frequently directs me along roads prohibited for use except for access
	Routed onto a Private road or road for emergency vehicles only (8%)	Instructed to drive on an access restricted business roadway network which only employees are permitted on
		use police/highways agency slip roads to access the M11!!
		Routed onto a private road
		enter/leave motorway via works access
		Once using a motorway junction that was for service vehicles only
	Routed on bus / tram / train lines (17%)	drive onto railroad tracks
		go onto train tracks
	Routed on cycle tracks / farm tracks / fjords / rivers / woodland (32%)	**Drive down unmettalled roads**
		drive down farm tracks
		through farmyards and across field tracks
		Directed me across a farmers field that had an exit on a different road that I would travel down.
		tried to send me down farm tracks
		Routed down a road that had been reclaimed and allowed to grow wild which was also blocked by a barrier
		Routed down public footpaths across a field no vehicle access possible (style through a hedge)
		the system frequently directs me along footpaths
		Bicycle path
		Frequently routes along farm tracks
Vehicle restrictions 3% ** 1%	**Width restrictions (7%)**	**Routed down extremely narrow roads**
		Frequently routes along unusable non-vehicular narrow tracks / lanes
		Width and weight restriction
	Weight restrictions (1%)	through weight limits
	Height restrictions (1%)	under low bridges
	Other vehicle unsuitability issues (3%)	Drive down steep narrow road with 180 degree bends not suitable for large vehicles
		Routed me down streets that were not acceptable for the vehicle we were in.
		Directed onto HOV section of beltway in Washington DC / Illegal but not dangerous
		we took a road in the motor home that we should not have taken
Other prohibited manoeuvres 44% ** 17%	**Instructed to perform prohibited manoeuvres such as U-turn, Lane issues, unauthorised reverse (34%)**	**in Australia you can't usually do a U-turn at traffic lights**
		180 degree turn
		U-turn on dual carriageway
		Trying to drive across a dual carriage way where the crossing is only for cars turning from the opposite side
		Reverse direction at a Motorway junction that did not allow reverse directions (in France)
Other 11% ** 4%	System efficiency issues	system occasionally does not give sufficient warning to move into freeway exit lane before manoeuvre
		directed to the wrong address in opposite direction
		Sometimes it will specify a roundabout when in fact its a junction
		route causes a drive through town centres rather than take the by-pass or ring road
		Does not inform me where route is interrupted by natural or man made obstacles or detours or where street name changes enroute

** Percentage of participants who have received dangerous/illegal instructions*
***Percentage of all participants*
Bold text represents dangerous/illegal route guidance instructions that participants have followed.
Bold percentage represents percentage of those who have followed dangerous/illegal route guidance instructions

4.4.6.2 Maps

Most respondents who have received inaccurate route guidance instructions had never updated the map on their navigation system (58%), although a significant proportion had (42%). Figures 4.11 & 4.12 highlight some of the reasons why respondents had or had not updated their maps. Those who had purchased a map update were significantly older (mean = 47.7 years) than those who had not (mean = 42.5 years) ($t(713)=2.878$, $p<0.01$). Respondents had their current map installed for an average of 10 months, although there was a wide range (0-84 months). A fifth of respondents who had not updated their maps would not consider updating in the future or were unsure. Most of those who updated did so once a year or more than once a year (61%), although more than a third updated once every 2 years or more (39%). There was a significant positive correlation between the frequency with which respondents reported updating their maps[1] and the number of months they have been using their system (Spearman-rho=0.24, df=307, $p<0.01$) as well as the cost of updating (i.e. respondents that thought it was very expensive tended to update their maps less frequently). (Spearmans-rho= 0.231, df=307, $p<0.01$).

Figures 4.4 and 4.5 above show that about a fifth (22%) of respondents particularly liked their systems (re)routing/mapping capabilities, but that over a quarter (28%) particularly disliked these system capabilities. However, 52% of those who particularly disliked them had never updated the map on their navigation system, although 84% indicated they would update sometime in the future.

[1] This variable ranged from very frequently to very infrequently (see appendix F).

Figure 4.13: pie chart showing reasons why some respondents have updated the map on their IVNS (N=441)

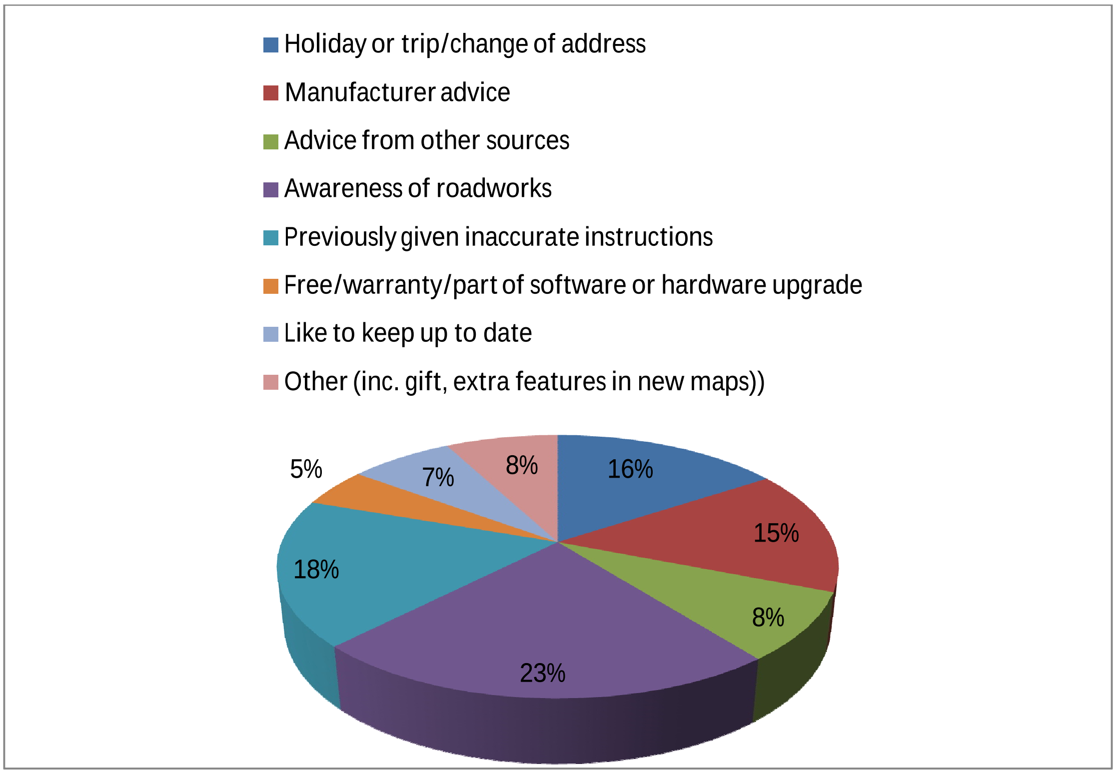
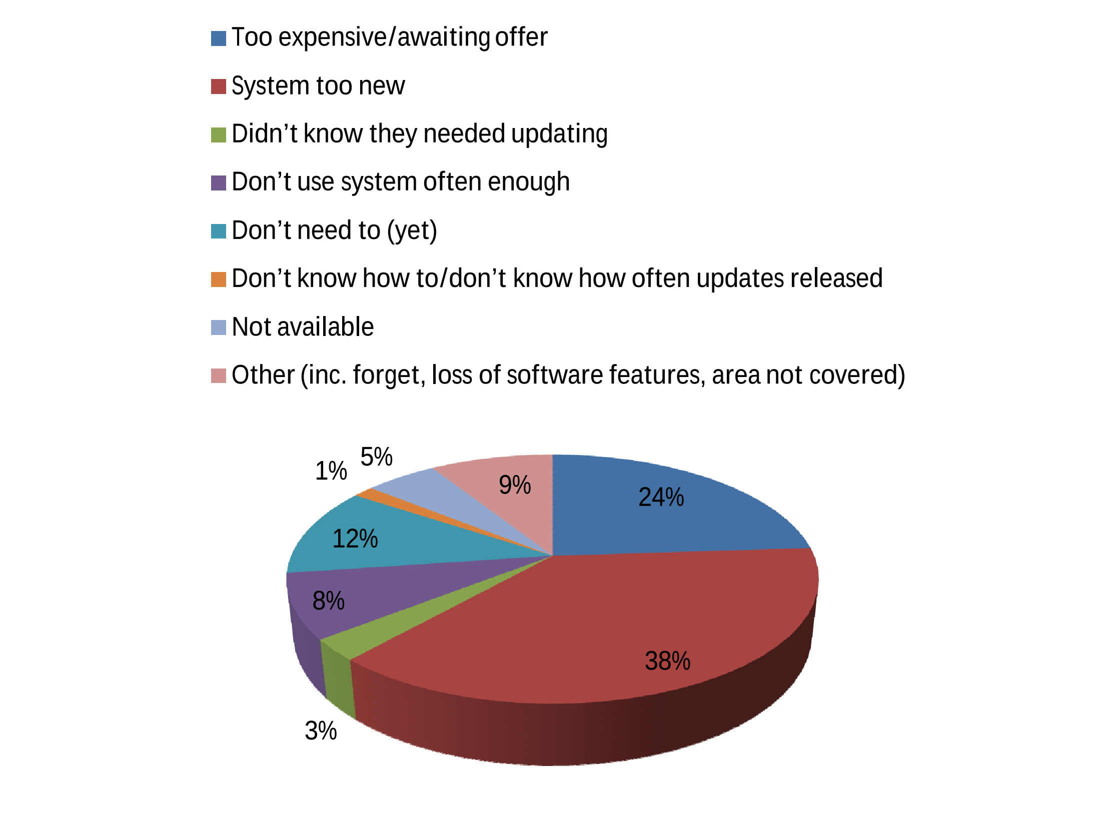


Figure 4.14: pie chart showing reasons why some respondents haven't updated the map on their IVNS (N=550)



1.5 Discussion

1.5.1 Sample validity

The present study attracted a much higher number of IVNS users than the previous study. Drivers of all ages were well represented. In light of the previous sample and due to previously highlighted difficulties in attracting elderly respondents in IVNS user research (Green, 2001), it was particularly surprising that older (>=60) and younger drivers (<=29) were so well represented. Figures 4.3 and 4.4 can only be used as a rough guide to establish sample representativeness as they relate to UK drivers only and the present sample was more culturally diverse, but they do illustrate quite well that in terms of age, a fairly representative sample of drivers participated.

Similarly there were wide ranges in terms of the number of years holding a driving license, mileage and IVNS experience. It is likely that these sample characteristics could at least partially be attributed to the much wider sampling frame used in the present study. As some authors (e.g. Joiner et al, 2005) have expressed concerns about gender disparity on specialist websites and because it was likely that the previous study also attracted a high proportion of

IVNS enthusiasts, the present study employed a much wider sampling frame. In addition to driving and IVNS-related internet forums, bulletin boards and mailing lists, the survey was also advertised on other general interest internet forums as well as those specialising in issues unrelated to driving and IVNS.

It was hoped that adopting a much wider sampling frame would also attract a much higher proportion of female IVNS users, but the results clearly show that still only a small minority participated (although they were represented in almost every age band). As noted in the previous chapter, other online IVNS user studies have had similar difficulties attracting female participants (e.g. Varden, 2008; Li, 2006). Varden (2008) suggested this could simply mean that a much higher proportion of males use IVNS than females. The previous study partially supports this assertion as it attracted a high proportion of female drivers, but only a very small proportion of female IVNS users. In a review of several online studies, Krantz and Dalal (2000) noted a wide range in the dispersion of females across studies ranging from 7% to 71%. Hewson (2003) suggests that the gender of the sample will depend very much on the topic being investigated. For example Gosling et al. (2004) cited a questionnaire study that sampled pet owners, in which 83% of participants were female. In the last few years several authors have concluded that men and women use the internet in equal numbers (e.g. Lenhart et al, 2003; Gosling et al., 2004).

While some other IVNS user surveys employing more traditional methodologies have attracted higher proportions of female respondents, in most cases they have included much higher proportions of males (e.g. Svahn, 2004; J.D. Power, 2004-2008). The DfT (2005) survey reported that an equal proportion of males and females had an IVNS in their car, but the question was worded so that it is not clear whether respondents merely had a system in their car, used the system or owned it. In the US, the national highway traffic safety administration (Royal, 2003) surveyed over 4000 drivers, and found that only a slightly higher proportion of males (6%) reported owning an IVNS than females (5%), although a higher proportion of males (10%) than females (7%) reported owning PDA`s. In a recent survey, most female drivers (60%) also indicated that they would feel safer with an IVNS, suggesting there is demand from female consumers. (Zoomerang, 2006). It is unlikely the findings reported in the present study and other online studies reflect the true proportions of female IVNS users in the driving population, and this limits its' external validity. Gender disparity in IVNS use will probably both reduce and become much clearer over time as the price of IVNS continues to fall, the range of devices capable of performing route guidance functions increases and the number of IVNS user surveys conducted increases. It is clear from the present study and from previous studies that sampling frames must be carefully designed and appropriately wide to attract female IVNS users whether the studies employ the internet or more traditional methodologies.

The present study attracted a culturally diverse sample drawn from North America, UK and the rest of Europe. This was important as it provided insight into behavioural adaptation issues affecting all drivers, regardless of individual country idiosyncrasies. A drawback of other IVNS user surveys (e.g. Svahn, 2004 sampled German IVNS users only; DfT, 2006 sampled UK drivers only) is that they employed culturally specific sampling frames. Another drawback of some previous surveys is that they only sampled integrated IVNS users (e.g. Svahn, 2004; J.D. Power, 2003-2008). The present study sampled a much wider range of IVNS users; including those using PDA/mobile phone based systems, nomadic systems, integrated systems as well as home-made systems. Chapter 2 noted system variation as a key problem in interpreting many of the results from experimental studies that had compared driving behaviour using paper maps with IVNS. While this is a major drawback when comparing controlled experimental studies with specific hypotheses, it can be useful in initial surveys such as the present study, as it allows researchers to find out about some of the wider issues regarding behavioural adaptation to IVNS affecting most IVNS users, regardless of individual system idiosyncrasies.

Students and unemployed drivers were under-represented in the present sample, but it did attract a wide range of drivers who were self-employed, employed and employed in managerial positions. Although the market penetration of IVNS continues to increase and their cost continues to fall, recent surveys have suggested that the majority of IVNS users are employed at some level (Svahn, 2004; DfT, 2006). Drivers unskilled in computing were also severely under-represented in the sample, and it is likely that this was directly due to the sampling frame.

Overall, with the exception of a few discrepancies (e.g. gender) the sample was fairly representative in terms of most demographic factors. This helps to strengthen external validity. Table 4.3 shows that in most cases, the sample is broadly similar to that obtained in another user survey using traditional methods. In fact, table 4.3 suggests the present study may be even more representative in terms of socio-economic status, presumably because it sampled a much wider range of IVNS users. The present study indicates widespread user acceptance of IVNS

1.5.2 IVNS users

In most previous surveys the vast majority of respondents have been aged between 20 years and 50 years, this finding was largely replicated in the present study, but it also showed that a high proportion of those aged over 60 years also use IVNS. Previous surveys using both internet-based (e.g. Varden, 2008) and traditional sampling frames have failed to attract older participants. Some authors have suggested this may be because older adults are less likely to use new technology (Gregor, Newell and Zajiceck, 2002; Selwyn et al., 2003) but the present data suggests that a significant proportion of elderly drivers do also use these systems.

As shown above, some previous IVNS user surveys have exclusively sampled integrated IVNS users, but in the present study most respondents (82%) used nomadic or PDA based IVNS and only a minority used integrated systems (14%). As they are after-market options, nomadic and PDA based IVNS are typically cheaper and may be less complex than some integrated systems. This could have implications in terms of many different aspects of driver behavioural adaptation to IVNS including system reliability, reliance, perceived and actual workload, distraction, usage, system interaction etc. For example, Svahn (2004) investigated active and passive integrated IVNS usage in familiar and unfamiliar areas. Until the present study, no previous research had examined usage of a much wider sample of IVNS users. Due to both within system variation (i.e. variation in different integrated systems) and between system variation (i.e. variation between portable and integrated IVNS), it would have been difficult to generalize Svahn`s (2004) results to the wider IVNS using population.

Most respondents considered themselves to be expert computer users or as possessing considerable skills. Computing skill was neglected in the previous study, but Svahn (2004) showed that it was related to system usage in familiar and unfamiliar areas and other user preferences. In Svahn (2004) too, most IVNS users possessed considerable computing skills. Varden (2008) asked respondents how comfortable they felt using computers, cars and IVNS. He reported significant positive correlations between comfort levels for all three. Overall the results also showed that the vast majority of IVNS users were comfortable or very comfortable using computers.

1.5.3 User preferences, acceptance and usage

In the previous study the majority of respondents indicated they were satisfied with their IVNS, so in the present study participants were asked to provide open ended responses concerning features they particularly (dis)liked about their IVNS, in order to derive some of the components of user-(dis)satisfaction. Both open ended items were subjected to a computerized linguistic analysis[2], in which words were categorized semantically. Categories were then further refined and verified manually.

Figures 4.5 and 4.6 show some of the components of user satisfaction and dis-satisfaction. Respondents particularly liked a range of IVNS features and functions. A high proportion of respondents clearly found IVNS easy to use, and this probably contributes to their satisfaction and acceptance. A high proportion of respondents also particularly liked their systems' routing/re-routing capabilities. System versatility also seems important with many respondents reporting that they liked a range of extra functions bundled with IVNS (including mp3 players, PDA functions, TMC, Bluetooth etc). Most of these IVNS features and functions also featured prominently as components of user satisfaction in some user-surveys outlined in chapter 2 (J.D. Power, 2004; Svahn, 2004), but these surveys only sampled integrated IVNS users. Similar results were found in the GFK (2008) survey, but this sampled German consumers looking to purchase IVNS rather than actual IVNS users.

A lot of respondents also particularly liked the auditory and visual guidance capabilities offered. This is also apparent from the finding that most rated voice and screen as equally important sources of route guidance information. In Svahn (2004) a higher proportion of respondents (50%) preferred display only or mainly display, although a significant proportion (47%) also rated voice and screen of equal importance. This discrepancy may be due to the much wider range of IVNS users sampled in the present study that may have used screens varying significantly in terms of size, position, fidelity, contrast, detail etc. If most respondents' preferences for auditory and visual route guidance information translate into their strategic decision to utilise one form of guidance or both, this represents a form of strategic level behavioural adaptation that could have knock on effects further down the hierarchy in terms of tactical and control level driving behaviours such as hazard perception, glance behaviour, speed or following distances.

2 Linguistic analysis was performed using the SPSS text analysis for surveys 2.1 software.

Since 14.5% of respondents listed “it works” as a reason for liking their IVNS, and only a minority (2.2%) report that they like nothing about their systems, the results suggest that IVNS users in this sample too were generally satisfied with their systems. This general user satisfaction is also reflected in figure 4.6 which shows that nearly a fifth of respondents reported that there was nothing that they didn’t like about their IVNS. Previous IVNS user surveys have insufficiently addressed the components of user dis-satisfaction, so it was interesting to find out areas for improvement in IVNS design. Although most respondents reported that they liked the availability of a range of extra functions, they also reported problems with some of these (e.g. TMC, POI, speed cameras). Figure 4.6 also suggests that IVNS designers still need to address issues regarding system configurability and data entry, routing/re-routing algorithms, display and auditory guidance.

Section 4.5.2 outlined the wide variation in the sample of IVNS users obtained, and this section and the previous study have also shown that although there are still aspects of user dis-satisfaction, most respondents were satisfied with their systems. These factors, in conjunction with continuously increasing unit sales indicate high user acceptance. IVNS user acceptance can be further understood by investigating IVNS usage. As in the previous study, most respondents reported that using an IVNS hadn’t affected the extent to which they make unfamiliar journeys, but in both studies about a quarter of the sample reported that they had made more unfamiliar journeys since using an IVNS, this represents strategic level behavioural adaptation. Figure 4.8 shows that most IVNS users sampled, reported that they frequently used their systems in an active manner when driving in unfamiliar areas. IVNS are often purported to be most useful when driving in unfamiliar areas, and these findings suggest this is the context in which most drivers in the present study also made the strategic decision to actively use their systems frequently[3]. It was interesting that 49% of respondents also used their systems passively when driving in unfamiliar areas quite often or even more regularly. In Svahn (2004) an even higher proportion (90%) of respondents also reported passive system usage in unfamiliar areas. Further research could establish the extent to which drivers behave this way due to poor system reliability, because there are some unfamiliar situations in which they would simply prefer not to utilise automated route guidance facilities or some other reason.

[3] Usage in unfamiliar areas has been characterised here as strategic level behavioural adaptation, but strictly speaking it does not satisfy the assumptions of the OECD (1990) definition, which states that behavioural adaptations are unintended by system designers (see chapter 2).

Svahn (2004) showed that German IVNS users mostly engaged in passive system usage when driving in familiar areas. He argued that IVNS design should be optimized to assist drivers using their systems passively in this way, since research has shown that most drivers make familiar journeys to familiar destinations most of the time (Bonsall and Parry, 1990). Figure 4.8 suggests a tendency for respondents in the present study to prefer passive usage over active usage when driving in familiar areas, although it is interesting that such a high proportion still engaged in active usage occasionally in this context (perhaps due to congestion along normal routes). It is also interesting that only about 15% of respondents reported that they had never engaged their IVNS in familiar areas, this shows that most respondents have made the strategic decision to use these systems beyond the scope of their originally designed purpose.

Due to the poor wording in the previous study of the item designed to find out whether respondents thought using an IVNS had affected their ability to learn new routes, the present sample were asked a similar question. The results showed that most respondents reported no change in the length of time taken to learn new routes since acquiring and IVNS, and only a minority thought it had increased or slightly increased. Both the previous and present findings dispute previous work and predictions concerning the potential detrimental effect of IVNS use on the formation of cognitive maps (e.g. Burnett and Lee, 2005; Antin et al., 1990). However, it also possible that self-reports are unreliable in this context, drivers may be unaware of any impaired spatial performance (e.g. self-deception) or may be over confident (e.g. over-confidence bias), although according to Cornell, Sorenson and Mio (2003) people are generally quite good at rating their own spatial abilities. To answer this question further research should objectively examine cognitive map formation and development, to find out the extent of any mismatches between perceived and actual spatial skills in this context of IVNS.

1.5.4 System interaction while driving

The results clearly showed that a high proportion of respondents have entered destinations while driving occasionally or even more often. Although some systems can facilitate vocal destination entry, the vast majority require drivers to touch the screen or buttons to complete this task. As mentioned in the previous chapter, while a great deal of work has explored the effects of destination entry while driving on behaviour and performance, much less work has investigated the extent to which drivers actually do this. An exception is the

Privilege insurance (2006) survey in which more than half the sample admitted they had taken their eyes off the road to use their system while driving, and 10% of drivers reported that they always configured their destinations en-route. In the present study, about three quarters of the sample admitted that they have entered destinations while driving.

Figures 4.9 and 4.10 illustrate the discrepancy between respondents' attitudes concerning destination entry while driving and their actual behaviour – while a third of respondents thought destination entry in any form should not be allowed while driving, only a quarter never entered destinations themselves. A great deal of work in social psychology shows that although related, attitudes do not always influence behaviour. A simple example that is often cited concerns smoking. Most people don't want to die early, and most people know that smoking causes early death, but still many people smoke; similar arguments have also been made concerning speeding (Iverson and Rundmo, 2004) due to the association between high speed and accidents. Figure 4.10 suggests that most respondents are probably aware of the dangers of destination entry while driving, as a third thought no form of destination entry should be allowed while driving and of those who thought some form of destination entry should be allowed, only a minority considered destination by address and postcode to be acceptable while driving. A much higher proportion considered destination entry by POI and stored location to be acceptable, presumably because these are more quickly executed, less distracting destination entry tasks. Similarly, fig 4.10 shows that much higher proportions of respondents considered quickly executable tasks such as change volume or change view to be acceptable while driving than potentially longer, more demanding tasks such as browsing points of interest or changing user preferences.

The second aim of the thesis was to identify individual difference variates in drivers' experiences of behavioural adaptation. The previous study partially addressed this aim by describing significant correlations between driver characteristics and the frequency with which they committed driving errors. The present study also identified individual difference variants in the extent to which drivers engage in system interaction while driving. Although there were significant associations between several demographic factors and the frequency with which drivers entered destinations while driving, and their views on this and other forms of system interaction while driving, two of the most striking and most consistent factors are age and computing skill.

Regarding computing skill, no previous research could be found that had directly related computing skill to destination entry while driving, but it makes sense that people confident at using computers might perform IVNS tasks more quickly and efficiently, due to their experience in entering data via keyboards (which have the same QWERTY format as most touch-based IVNS destination entry methods), they may also be better at recognising and interpreting information presented on visual displays (Ho et al., 2005). Svahn (2004) found a significant negative correlation between "reduced awareness at system interaction" and computing skill, suggesting that more experienced computer users might be more confident that they can minimise the distraction associated with system interaction while driving.

Regarding age, there is plenty of evidence in the literature concerning the associations between [young] age and speeding and other risk taking behaviours such as driving violations (Zhang et al., 1998; Aberg and Rimmo, 1998; Blockey and Hartley, 1995; Parker et al., 1995; Simon and Corbett, 1996). So it is not particularly surprising that such highly significant associations were also found in the present study concerning system interaction while driving. This study has shown that older drivers were much more likely to have never or hardly ever entered destinations while driving and figure 4.11 shows that [young] age was most strikingly associated with more frequent destination entry while driving.

These age effects are consistent with behavioural compensation described in chapter 2. According to Holland (2002) older drivers invariably perceive increased risks on the road due to age-related declines in perceptual and cognitive abilities as well as motor skills. Several studies have indicated that older drivers compensate for these deficiencies by taking fewer driving risks (Hakamies-Blomqvist, 1994; Holland and Rabbit, 1992; Simms, 1992, 1993; Rackoff, 1974).

Interestingly, although those participants who had never entered destinations while driving were significantly older than those who had, figure 4.11 shows that a fairly high proportion of older drivers have also entered destinations while driving. In a fairly recent article the European Road Safety Observatory (ERSO - 2006) proposed that with the advent of a wide range of intelligent transport systems in vehicles (e.g. vision enhancement systems, collision warning/avoidance systems, IVNS), behavioural adaptation may actually appear as a withdrawal of compensatory behaviour, where older drivers take more risks such as driving at night, driving in heavy traffic or while distracted.

It is not surprising that age and computing skill were also significantly associated with destination entry features and other forms of system interaction that respondents thought *should* be allowed while driving, but it was interesting that even though those who thought they should be allowed to interact with their systems while driving were significantly younger and had held their driving licenses for significantly less time, they were significantly more experienced drivers. It does make sense that drivers who drive more frequently and further may be more inclined to save time or increase mobility by completing certain tasks while driving, instead of pulling over, which may also explain why those who considered destination entry by any method to be acceptable had driven significantly further than those who considered destination by point of interest or stored location in the past 12 months and 5 years.

The present study has illustrated the extent to which respondents use their IVNS while driving, some of their thoughts on this and individual differences in the extent to which they behave this way. However, there is insufficient detailed information concerning the reasons why drivers might behave this way, and the situations in which they do. For example, some drivers may only do this while driving in light traffic or in the absence of passengers. Therefore future work in this area should consider the contexts in which drivers interact with their systems while driving.

1.5.5 System reliability and maps

Respondents were asked to rate the degree of correspondence between system-generated routing advice and their own individual preference when driving in familiar areas. It was hoped this item would be a useful measure of perceived system reliability/efficiency, as most drivers are aware of optimal routes in areas they are familiar with. Svahn (2004) reported that most German integrated IVNS users rated the correspondence as significant or reasonable (65%), with only a minority (12%) indicating low or insignificant correspondence. However, in the present study most respondents rated correspondence as moderate (54%), although a higher proportion chose high or very high correspondence (32%) than low or very low correspondence (14%).

Responses to the above item provided a good indication of perceived reliability because respondents had a benchmark (i.e. their own individual preference) against which to rate it, but over time, without such an explicit benchmark, users can also develop conclusions about perceived system reliability. Clearly most respondents in the present study questioned the fallibility of route guidance instructions they have received from their IVNS, with 85% having received unreliable guidance. Moreover, over 40% of these respondents report that they have received inaccurate instructions that were dangerous or illegal, in a range of different contexts. Respondents have been instructed to perform prohibited driving maneuvers, or to drive into areas that are prohibited for legal, safety or other reasons. Relatively few respondents have received instructions guiding them into areas for which their vehicle dimensions are unsuitable, although this may be an artifact of the sampling frame, as HGV/LGV drivers were not specifically targeted.

Inaccurate and unreliable guidance will arise due to a variety of reasons, for instance poor mapping information and erroneous routing algorithms. For example, a recent study showed that software errors are responsible for failures of many IVNS to locate ring roads in cities, so instead they send drivers through increasingly jammed neighbourhood streets typically designed for low traffic volumes (Stichting Onderzoek Navigatiesystemen, 2007). Clearly, the currency of the underlying map data is of particular importance. This survey revealed that inaccurate route guidance instructions were by no means exclusively received by users who had *not* regularly updated their maps – as 42% of those who had updated maps had still received poor guidance. This is not particularly surprising as internationally, even the most accurate maps will become out-dated very quickly.

Many respondents received free map upgrades. Although it is unlikely that upgrades will ever be universally free, the general consensus of respondents in this survey was that they're presently overly expensive. The results suggest manufacturers should increase the appeal of map upgrades to younger drivers, although greater foreign mobility (e.g. family holidays, business trips) may also explain why respondents who had updated were significantly older than those who had not.

Chapter 2 showed how several studies had found that IVNS reliability and route guidance accuracy affected system trust (Kantowitz et al., 1994, 1996; Bonsall and Joint, 1991), and that trust is strongly associated with reliance (see Lee and See, 2004). The present study suggests that receiving inaccurate, unreliable and/or dangerous/illegal route guidance instructions is a pervasive phenomenon affecting the majority of IVNS users. So it is particularly surprising that such a high proportion have followed them on at least one occasion. Two recent studies have also shown the prevalence with which drivers behave this way. In a recent survey (Direct-line, 2008), a UK insurance company found that out of 14 million British drivers who presently use IVNS, about 5 million have followed instructions guiding them the wrong way down a one-way street (incidentally this was one of the most frequent contexts in which respondents in the present study had followed inaccurate route guidance instructions). Varden (2008) also reported that a significant proportion of IVNS users had followed IVNS advice when contradicted by road signs and other people, but the present study provided a much more detailed account of the varied contexts in which this had occurred.

It shows this is a key behavioural adaptation concern that requires further investigation. It would be useful to obtain detailed qualitative accounts of the situations in which drivers receive and follow inaccurate/unreliable route guidance instructions and any further individual difference variants in their experiences of this. It would also be useful for future research to examine the extent to which this behaviour is caused by a lack of attention or too much trust. Varden`s (2008) finding that respondents followed IVNS advice that contradicted road signs, suggests that respondents were aware of the road signs but chose to rely on the IVNS, and in the present study, a significant proportion of respondents reported that IVNS use had increased or slightly increased their attention to surrounding traffic and road signs. However, due to the subjective nature of self-reported driving behaviour, and because Varden (2008) qualified his findings by suggesting that participant interviews had indicated they hadn't blindly followed inaccurate instructions, these findings alone cannot be used as sufficient evidence that IVNS users do process road signs (i.e. favouring the trust/reliance argument).

In the present study, age was the only variable significantly associated with following inaccurate instructions, and there is research linking it to both reduced attention and increased trust/over reliance. Increasing age is typically associated with declines in physical and mental ability (see Matthews et al., 2000). It has also been linked to failures in a range of driving performance abilities, including perception, memory and attention. Specifically, it has been associated with impaired performance on tasks of selective (see Rogers, 2000), divided (e.g. Korteling, 1991) and sustained (e.g. Mouloua and Parasuraman, 1995) attention. When performance is not impaired, research suggests that older adults must work harder to maintain similar performance to younger counter-parts (Bunce and Sisa, 2002).

In their model of trust and reliance in automated technology for older adults, Ho et al. (2005) suggest that complacency (i.e. over-reliance) may be the result of age-related cognitive deficits in attention-allocation, working memory, mental workload, decision making and interpreting stochastic information. These cognitive changes may reduce self-confidence in manual performance. Additionally they suggest that older adults may be less familiar with computer technology and less aware of potential unreliability. A range of driving research using ATIS (Fox and Boehm-Davies, 1998) and gauge warning monitoring tasks (Sanchez, Fisk and Rogers, 2004) has indicated that older drivers trust automated vehicle systems more than their younger counterparts. Using a flight simulation task, Vincenzi and Mouloua (1999) showed that older adults were less likely to notice automation errors and correct for them when they occurred. Ho (2005) also found that older adults placed greater trust in an automated medical management system, and made more errors because they relied on the system too much.

4.6 Summary and implications for behavioural adaptation

This chapter describes a second online survey aimed specifically at IVNS users. It further contributed to the first two aims of the thesis, by elaborating on aspects of behavioural adaptation insufficiently addressed in the driver survey, thoroughly investigating aspects of safety-negative behavioural adaptation that weren't covered in the driver survey and identifying more individual difference variates in experiences of behavioural adaptation to IVNS, most notably age, driving experience and computing skill. Although study length was also a key concern in the design of the IVNS user survey, in combination with the driver survey it has further addressed the first aim of the thesis and partially addressed the second. To fully address the second aim it will be necessary for later studies to explore in detail the varied contexts in which behavioural adaptations to IVNS occur.

The IVNS user survey achieved a large sample size. A limitation of the driver survey was that although 440 drivers participated, this included only 157 IVNS users. In the present study, 872 IVNS users participated, enabling identification of several significant trends that affect a wide range of users. In terms of age, it was fairly representative of ordinary UK drivers and IVNS users. Other demographic factors also compared favourably to similar research using more traditional methodologies, with the exception of gender. Both surveys have identified major difficulties in attracting female IVNS users, although as shown above, this is also a significant problem in IVNS user research using traditional methodologies.

As in the previous study, results of the present study must also be interpreted with caution as it concerns self-reported driving behaviour, and as shown previously this means responses can be prone to certain biases. As before, it appears that the anonymity afforded by conducting this study online minimised the impression management aspect of social desirability bias, as respondents provided seemingly frank and honest responses to sensitive items (e.g. system interaction while driving), but responses to some items (e.g. distraction potential of IVNS relative to paper maps or ability to learn new routes) may still have been prone to the self-deception aspect of social desirability bias or other response biases such as over- confidence.

Using linguistic analysis of open-ended item responses, this study identified the key components of user satisfaction and dis-satisfaction. The vast majority of responses received (including some responses to the dis-satisfaction item) suggest that most IVNS users are satisfied with their system, and this indicates that acceptance (a pre-requisite for behavioural adaptation) is generally high. The dis-satisfaction responses also provide design insights to help further increase IVNS acceptance.

The results described in detail, the contexts in which drivers use their IVNS. They showed that about a quarter of respondents ventured more frequently into unfamiliar areas, and that most drivers frequently used their systems when travelling in unfamiliar areas. Although these are behavioural effects intended by system designers, in the author`s opinion, they still represent strategic level behavioural adaptation. Further evidence of strategic level behavioural adaptation concerned the frequency with which drivers reported using their systems in only a passive manner while driving in unfamiliar areas and using their systems actively (and passively) even in familiar areas. This could suggest very high trust, if drivers are prepared to delegate control to automation, even when they know where they could be going (i.e. high self confidence).

Based on drivers' preferences the results also suggested that most drivers prefer to make the strategic decision to utilise both auditory and visual route guidance, and as shown, this could have implications in terms of the extent to which following route guidance instructions distracts the driver. In other words, there could be knock-on effects of their decision to rely on both types of information, in terms of lower level tactical and control level behaviours (e.g. glances, hazard detection).

This study also demonstrated that system interaction (particularly destination entry) while driving is a significant behavioural adaptation issue affecting a large proportion of drivers. The results illustrated the discrepancies between the perceived risks of different types of destination entry and other forms of system interaction, and actual behaviour. The results also highlighted the strong associations between [young] age and [high] computing skills and engagement in this type of behavioural adaptation.

Although reliability and perceived reliability of route guidance information has received some research attention, much less research has considered tendencies to follow inaccurate guidance, which as shown in chapter 2 from a safety perspective could be considered a form of negative tactical level behavioural adaptation. This survey, more than any others to date, documented the wide range and diversity of contexts in which this has occurred. The precise explanation for this phenomenon is presently unclear, the discussion showed how it could be caused by inattention and over trust. The finding that [high] age is associated with the extent to which drivers might follow inaccurate guidance instructions also lends credence to both arguments. In order to fully address the second aim of the thesis, further research is needed to fully explore the contexts in which drivers might follow inaccurate route guidance instructions, by obtaining rich and detailed qualitative accounts.

Chapter 5 – IVNS user diary study

5.1 Introduction

This chapter describes an IVNS-user diary study, in which participants recorded diary entries about their IVNS usage over a two week period and completed questionnaires concerning driver characteristics, as well as a battery of cognitive and attitudinal scales from the literature concerning trust in automation (Jian et al., 2000), automation-induced complacency (Singh et al., 1993), perception, attention (Broadbent et al., 1982; Brown and Ryan, 2003) driving confidence and self-rated driving ability (Parker et al., 2001).

A diary study was used to fully address the second aim of the thesis (i.e. exploration), by comprehensively exploring aspects of behavioural adaptation to IVNS highlighted in the previous chapters, as well as collecting detailed accounts of the specific contexts in which drivers used their IVNS during a 2-week timeframe. As the previous chapters identified several demographic individual difference variables (most notably age and computing skill) that were associated with the frequency with which drivers experienced different types of behavioural adaptation to IVNS, this study also employed several questionnaires and scales to identify any further individual difference variates beyond demographic data alone.

5.2 Diary studies

Diary studies are a useful method of collecting rich qualitative data. They are particularly convenient for initial investigations into topics. Surveys and questionnaires are most appropriate for identifying common trends in large sample populations, but responses typically lack sufficient detail (even when using open-ended items) to fully describe subjects under investigation. Diary studies enable researchers to find out about the specific contexts in which behaviour (or whatever else is being investigated) occurs. They have previously been used to investigate a diverse array of topics including aspects of traffic psychology (e.g. Eost and Flyte, 1998; Behrens and Mistro, 2008). Reason (1990) developed his error classification scheme based on several diary studies in which participants were asked to describe action slips that occurred during their daily lives. A diary study was considered to be the most appropriate method of reviewing the varied contexts in which IVNS users interact with their system while driving, receive and follow inaccurate route guidance instructions, use their systems in familiar and unfamiliar areas and experience any other forms of control, tactical or strategic level behavioural adaptation during a 2-week timeframe.

5.3 Scales and questionnaires

In addition to diary entries, diary study participants were also asked to complete several scales, to enable quantitative analyses concerning driving confidence, self-rated driving ability, perception, attention, trust and automation-induced complacency. Each scale was selected based on its relevance to each field of study as well as its use in other peer-reviewed empirical studies in these fields (see 5.3.1 – 5.3.3 below).

5.3.1 Driving confidence

Parker et al (2001) found that high driving confidence scores were associated with low levels of lapses and high levels of violations (assessed using the DBQ – Reason, 1990), and a low score on the neuroticism scale, and high score on the extraversion scale of Eysenck`s (1975) personality questionnaire (EPQ). The driving confidence scale contains 13 items (see appendix K), respondents are required to rate how nervous they feel performing various driving manoeuvres, how flustered they feel during potentially dangerous situations and how relaxed, calm, stressed and confident they generally feel when driving. All items use the following response format:

1. Not at all
2. A little
3. Moderately
4. Very
5. Extremely

Chapter 4 discussed two plausible potential explanations of drivers' tendencies to follow inaccurate, unreliable and/or dangerous/illegal system-generated route guidance instructions, which drew on perception/attention and trust/reliance. In an initial attempt to identify associations between this phenomenon and these explanations, this study employed several scales, each of which are briefly described below, following a short introduction to each topic.

5.3.2 Perception and attention

If drivers follow inaccurate IVNS-generated route guidance instructions despite road signs/markings to the contrary, this may be due to failures in either perceiving these road signs/markings or attending to them.

Previous chapters have shown that driving errors can be classified as: slips/lapses, mistakes and violations. The study described in chapter 3 used the DBQ to investigate the extent to which IVNS users and other unequipped drivers committed these errors, because the DBQ includes several common behavioural examples of each type of error. It showed that IVNS use was associated with reductions in the frequency with which drivers reported some slips/lapses (i.e. failures of memory/attention), particularly those related to navigation.

Everyone experiences lapses[1] of attention at least occasionally (Broadbent, Cooper, Fitzgerald and Parkes, 1982; Norman and Shallice, 1986), and due to a range of factors (e.g. age, traumatic brain injury) some people experience them more frequently than others (Robertson, Manly, Andrade, Baddeley and Yiend, 1997). The consequences of these may be merely inconvenient (e.g. missing a turn) or much more serious, such as accidents, loss of life or injury (Robertson, 2003). Over the past 60 years, several measures have been developed to examine the frequency with which people experience all kinds of lapses of attention or absent mindedness during everyday life. These include subjective self-report scales (e.g. cognitive failures questionnaire, mindful attention awareness scale) as well as objective cognitive tests (e.g. sustained attention to response task, clock test).

(i) The cognitive failures questionnaire

The cognitive failures questionnaire (CFQ – see appendix H) is a self-report scale, which assesses the frequency with which participants experience lapses in attention, perception, memory and motor function in everyday life (Broadbent, Cooper, Fitzgerald and Parkes 1982). It contains 25 items, each worded in the same direction and with the following response format:

[1] Lapses of attention as they are referred to here are unrelated to their classification in Reason`s (1990) classification scheme reported in the previous chapter.

4. Very often
3. Quite often
2. Occasionally
1 Very rarely
0 Never

The CFQ provides information largely distinct from standard intelligence and personality scales (Boradbent et al., 1982), and is useful in understanding distribution of attention under stress or during multiple task performance (Reason, 1988; Harris and Wilkins, 1982; Martin and Jones, 1983). It has proven ecological validity in different contexts. For example, in driving, a high CFQ score has been associated with an increased likelihood of causing traffic accidents (Larson and Merritt, 1991; Larson, Alderton, Neideffer and Underhill, 1997). It also correlates with other objective measures of attention (Robertson, Manly, Andrade, Baddely and Yiend, 1997; Tipper and Baylis, 1987).

(ii) The mindful attention awareness scale

The mindful attention awareness scale (MAAS – see appendix I) is a subjective measure of absent mindedness which assesses the frequency with which individuals perform actions "automatically", "without being aware", "without much awareness" or "without paying attention" (Brown and Ryan, 2003 pp. 825-826). It contains 13 items, each with the following response format:

1. Almost always
2. Very frequently
3. Somewhat frequently
4. Somewhat infrequently
5. Very infrequently
6. Almost never

The MAAS also has good ecological validity. It correlates with the big-5 personality dimension neuroticism (Brown and Ryan, 2003) and the attention-related cognitive errors scale (Cheyne, Jonathan and Carriere, 2006).

5.3.3 Trust/reliance

Alternatively, drivers might also follow IVNS instructions despite contradictory road signs/markings, not because they failed to perceive or attend to the road signs/markings, but because they implicitly trust their IVNS to provide accurate route guidance information and are prepared to rely on this information. Therefore, two scales were also included to examine drivers' propensity to trust their IVNS and the extent to which they tend to over-rely on IVNS (i.e. automation-induced complacency).

(i) Trust in automation scale

Trust in automation can only be measured subjectively as it is a purely psychological state (Wickens and Xu, 2002). Most previous attempts to measure trust (e.g. Lee and Moray, 1994; Muir and Moray, 1996) have been based on theoretical rather than empirical notions (Bisantz and Seong, 2001), but Jian et al (2000) and Madsen and Gregor (2000) developed empirically based scales. A drawback of Madsen and Gregor`s (2000) scale is that it is only appropriate for long-term research as it assumes several months system experience, but the Jian et al. (2000) general purpose scale (see appendix L) has been used to measure trust in a range of automated devices including automated decision aids and adverse condition warning systems (Bisantz and Seong, 2001; Gupta et al, 2002), and in a recent study, it was used to measure trust in IVNS (Varden, 2008). It was designed using a bottom up approach in which participants rated words as relevant to interpersonal trust, trust in automation or both, and in terms of whether they referred to trust or dis-trust. A paired comparison study then examined the 30 most highly rated trust and distrust words, and finally a factor analysis reduced these to 12 factors (7 concerning trust and 5 concerning distrust), which were then translated into questions, each with the following response format:

1. Not at all
2.
3.
4.
5.
6.
7. Extremely

(ii) Complacency potential rating scale

In many studies, the extent to which individuals demonstrate automation-induced complacency has typically been inferred from task performance (e.g. Parasuraman et al, 1993, Singh et al, 1997), but Singh et al (1993) also created the complacency potential rating scale (CPRS – see appendix M). This is a subjective scale which purports to measure complacency potential (an individual's tendency to over-rely on automation). Based on factor analysis of scale responses, Sing, Molloy and Parasuraman (1993) identified four factors (i.e. confidence-related, reliance-related, trust-related and safety-related complacency) that the authors argued formed components of complacency rather than general attitudes towards automation. It is a general-purpose scale with proven reliability (test re-test - r = 0.9, internal consistency - r=0.87 – Singh et al., 1993) in which participants must rate their attitude towards a range of everyday automated systems (e.g. cash machines, video recorders, aircraft/medical automation). It was developed in the aviation field, but it is a general-purpose scale, which has been employed in several studies over the past fifteen years to detect complacency potential (e.g. Prinzel, DeVries, Freeman and Miklulka, 2001; Stark and Scerbo, 1998; Riley, 1994). There may be associations between responses to this scale and the extent to which drivers follow inaccurate route guidance instructions, as this may be a symptom of a wider potential for complacency in other contexts. The CPRS contains 20 items[2] (four of which are filler items that should be excluded from analysis), each with the following response format:

1. Strongly agree
2. Agree
3. Undecided
4. Disagree
5. Strongly disagree

[2] One item was excluded from this study as it concerned conventional cruise control in vehicles, which is standard in the US (where this scale was authored), but is much less common in the UK.

5.4 Main objectives

1. In detail, explore several aspects of behavioural adaptation and IVNS usage identified in previous chapters, paying particular attention to the diverse contexts in which they occur.
2. Identify individual difference variants in experiences of behavioural adaptation to IVNS in terms of both demographic factors and responses to self-report scales.
3. Examine the contexts in which drivers experience different aspects of behavioural adaptation to IVNS and analyse these in conjunction with responses to self-report measures to determine any associations between following inaccurate route guidance instructions and measures of perception, attention and/or trust.

5.5 Method

5.5.1 Participants

Table 5.1 below illustrates some of the main characteristics of diary study participants. 20 participants (18 male, 2 female, mean age =36.8 years, SD=7.9 years, range = 24-54 years,) took part in this study. They were all working drivers who at selection, initially reported that they drove frequently (once a month or more) in unfamiliar areas. 19 participants were paid a total of £25 for completing this study and one received just £15 for completing only the first week of the diary study and the questionnaires.

5.5.2 Design

The main body of this research utilised a diary study methodology in which participants were instructed to keep records detailing route guidance and other information they had received from their IVNS, the contexts in which they had used their IVNS and any preferences in the ways they used their IVNS over a 2-week period. An online questionnaire design was also used to collect a range of additional individual difference, attitudinal and behavioural self-report data from participants.

Table 5.1: showing main characteristics of participants in the diary study (N=20)

Item	Categories	No. of participants/descriptive statistics
Gender	Male	18
	Female	2
Country of residence	UK	15
	USA	2
	Australia	1
	Ireland	1
	Japan	1
Age	Mean	36.8 years
	Median	38.5 years
	SD	7.9 years
	Range	24-54 years
No. years with full driving license	Mean	20.1 years
	Median	21 years
	SD	8.7 years
	Range	5-37 years
Approx. mileage past 12 months	Mean	40 thousand miles
	Median	25 thousand miles
	SD	36 thousand miles
	Range	6-114 thousand miles
Self-rated computing skill	Expert	3
	Considerable skills	10
	Moderate skills	5
	Some skills	2
	Insignificant skills	0
	No skills	0

5.5.3 Materials

Participants recorded their diary entries on standardised diary entry forms (see appendix N) remotely using their own computers. Contextual information concerning the date, location, number of passengers and journey familiarity accompanied each diary entry.

The questionnaires were designed using html authoring software, and the results were obtained in a text format to be readily imported into a spreadsheet. 5 scales were used to examine attention, trust, complacency potential and driving confidence. These were the mindful attention awareness scale (MAAS) (Brown and Ryan, 2003), the cognitive failures questionnaire (CFQ - Broadbent et al, 1982), the scale of trust in automated systems (Jian et al 2000), the complacency potential rating scale CPRS (Singh et al 1993), and the driving confidence scale (Parker et al., 2001). Two additional questionnaires were also used:

1. An eligibility questionnaire which was defined by 11 items. This questionnaire collected ratio, ordinal and nominal level data, and some items required text entry. The ratio level items were age, number of years with a full driving license, and number of months using an IVNS. The ordinal level variables concerned the frequency with which respondents made familiar journeys, unfamiliar journeys and drove on holidays/business trips. These items used the following response format:

    1. Never
    2. Hardly ever (e.g. once or twice a year)
    3. Occasionally (e.g. once or twice a season)
    4. Quite often (e.g. monthly)
    5. Frequently (e.g. weekly)
    6. Nearly all the time (e.g. daily)

    The nominal level items were gender, experience with previous IVNS, and destination entry features/other IVNS functions that *should* be allowed while driving. The items requiring text entry concerned the make and model of respondents present IVNS, and respondents' email address.

2. A general purpose questionnaire containing selected items from the study reported in the previous chapter, which was defined by 10 items. This questionnaire also collected ratio, ordinal and nominal level data. Ratio level items were mileage over the past 12 months and 5 years. Ordinal level items concerned self-reported computing skill, IVNS distraction relative to paper maps and perceived degree of correspondence between system-generated route guidance and participants' own individual preference when driving in familiar areas. These items used the same response format as in the study reported in the previous chapter. Nominal level items concerned perceived system reliability and

dangerous/illegal route guidance instructions both received and followed before the diary study. The items requiring text entry concerned participants' email address, and the "other, please specify" option associated with the bold nominal items outlined above.

5.5.4 Scoring the scales

Table 5.2 below shows the scoring procedure for each scale used in this study, and how to interpret the scores.

Table 5.2: illustrating the scoring procedure for scales used in the diary study

Scale	Scoring procedure	Interpretation
Driving confidence scale (Parker et al., 2001)	Sum scores to individual items	A high score indicates low confidence
Cognitive failures questionnaire (Broadbent et al., 1982)	Sum the scores to individual items	A high score indicates more cognitive failures
Mindful attention awareness scale (Brown and Ryan, 2003)	Take the mean of all 15 items to arrive at a value between 1 and 6	Higher scores indicate greater mindfulness
Scale of trust in automation (Jian et al., 2000)	Take the mean score for all trust and distrust items separately	A high trust score indicates high trust and a high distrust score indicates high distrust
Complacency potential rating scale (Singh et al., 1993)	Reverse relevant item responses then sum the scores to individual items except the four filler items	Find the median score. All participants who scored higher than this have a high complacency potential

5.6 Procedure

The following methods were used to recruit participants for this study:

1. Advertisements were placed in a local IVNS dealership.

2. Advertisements were distributed randomly among cars in several local car parks.
3. The study was advertised and promoted on the same IVNS and driving related internet forums, bulletin boards and mailing lists as the previous surveys.
4. The study was advertised and promoted on several specialised internet forums, bulletin boards and mailing lists aimed at worker drivers (e.g. couriers, delivery drivers, logistics drivers etc.)
5. Emails promoting the study were sent out to several employers of worker drivers.
6. IVNS user-survey participants were invited to email the researcher if they wished to participate in further IVNS user studies.

All study advertisements (see appendix O) briefly described the pre-requisites of participation (e.g. IVNS users, drivers with full driving license, email access), the payment plan and responsibilities of participation (e.g. complete diary entries whenever IVNS is used, type and email diary entries once each week, complete associated scales). They also included a website address for prospective participants to visit and complete an eligibility questionnaire, which among other questions, asked them to provide their email address for correspondence (see appendix P). Therefore, all participants who initially expressed interest in participating in the study were self selecting. Only respondents who indicated in the eligibility questionnaire that they drove frequently (once a month or more) through unfamiliar areas were invited to take part in the study. (see section 5.4.1). Those who were selected were sent a participant information pack (see appendix Q) which outlined the principle areas of investigation and provided detailed instructions as well as a personalised timetable showing approximate dates for completion of study phases 1 and 2 (see appendix R).

Participants were instructed to read the participant information pack carefully, and then, over the course of the next 2 weeks, to complete a separate diary entry every time they thought that their user-experience fell within the parameters of behavioural adaptation. They were asked to complete their diary accounts as soon as possible after their user-experiences, and to email all diary entries for a week at the end of each week (as detailed in their timetable). They were instructed to complete the 5 questionnaires at their convenience over the 2-week study period. They were paid £5 for completing the questionnaires and a further £10 for submitting each set of diary entries.

5.7 Results

5.7.1 Sample characteristics

Most driver age bands were well represented in the sample, although female drivers and those over the age of 50 were somewhat under-represented (see figure 5.1). Participants had held a full driving licence for an average of 20.05 years (range=5-37 years, SD=8.7 years). Using the driving experience classification scheme devised by Rothengatter et al. (1993) only 1 participant was an inexperienced driver, 4 were experienced drivers and 15 were very experienced drivers. Most participants lived in the UK, USA or Australia, and more than half (N=13) considered themselves expert computer users or as possessing considerable skills, and they all possessed at least some or moderate computing skills.

The majority of participants used separate (nomadic) or PDA/mobile phone based IVNS, with only 2 participants using integrated systems (see figure 5.2). All participants used IVNS with tactile interfaces only. For most participants (N=13), the IVNS featured in this study was the first they had owned. Participants had been using their IVNS for an average of 30 months (range = 1-132 months, SD =29.9 months). Although most participants have been using an IVNS for under 2 years, a significant proportion has been using one for much longer (see figure 5.2).

Figure 5.1: showing the age distribution and gender of diary study participants (N=20)

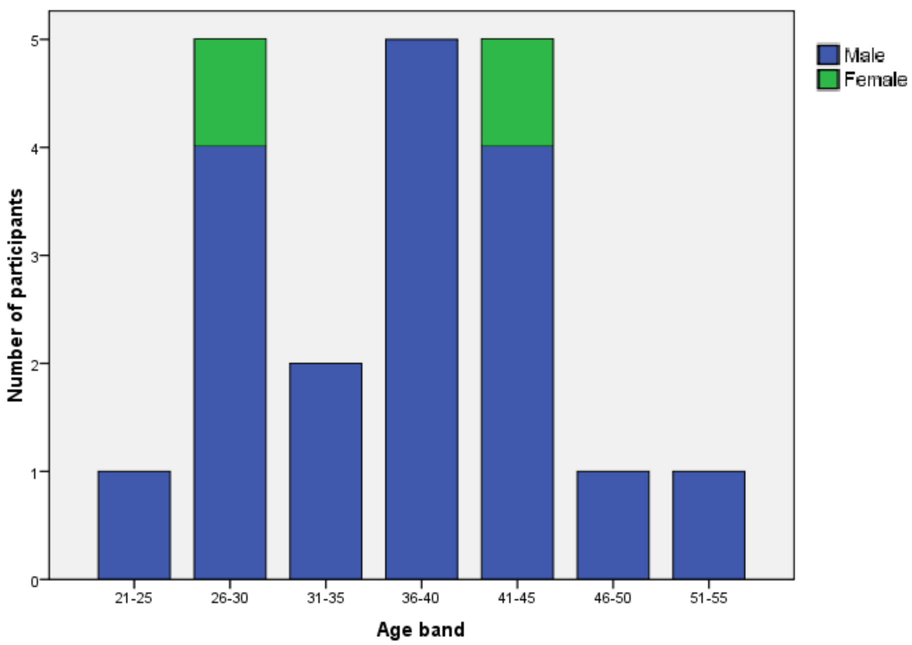


Figure 5.2: pie chart showing the range of IVNS used by diary study participants[3] (N=20)

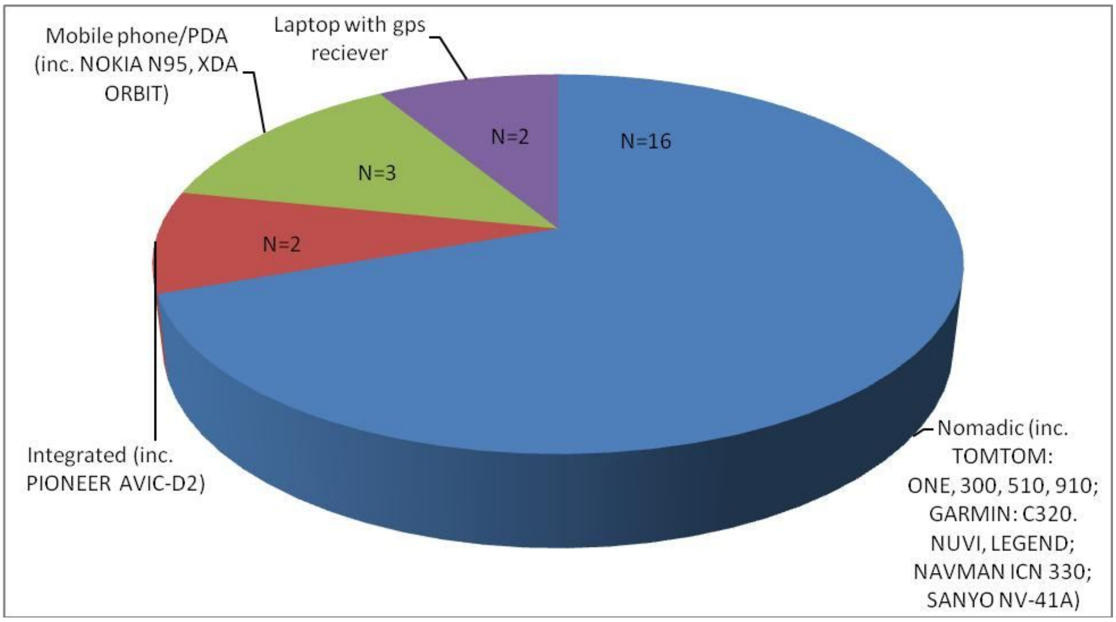
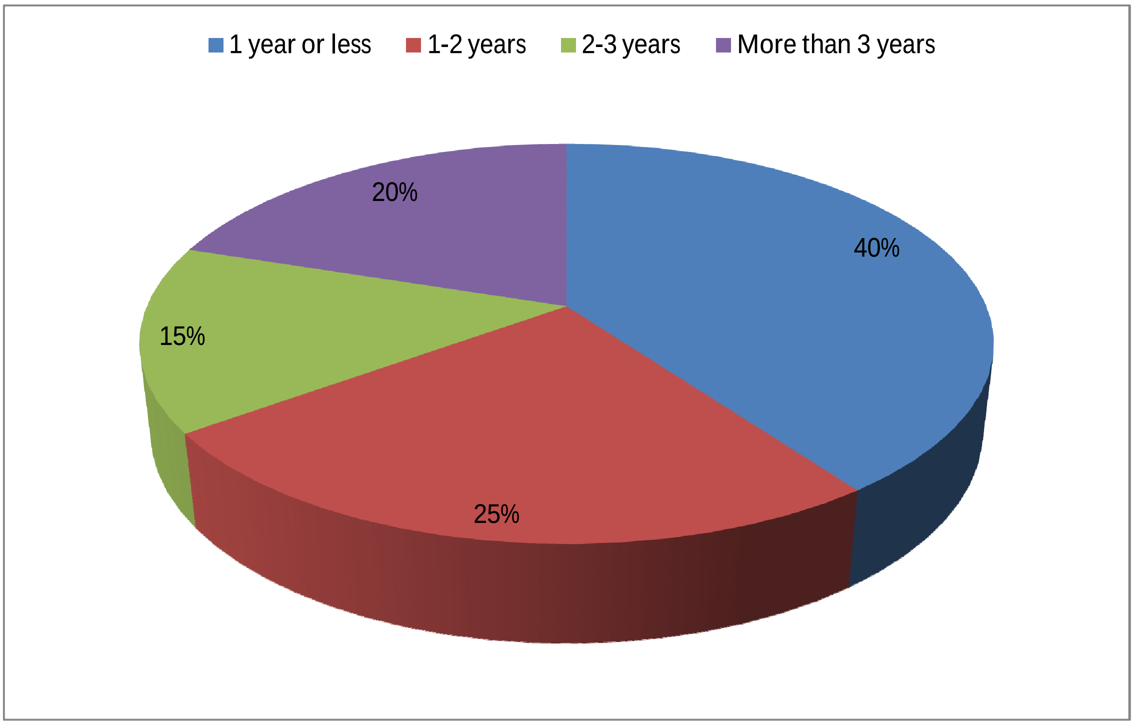


Figure 5.3: pie chart showing the length of time diary study participants had been using an IVNS (N=20)



[3] The number of systems featured in figure 5.2 add up to greater than 20 because some participants used more than one IVNS

5.7.2 Classifying diary entries and questionnaire responses

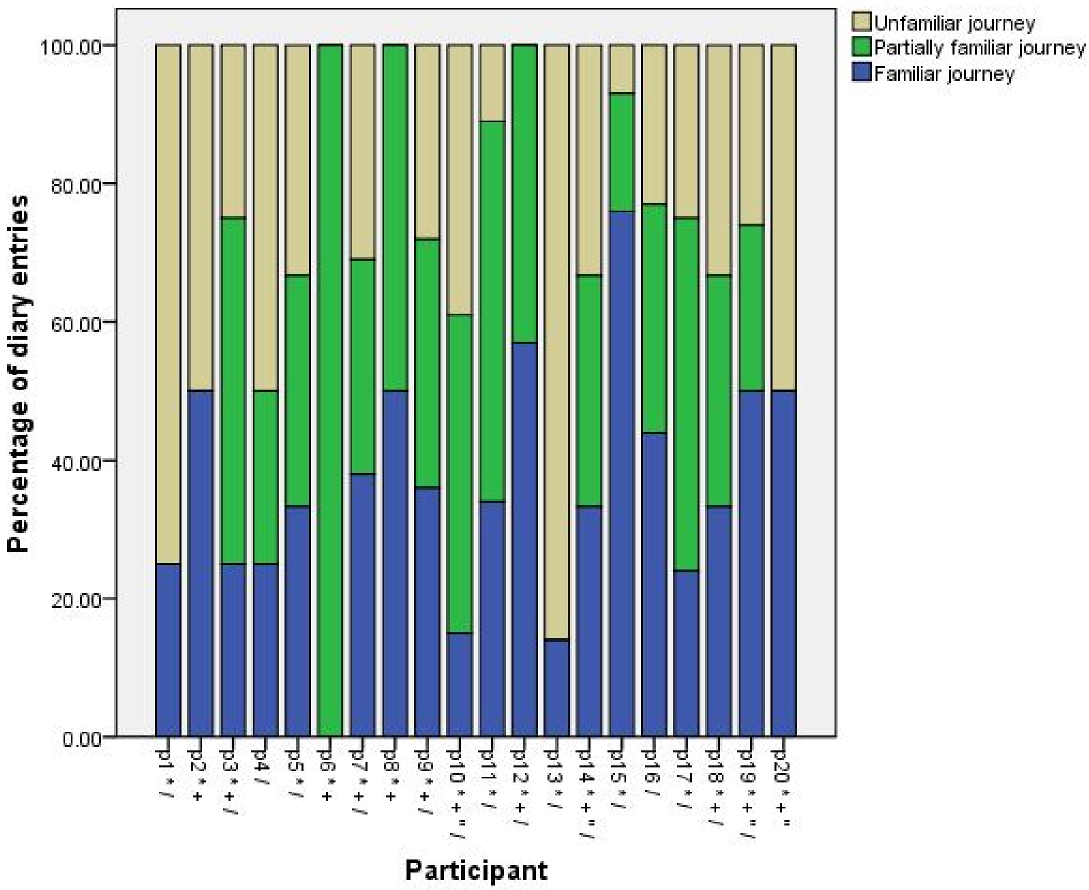
Participants' diary entries were examined in detail. They were classified according to three main criteria. Firstly, all entries which mentioned engagement in any form of interaction with the IVNS were highlighted. System interaction encompassed destination entry by address, postcode, stored location or POI, changing settings, manipulating the map, browsing POI and any other occasion in which participants physically interacted with their IVNS (e.g. by touch screen, keypad, buttons). These entries were further classified according to whether the form of system interaction could be considered as positive or negative (in terms of safety). Positive system interaction included all cases in which participants physically interacted with their IVNS while stationary in their vehicle (entries concerning system interaction outside of the vehicle are shown later with user preferences). Negative system interaction included all cases in which participants physically interacted with their IVNS while driving.

Secondly, all entries in which participants mentioned they had received inaccurate route guidance information or in which their systems had displayed poor/inefficient routing performance were also highlighted. Inaccurate guidance information was further classified according to whether it could be considered as dangerous/illegal, and according to whether participants had followed it. In addition to the diary entries, participants were also asked to report any occasions in which they had received or followed dangerous/illegal guidance from their IVNS before the study began.

Thirdly, diary entries were classified according to whether they mentioned any user preferences. Participants were encouraged to illustrate as completely as possible the ways in which they use their IVNS. On many occasions these preferences highlighted instances in which participants appear to have adapted both their strategic and tactical driving (and non-driving) behaviour to accommodate a range of system characteristics. In many cases participants also offered suggestions and opinions concerning a range of topics, these are also illustrated.

Contextual information concerning route familiarity accompanied each diary entry. Although most entries concerned familiar journeys, a significant proportion concerned partially familiar or unfamiliar journeys. Figure 5.3 shows the percentage of diary entries recorded by participants for familiar, partially familiar and unfamiliar journeys. It also highlights participants who received inaccurate and dangerous/illegal route guidance instructions, those who followed dangerous/illegal route guidance instructions and those who engaged in negative system interaction, during the diary study. Clearly most participants made all 3 types of journey over the course of the diary study and a significant proportion of diary entries concerned unfamiliar and only partially familiar journeys.

Figure 5.4: graph showing the percentage of diary entries recorded by participants for familiar, unfamiliar and partially familiar journeys (N=20)



Please note: Journey familiarity for p13 was inferred for diary entries in which this contextual information was withheld

*Key: * received inaccurate route guidance instructions during the diary study*

+ received dangerous/illegal route guidance instructions during the diary study

“ followed dangerous/illegal route guidance instructions during the diary study

/ physically interacted with their system while driving, during the diary study

5.7.3 System interaction while driving

66 respondents initially expressed an interest in taking part in this study by completing an eligibility questionnaire which contained a list detailing various forms of IVNS interaction. Just like in the IVNS user survey, they were asked which of these, if any, should be accessible to drivers while they are driving (see figure 5.5).

Also following the IVNS user survey, diary study participants were asked whether they thought that using an IVNS while driving has affected the level of attention they pay to surrounding traffic and road signs relative to traditional navigational methods. Nearly half of participants thought that using an IVNS instead of traditional navigational methods had increased or slightly increased their attention (N=9), while just over a quarter (N=6) thought it had decreased or slightly decreased the level of attention paid to these external stimuli.

Figure 5.5: showing different forms of system interaction that participants/respondents in the IVNS user survey, eligibility questionnaire and the diary study, thought *should* be allowed while driving.

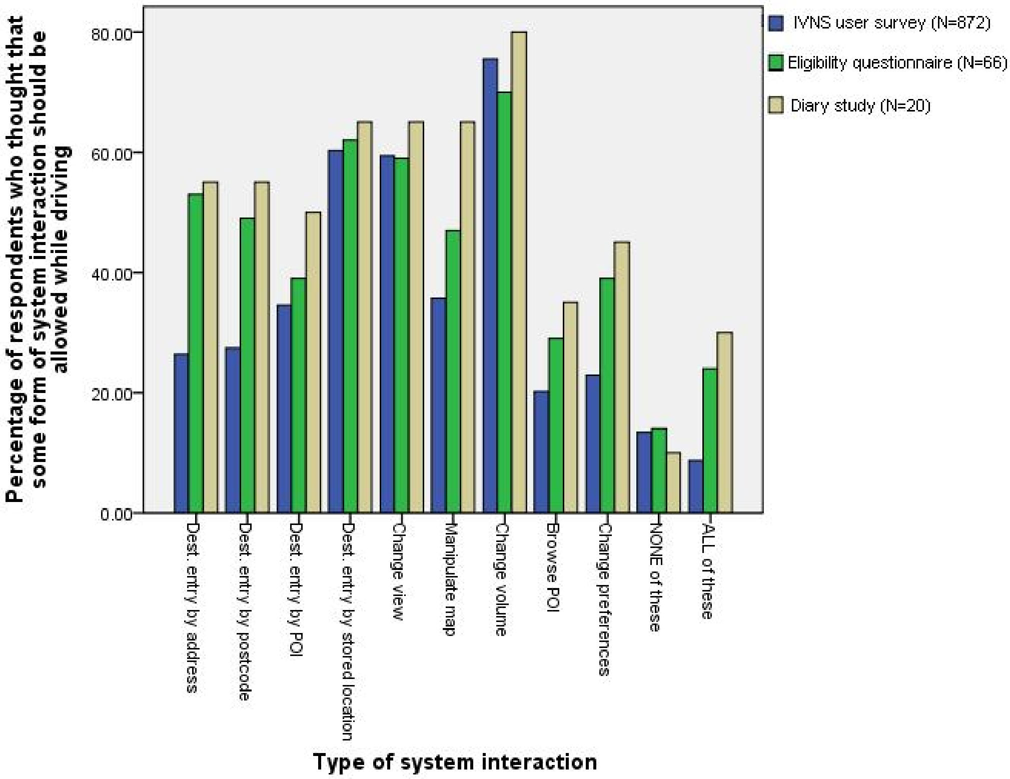


Table 5.3 shows a selection of qualitative contexts in which participants described interacting with their system while driving during the diary study. Further analyses compared the characteristics of participants who physically interacted with their IVNS in some way during the diary study (N=16) with those who did not (N=4). In most cases both groups were broadly similar, but there were some differences. Those who had used their system while driving:

- Were significantly younger ($t(18)= -2.664$, $p<0.05$).
- Had held their driving licences for significantly less time ($t(18)= -2.083$, $p<0.05$).

Chapter 2 described how most studies which have examined system interaction while driving have focused solely on destination entry tasks, due to their relative complexity. Table 5.3 shows that in this study, many cases of negative system interaction using the present definition involved fairly menial/simple forms of interaction (e.g. zooming, adjusting the map, scrolling through POI). So negative system interaction was redefined to include only those diary entries in which participants reported that they entered destinations while driving (i.e. destination entry by address, postcode, POI or stored location). Unfortunately it was not possible to redefine in terms of the length of time taken for the interaction or the number of key presses it entailed because not all participants provided this contextual information (although they were asked to in the participant information pack). The analyses showed that compared to those who had not entered destinations while driving (N=14), those who had (N=6) were:

- Significantly younger ($t(18)=-2.897$, $p<0.01$)
- Had held their driving licences for significantly less time ($t(18)=-2.235$, $p<0.05$).

Table 5.3: showing a selection of the contexts in which diary study participants physically interacted with their IVNS while driving (N=16) during the 2-week timeframe (only cases with mostly complete contextual information are shown).

Participant	IVNS	Route familiarity	Reason for system use	Method of system use	No. keystrokes	Length of time for system use	Traffic situation	Perceived distraction
p11	TOM TOM GO 300	Partially familiar	To find supermarket to buy sandwich	*Entered destination from stored POI*	*8*	*less than 10 seconds*	*Began whilst stationary at lights and continued after setting off*	*No significant impact on attention to driving*
		Familiar	Change volume	*Move finger over slider bar on screen*	*2 attempts*	*5-6 seconds*	*quiet country road*	*Diverted attention a little from driving to touch correct area of screen. Minimal impact on safety*
		Partially familiar	To find petrol station on route	*Selection from screen not data entry*	*7*	*7-8 seconds*	*road quiet*	*Minimal distraction as no data entry just selection*
		Partially familiar	Determine route planned and change destination	*touchscreen selection and dragging*	*12+*	*2 mins*	*relatively quiet road*	*I found the 2nd stage quite distracting as I couldn't ask the device to travel via a road name, but had to find a place along route and navigate via this point. This involved dragging the map on screen*
		Unfamiliar	Looking for restaurant	*Browse POI*	*8*	*15 seconds*	*motorway was busy*	*Slowed down to about 50mph and performed tasks in stages to minimise distraction*
p16	UNSPECIFIED INTEGRATED	Familiar	lunch from favourite sandwich shop	*typing destination entry and scrolling though choices*	*unknown*	*about 2 minutes*	*Traffic was tame enough not to cause any issues*	*I feel I drove safely and mostly distraction free*

Participant	IVNS	Route familiarity	Reason for system use	Method of system use	No. keystrokes	Length of time for system use	Traffic situation	Perceived distraction
p9	GARMIN NUVI 200	Unfamiliar	to zoom out to recheck route	*zoom out*	*a few*	*unknown*	*a straight major road with no other traffic around*	*Don't think I was distracted from driving for more than a second, in a safe location*
		Unfamiliar	obtain bigger picture of map	*zoom in*	*a few*	*unknown*	*route was fairly straight forward*	*Checking my system was cursory and didn't distract me from driving*
		Unfamiliar	zoom in on map to important junction where I had to make a turn	*zoom in and zoom out*	*several*	*unknown*	*major cross country road*	*I went through routine of zooming in and out two or three times, picking my spot for the button presses to minimise any potential for compromising road safety*
p10	AUTO-ROUTE 2007 ON LAPTOP WITH GPS RECEIVER	Unfamiliar	Re-enter postcode as system fell to floor and reset	*Retrieve postcode from paperwork and enter on non user friendly interface*	*unknown*	*unknown*	*unknown*	*This took almost all of my concentration to do…I didn't stop as its very difficult to find a place to pull over when you drive a lorry*
		Familiar	Press ok button to acknowledge I was in a mobile speed trap area	*tapping screen*	*10-12 times due to system malfunction*	*2 or 3 mins*	*dual carriageway night time busy road*	*Found myself very distracted……it was getting dark and it was a busy road, I really didn't need to be distracted at that moment in time*

Participant	IVNS	Route familiarity	Reason for system use	Method of system use	No. keystrokes	Length of time for system use	Traffic situation	Distraction caused
p13	NAVMAN ICN 330	Familiar*	entering a regular address	*key presses*	*4*	*unknown*	*unknown*	*These roads I am used to so no need to worry about anything*
p4	TOM TOM GO 910	Partially familiar	Find alternative route due to heavy traffic	*route recalculation*	*Unknown*	*2 mins*	*Heavy traffic due to roadworks*	*No safety problems*
p1	TOM TOM 510	Unfamiliar	partially entered destination	*typing address*	*6*	*unknown*	*very busy street with cars stopping and starting all the time*	*I wasn't entirely happy doing this as my attention was taken away from driving…I did about 6 keypresses while driving then pulled over to complete the rest while parked*
p12	GARMIN	Partially familiar	display map	*turned unit on a pressed button twice to display map*	*3*	*unknown*	*the road was busy*	*I don't feel doing this distracted me from my driving*
p18	TOM TOM ONE AND GARMIN STREET PILOT I3	Partially familiar	thought he knew the way home but got lost so used the navigate home function	*pressed navigate home*	*couple of keypresses*	*less than 15 seconds*	*heavy rush hour traffic*	*I dont think my attention was significantly diverted from driving as this was a simple task*
p3	PIONEER AVIC-D2	Familiar	load saved address	*load saved address*	*3*	*10 seconds*	*residential road*	*I always kept eye on road entered it without incident*

***** *Route familiarity implied from text as this participant withheld this contextual information from some diary entries*

5.7.4 Trust and complacency ratings

Table 5.2 showed that the CPRS was scored using a median split procedure so by definition; there were an even split of participants with high and low potentials for complacency, these ranged from 23 to 46. There was an association between age and complacency potential. Using a median split procedure (median age=37 years), participants were classified as either young or old. The older group (those >=37 years) had a significantly higher potential for complacency than their younger counterparts ($t(18)= -2.441$, $p<0.05$).

Section 5.1.2.2 showed that trust ratings were made on a scale ranging from 1 (not at all) to 7 (extremely), and that the scale contained both positively framed (i.e. trust) and negatively framed (i.e. distrust) questions. Figures 5.6 and 5.7 show that a large proportion of participants indicated a high degree of trust in their IVNS, as the majority of responses for the positively framed questions ranged from 4 to 7, and the majority of responses to negatively framed questions ranged from 1 to 3.

Figure 5.6: showing participants' responses to positively framed (i.e. trust) questions (N=20)

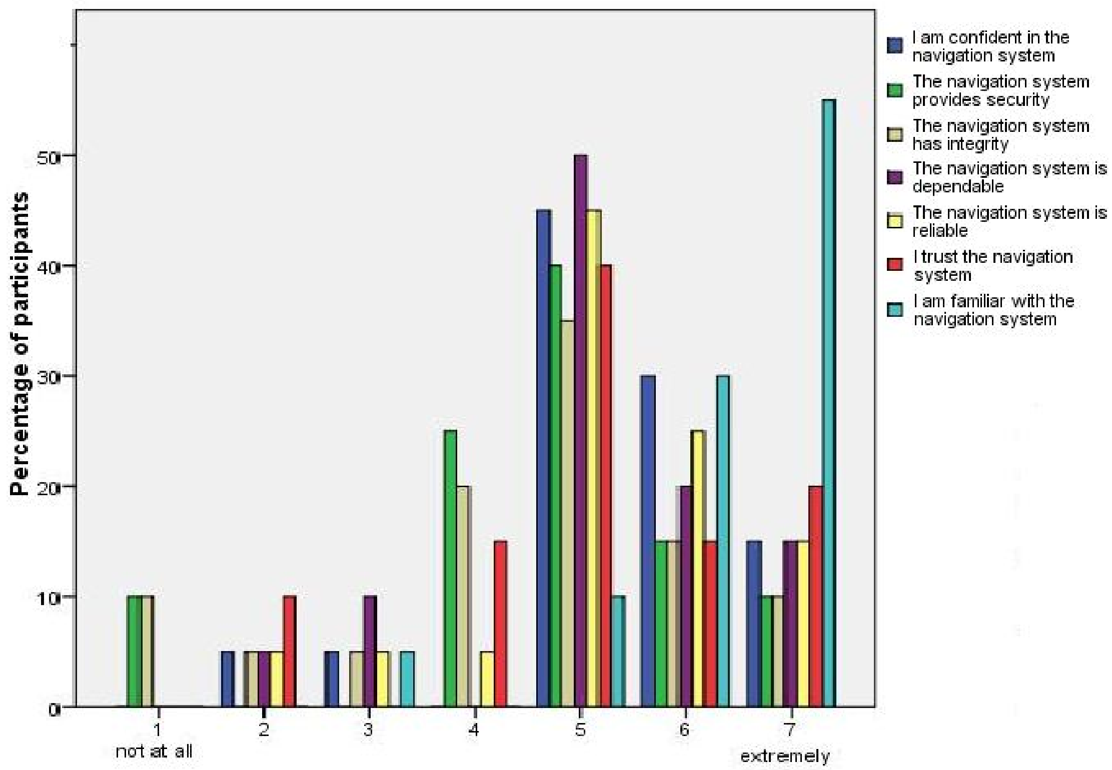
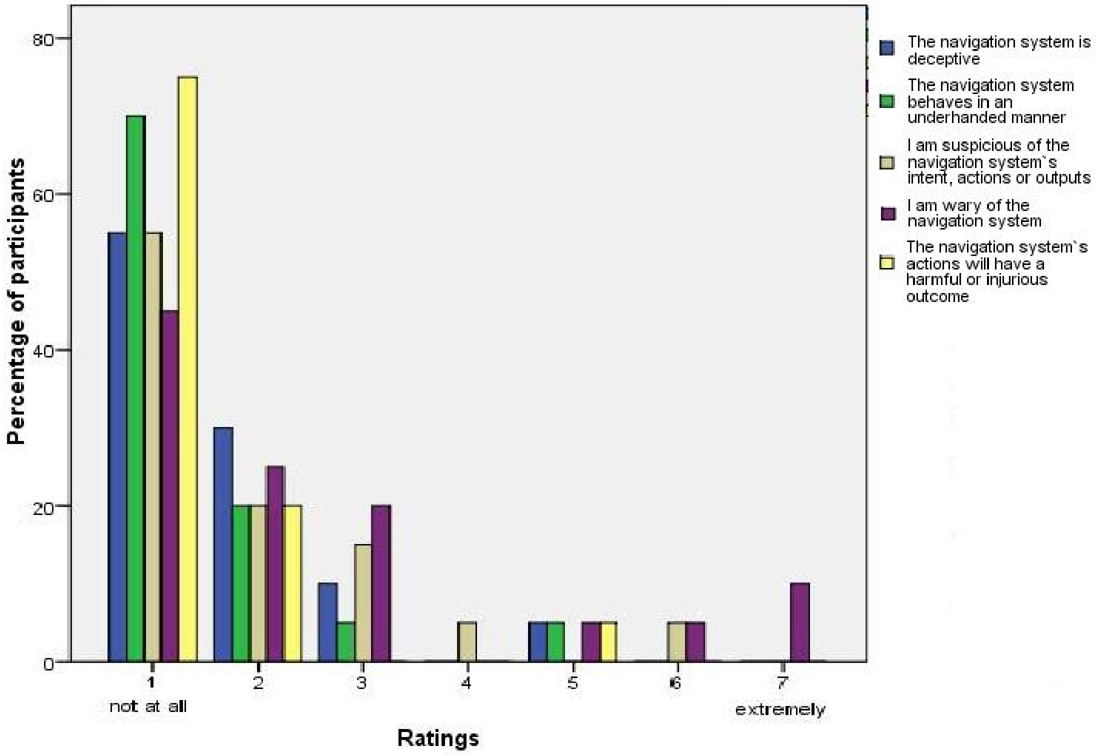


Figure 5.7: showing participants' responses to negatively framed (i.e. distrust) questions (N=20)



IVNS experience was associated with distrust. Participants who had been using an IVNS for less than or equal to 12 months, distrusted it significantly more than those who have been using one for longer than this (Mann Whitney U(18)= 20.5, Z=-2.152, p<0.05). Differences between groups were most pronounced for the individual distrust item "*the system is deceptive*" (Mann Whitney U(18) = 11, Z=-3.177 p<0.01).

In some cases participants' diary entries explicitly mentioned trust/distrust and reliance in relation to their IVNS. Sometimes these concepts were mentioned in the contexts of unfamiliar journeys, for example:

The journey I took today was for a drop in a completely new street so I was relying on the sat nav – Participant 10

I left the M62, got onto a smaller road (didn't know which one, I trusted the Tomtom), so followed the instructions – Participant 7

I had confidence in the GPS to keep us going in the right direction when we would normally have given up or stuck to more major roadways – Participant 17

At times these concepts were mentioned because of general system/routing experience, for example:

I was in a hurry to make a flight, but also used a paper map due to distrust of nav system routing - Participant 3

I do find that the GPS gives a new sense of confidence and that you tend to look at every road sign less because the GPS knows where you are going – Participant 17

Im getting used to the unit, therefore I have a deep mistrust of it now. This means I have started to regularly ignore it and go my own way – Participant 10

5.7.5 Inaccurate route guidance information received and followed

Most participants appeared to be fairly satisfied with their system`s routing capabilities. When asked about the degree of correspondence between their system`s routing advice and their own individual preference when travelling in familiar areas, only a quarter of participants rated it as low or very low, and just over a quarter (N=6) rated it as moderate. However, only 2 participants considered system-generated route guidance to be completely reliable all the time, and 12 participants reported that they had received dangerous/illegal route guidance instructions from their IVNS before the study began. Nearly half of these participants (N=5) had also followed dangerous/illegal route guidance instructions before the study began, on at least one occasion (see table 5.4).

All but one of the participants reported that they had received inaccurate or poor/inefficient route guidance from their IVNS at some point during the diary study. These diary entries are shown in table 5.5. Table 5.6 shows inaccurate instructions followed by participants both during the 2 weeks of the diary study and before the study began. In both tables a distinction is drawn between instructions that were merely inaccurate or poor/inefficient and those that may be considered as dangerous/illegal. To avoid repetition, all cases illustrated in table 5.6 were omitted from table 5.5.

Table 5.4: showing dangerous/illegal system-generated route guidance instructions participants had received and followed before the study began

Dangerous/illegal guidance	Number of participants who received dangerous/illegal guidance (N=20)	Number of participants who followed dangerous/illegal guidance (N=12)
Drive through one way/no entry street	6	1
Perform prohibited manoeuvres	9	n/a
Drive through pedestrianised zones	2	n/a
Inappropriate width/height/weight	5	2
Drive in bus lanes/tram lines	1	n/a
Drive on cycle tracks	1	n/a
Drive on private road/farm tracks	5	2
Drive through fjords/rivers	2	n/a
Use roads with excessive incline	1	n/a

Further analyses compared demographics and various scale responses of two groups of participants: those who had followed dangerous/illegal route guidance instructions either during the study or before the study began, and those who had not[1]. There were no significant differences between the groups regarding the number of months they have been using an IVNS, mileage, MAAS score or CFQ score, but those who had followed them:

- Considered themselves to be significantly less skilled at using computers (Mann-Whitney $U(13) = 8.5$, $Z=-2.239$, $p<0.01$).
- Were significantly older ($t(13)=3.072$, $p<0.01$).

[1] These analyses only concerned those who had actually received dangerous/illegal system-generated route guidance instructions (N=15) and either followed them or not. Those who had not received them were excluded.

- Had held their driving licences for significantly longer ($t(13)= 3.834$, $p<0.01$).
- Considered their system to be significantly *less reliable* (Mann-Whitney $U(13) = 9.5$, $Z=-1.981$, $p<0.05$).
- Were significantly *less wary* of their system (Mann-Whitney $U(13) = 6.5$, $Z=-2.372$, $p<0.05$).
- Were significantly less confident drivers (Mann-Whitney $U(13)=9$, $Z=-2.017$, $p<0.05$).
- Had a significantly higher potential for complacency ($t(13)=2.432$, $p<0.05$).

Table 5.5: showing diary entries in which participants' IVNS provided inaccurate or dangerous/illegal route guidance instructions or poor/inefficient routing performance (N=19)

Participant	Diary entry	Route familiarity	Dangerous/illegal, inaccurate or poor/inefficient
p11	*I reached a roundabout at which I knew I needed to turn right…The device failed to recognise the roundabout and instead instructed me to bear left (there is a slight kink in the road prior to the roundabout).**	Familiar	Inaccurate guidance
p18	*I was instructed to turn left and continue to the next roundabout…Halfway down the road there was a dead end sign, followed shortly by a no-entry sign. I was forced to do a u-turn.*	Unfamiliar	Dangerous/illegal guidance
p19	*I was presented with a restricted time zone road which was not detailed in the guidance, the restricted road was for buses and taxis during daytime operation…The map was 2006 UK version and this road has been there for a very long time with this restriction in place.*	Familiar	Dangerous/illegal guidance
	I decided to detour/find alternative route…it decided to take me on a route which then doubled back on itself to the same roundabout I diverted from	Partially familiar	Inaccurate guidance
	On entering Calais…decided to try and re-route me to re-direct to the ferries. Even after booking into the channel tunnel main entrance, the navigation was unable to correctly inform me to board the channel tunnel connection until I was within 1.0km of boarding the train	Partially familiar	Inaccurate guidance
	Once on the other side (UK) the navigation failed to continue with the directions and…tried to send me back to the channel tunnel back into France.	Partially familiar	Inaccurate guidance
	Navigation was accurate up until pulling up on to my driveway directly in front of my home. The icon on the screen then changed to display my position as being on a parallel road to mine…the following morning…the map showed the correct location of the vehicle	Familiar	Poor/inefficient routing performance
p9	*As I approached the junction I noticed a weight limit sign which prohibited me from using the recommended road*	Unfamiliar	Dangerous/illegal guidance
	The route my mapping system suggested was to turn off the motorway system and to travel through a part of the city.As I drive a large lorry and there is a motorway ring around the city, I ignored this part of the suggested route and chose to follow the motorway ring	Familiar	Poor/inefficient routing performance
	The route my system suggested was to follow two sides of a square and then to start down the third side for a relatively short distance, all on motorway. I know that there is a lot of construction work being carried out on the second side of this square. I therefore decided to ignore this part of the route	Partially familiar	Poor/inefficient routing performance

Participant	Diary entry	Route familiarity	Dangerous/illegal, inaccurate or poor/inefficient
p9 (continued)	*My system always suggests going around the Rotterdam motorway ring in an anti-clockwise direction. I know from experience that traffic moves very slowly on the West-bound Northern side of the ring. So I go clockwise using the West-bound Southern side. This route saves at least 10 minutes*	Familiar	Poor/inefficient routing performance
p6	*The return route was incorrect…a local road has been divided into 2 cul-de-sacs…the system knows there are 2 roads but doesn't recognise that the ends of the 2 roads are blocked where they meet. I knew the route was wrong…I knew the reason why and ignored this instruction*	Partially familiar	Inaccurate guidance
	There were 2 junctions at which roundabout had been placed which did not appear on the Satnav…the general appearance of the roundabout suggested they were fairly new…clearly the verbal instructions being delivered weren't consistent with a roundabout	Partially familiar	Inaccurate guidance
	A road that was closed for road works which the Satnav had wanted me to drive along	Partially familiar	Dangerous/illegal guidance
	The Satnav believed that these roads connected directly with a roundabout, while the reality is that the A310 passes over the A127 on a flyover and there are no direct ramps between the two roads	Partially familiar	Inaccurate guidance
	As I approached this non-existant junction it then asked me to turn left where no road existed…I realised what was happening and ignored this direction	Partially familiar	Inaccurate guidance
	The Satnav wanted me to take an immediate right turn into a residential street. This junction is in fact blocked with bollards and has been for the last 10 years as I learned subsequently	Partially familiar	Dangerous/illegal guidance
p7	*Before I started this study on several occasions when I ignored its instructions I found that my TOMTOM would attempt to route me along "unmade" roads such as farm tracks and very narrow roads*	n/a	Dangerous/illegal guidance
p8	*My TOMTOM 1 version 1 attempted to direct me onto a left turn which was quite obviously a farm track. I noticed that the mapping system within my navigation system showed this track quite clearly as a road.**	Familiar	Dangerous/illegal guidance
	Other instances have included my Satnav directing me to turn into roads which are clearly unsuitable for any vehicle larger than a family car	n/a	Dangerous/illegal guidance
	…tried repeatedly to route me along roads unsuitable for my vehicle size.	Partially familiar	Dangerous/illegal guidance
p13	*In this time the units map went off the road which happened all the time between Nerong and Morlands NSW…the unit gets back on track once on the older road*	Unknown but text suggests unfamiliar	Inaccurate guidance
	Being a new area the unit did not have the street in its memory	Unknown but text suggests unfamiliar	Poor/inefficient routing performance

Participant	Diary entry	Route familiarity	Dangerous/illegal, inaccurate or poor/inefficient
p13 (continued)	*With so many changes to the roads where I travel it sometimes does not recognise the new road…I just keep travelling until it does*	n/a	Poor/inefficient routing performance
p3	*Eventually was taken to road and told to turn down one way street the wrong way. Saw sign and turned the correct direction*	Partially familiar	Dangerous/illegal guidance
	Attempted to load route from work to airport…was unable due to airport name not being in the database…	Unfamiliar	Poor/inefficient routing performance
p20	*I tried to exclude the Taconic state parkway, but it didn't seem to want to do that. So I drove past the entrance to the parkway and then after a few miles it kicked in with a legal route*	Familiar	Dangerous/illegal guidance
	Having some knowledge of the area there were a couple of turns that did not make sense to me from the SatNav. Near Cold Springs, NY it said for me to turn left then a right then a left...when I could have just driven straight	Familiar	Poor/inefficient routing performance
p1	*Satnav asked me to take the exit onto the A1. However, I could see that I actually had to carry on to get to my destination as the sign posts were clear. I carried on and when I glanced at my sat nav screen it showed that I was travelling through empty space*	Familiar	Inaccurate guidance
p14	*The GPS always gets a bit lost when I travel a section of new road that isn't on the CD ROM*	Familiar	Insufficient information
p12	*On route to my delivery the sat nav tried to send me down a road which was far too small and congested for my lorry*	Partially familiar	Poor/inefficient routing performance
p2	*I have noticed several roads that need to be updated on the map, due to alterations to the traffic flow. i.e. one way systems*	n/a	Dangerous/illegal guidance
	… slight variations in road layout, mainly caused by roadworks since the map was published. Most of these were only minor irritants, and were easily overcome	Unfamiliar	Inaccurate guidance
p5	*…was aware that the device was issuing instructions some way behind where I actually was. Meaning I missed a couple of turnings and had to re-route or turn around*	Unfamiliar	Inaccurate guidance
p17	*…a new section of highway had opened in the past week as a bypass around a village and the GPS had us displayed in a field.*	Unfamiliar	Poor/inefficient routing performance
p16	*My friend's address could not be resolved in the navigation system because she lives on a small private road*	Partially familiar	Poor/inefficient routing performance
	since my destination was a government office, it wasn't recognized	Unfamiliar	Poor/inefficient routing performance

Participant	Diary entry	Route familiarity	Dangerous/illegal, inaccurate or poor/inefficient
p16 (continued)	*…ask it directions to a restaurant 5 miles away that I already know how to find. The system plotted an understandable, but poor route there, one that would take me through a couple residential areas, stop signs, and traffic lights.*	Familiar	Poor/inefficient routing performance
p10	*…discovered that it has an annoying tendency to tell me to turn right or left at ALL tight bends in the road and not just at junctions*	n/a	Inaccurate guidance
	The sat – nav had me turn right into a road that didn't exist (luckily I noticed as there was a building there	Unfamiliar	Dangerous/illegal
	I was informed by the sat nav that I had to turn right again into a road that wasn't there. It looks like the road had been converted into a pedestrian precinct, by the looks of it – several years ago	Unfamiliar	Dangerous/illegal guidance
	Upon reaching the destination I discovered that the street was a one way road and the Garmin was trying to take my up it the wrong way. Not impressed.	Unfamiliar	Dangerous/illegal guidance
	I found a street today that didn't appear on the sat nav. When entering the postcode at base I found that it didn't exist	Partially familiar	Inaccurate guidance
p15	*…at work, I had mapped out an itinerary for the trip home using Google mapping…What I didn't know… is that the maps on my navigation system are not as complete or up-to-date as the maps on Google. A few of the roads were missing from my navigation system's maps, putting some of my intermediary waypoints "in the middle of nowhere*	Partially familiar	Poor/inefficient routing performance
	*…the navigation system wanted me to turn left, to intersect the major arterial that links my neighborhood with the office complex where I work. Knowing that there is on-going major construction along this route, I chose to turn right instead***	Familiar	Poor/inefficient routing performance
	… I did keep an eye on it to see which roads were missing. It appears there are two key roads that do not exist on my navigation system's maps – and (as I discovered last week), without them you'll just drive around in a big circle (or two!).	Partially familiar	Inaccurate guidance

** Both of these participants indicated that if they were unfamiliar with the route, they probably would have obeyed inaccurate instructions*
***This participant mentioned this inefficient guidance a number of separate times. Only one of these reports is reported here to give a flavour of the problem.*

Table 5.6: showing inaccurate and dangerous/illegal route guidance instructions that participants followed/obeyed over the course of the 2-week diary study and before the study began (N=8)

Participant	Diary study or before study	Inaccurate instruction obeyed	Familiarity of journey	Potential area of explanation	Inaccurate or dangerous /illegal instruction obeyed
p19	Diary	*There were several occasions where **I was routed onto "D" roads where height restrictions were in place** but not road signed. The height restrictions were buildings which over hanged part of the narrow road which we were travelling on*	Unfamiliar	Trust **and** attention	Dangerous /illegal
	Diary	*I was then taken on a single track road which was a borderline dirt track*	Unfamiliar	Insufficient information	Dangerous /illegal
	Diary	***The SATNAV decided to direct me down** the A43, and then proceeded with minor roads (including unclassified single track roads) all the way to destination. **Followed the directions***	Partially familiar	Trust	Inaccurate
	Diary	***Still I followed the navigation and ended up travelling down minor "B" roads** between Besancon & Nancy ("D" roads which are similar to UK minor "B" roads going cross country) which was unacceptable at the dead of night with no fueling stations in sight.*	Partially familiar	Trust	Inaccurate
	Before	*Width and Height restricted, had to reverse back to main rd and reroute*	n/a	Insufficient information	Dangerous /illegal
P14	Diary	*One of the final roads turned out to be a bicycle path between some inner city garden plots **but on a motorbike it was fine.****	Partially familiar	Proceeding though aware directions aren't accurate	Dangerous /illegal
p1	Diary	*When I arrived at the **postcode I couldn't see the shop and then noticed that the street name on my destination was different to the one given by the post code on my sat nav***	Unfamiliar	Insufficient information	Inaccurate

Participant	Diary study or before study	Inaccurate instruction obeyed	Familiarity of journey	Potential area of explanation	Inaccurate or dangerous /illegal instruction obeyed
p20	Diary	*All went well until it directed me to turn at the next left turn. It was an illegal turn but I had to turn **as it was a fast road and the guy behind me was honking his horn as I slowed down**. There was a legal U-turn ahead **but it directed me to turn here***	Unfamiliar	Proceeding though aware directions aren't accurate	Dangerous /illegal
	Diary	*Instructed me to drive straight for .4 miles which led me over a bridge (over water) **so I did and then it instructed me to 'make a legal U-turn when possible'** so **with some confusion I did and then it said the same thing coming back** over the bridge again.*	Unfamiliar	Trust	Inaccurate
	Before	*Travelling on busy road and **followed navs direction onto an illegal left hand turn, too late to deviate to a legal turn further on***	n/a	Proceeding though aware directions aren't accurate	Dangerous /illegal
p13	Diary	*The unit had not reconized a new road which had been build ...The unit still got me to where I needed to be but maybe add 15mins to the trip. **Because I had never been to the state before I relied on the unit soley.***	Unfamiliar	Trust	Inaccurate
	Before	*Load limit road for access*	n/a	Insufficient information	Dangerous /illegal
p7	Diary	*The satnav directed me off the motorway at a junction. I left the M62, got onto a smaller road (didn't know which one, **I trusted the Tomtom), so followed the instructions**, then it rerouted, so had to turn around, and go back onto the M62 at the same junction.*	Partially familiar	Trust	Inaccurate
p2	Before	*Drive on private road/farmtracks*	n/a	Insufficient information	Dangerous /illegal

Participant	Diary study or before study	Inaccurate instruction obeyed	Familiarity of journey	Potential area of explanation	Inaccurate or dangerous /illegal instruction obeyed
p10	Diary	***The overview map on the sat nav confirmed to me that it was open at both ends and once I had made the delivery I could see that I would not have to turn around****. I made my drop and as I approached the end of the street I found that the end had been blocked by a small wall which had effectively created a cul-de-sac. It looks like it had been like that for a while as there was not just a wall but a footpath on the other side.*	Unfamiliar	Trust	Dangerous /illegal
	Diary	*After setting off to my destination I discovered that* ***it had taken me to an address which was two streets away,*** *this meant that I was late for a drop and looked very silly. When checking the settings I had inputted the postcode correctly. Because of this mis-information I had to perform a dangerous U turn in a crescent not designed for a large vehicle.*	Partially familiar	Trust	Inaccurate
	Diary	***Start following the directions and suddenly find that after about 15 minutes of driving*** *that its leading me back to Poole*	Unfamiliar	Trust **and** attention	Inaccurate
	Diary	*I am on a 2 lane road with nowhere to turn and I am faced with Dorchester high street. A road that vehicles over 7.5 tons are NOT allowed.* ***I had no other choice but to progress normally*** *and hope for the best. I have weight limits installed to the unit and bridge heights and it didn't let me know once. I even checked as I sat there in traffic and it showed nothing.* ***I had to break the law in order to get the drop done and this was because of the routing the sat nav gave me****. I learned later that there is another access road but this was not used by the Unit.*	Partially familiar	Proceeding though aware directions aren't accurate	Dangerous /illegal
	Before	***I have been guided down roads that are too narrow and found that I could not turn HGV around and had to keep going***	n/a	Proceeding though aware directions aren't accurate	Dangerous /illegal

Please note: Bold text denotes reasoning for potential area of explanation

** This participant used his IVNS in his car most of the time, but on this particular occasion he had taken his motorbike with it strapped around his neck*

5.7.6 User preferences and suggestions/opinions

Participants mentioned a diverse range of user preferences encompassing issues such as accommodating routing (in)accuracy/(in)efficiency, minimising distraction, utilising timing and distance information, adapting to faults and system-use in familiar areas. In some cases diary entries suggest possible strategic and tactical level behavioural adaptation (see table 5.7).

In many diary entries participants made suggestions or offered opinions about a range of pertinent topics. Some participants used more than one IVNS during the two weeks and offered detailed comparisons between different units in terms of ease of use, functionality, accuracy etc… Many participants mentioned features of their IVNS that they particularly liked/disliked, for example:

I like the speed and timing functions of the unit to keep track of my driving… When I arrived back to work, I was able to view the destination distance, which I used to provide my employer with the miles travelled on the trip – Participant 17

I was glad that the toll booth locations were on the system with a little bit of warning – Participant 16

In the past I have used the unit for distance…this is very useful when I fill out a log book – Participant 13

On the way had a phone call from the office, where are we. It was easy to tell them you always have your exact position on the screen – Participant 7

"… *tendency to tell me to turn right or left at all tight bends not just junctions .This can be quite distracting as sometimes there will be a junction near to a bend and I have to keep double checking to make sure it actually wants me to go straight. This is another reason for me to have to take my eyes off the road and my mirrors"* – Participant 10

Many participants offered suggestions concerning features they would like to see in future IVNS designs. For example, most of the HGV/LGV drivers wanted to see systems becoming available that incorporated vehicle dimensions (e.g. width, weight, height) into route planning algorithms:

One feature I would like available on a sat-nav is an HGV routing system. If you program in either most direct, or quickest, it has a tendency to route you in places where you wouldn't put you own car, let alone a truck. – Participant 2

I would love to see a map for trucks with routes to detour load limit roads, Low Bridges, etc. – Participant 13

Other drivers wanted to see systems with extra functions or better design considerations, for example:

At this point, I wish the system had a doppler radar function so I could see the extent of the storm system and plan my trip a little better while I'm already on the road. – Participant 16

I hate wasting time before I go programming the GPS. There are so many options that I never use that I wish there was a faster way to skip them. Perhaps some form of fuzzy logic that learned the choices I used most and hid the rest away until specifically asked for – Participant 14

Some participants gave detailed comparisons between IVNS and paper maps. Although they highlighted the pros and cons of each, in most cases IVNS were favoured overall, for example:

Before my purchase I would spend endless hours looking at maps and still get lost. This kind of wasted time I could not afford. Due to driving a 10 hour period I would be very tired and all I'd want to do is go to sleep. With roads being so narrow it was also very hard just to pull over and take a look at a map, so I found myself driving for miles just to have a look at a map. – Participant 13

When I used maps, usually didn't stop to find my way around, had to read the map whilst driving. That's even worse than entering a few numbers into the satnav. (However I do not like the idea when other drivers don't keep their eyes on the road). – Participant 7

When it's working properly I believe that a sat-nav system is safer than paper maps. With paper maps you have to find the correct page, find the right road, locate where you are on that road and plan where you need to go next, do most of these as you drive, do this almost every time you need to check. With a sat-nav (my system at least) you are always on the correct page, your proposed route is marked, your exact location is marked, it's constantly updated and constantly visible. It takes a second or less to glance at your map to see where to go next so you can check whenever you like. You should stop to check your map (paper or sat-nav) each time, but that is rarely convenient. You would have to find somewhere safe to park each time, which can be bad enough in a car, let alone a 44 tonne lorry. By the time you've done that, the sign posts which might help you are out of sight and you've probably passed the turning you needed anyway. – Participant 9

Issues concerning system maps and map updates were also popular among participants. For example:

When purchasing some GPS systems where the cost is between £100-£150, it almost makes sense to not bothering to purchase updated/latest uk/ european cd maps and just purchase a new gps. As and when I feel the need to update my maps I will weigh up the cost of purchasing either the maps or a new GPS – value for money ! - Participant 19.

I have heard that uk roads change by 15% every year and I think that sat navs require a much better map update system as this is not satisfactory. When a customer pays for a unit it can already be out of date at the point of purchase. – Participant 1

How come the maps in this unit have this grocery store, opened less than a year, on the map but don't know the address of the government building where I work that has existed for more than 8 years? - Participant 15

My favourite may not always meet the 'fastest' or 'shortest' criteria of the mapping program – Participant 17

Some participants also vented their frustrations about being prevented from being able to engage in various forms of system interaction while driving. For example:

I still am frustrated over not being able to enter some typed requests when moving - Participant 16

Participants offered suggestions and opinions about a wide range of other topics beyond those shown above. Further attention to these suggestions/opinions would be outside the scope of the thesis but there is little doubt that further analysis of some of these insightful accounts could usefully inform future IVNS design.

Table 5.7 : showing how participants' user-preferences and user behaviour illustrate strategic and tactical level behavioural adaptation to their IVNS (N=10)

Participant	Behavioural adaptation	Level of driving behaviour	Diary entry extract
p19	Positioning the IVNS in such a way as to minimise disruption to view	strategic	*During daylight usage with bright sun light, the LCD screen is difficult to see as the sunlight directly hits the SATNAV screen.* ***To avoid this, the SATNAV requires repositioning away from the windscreen and lower down to avoid direct sunlight***
	Expanding the system to overcome its limitations	n/a	***The SATNAV would find it difficult to calculate a long trip****…memory required for calculating routes…required 50% or more…* ***I now use a separate card for UK and a separate card for European maps.***
p9	Re-checking calculated routes	strategic	***I then check the route for anything unsuitable****. As I drive a 44-tonne truck this stage is important.* ***I will need a large area to turn round in.***
	Re-checking calculated routes	strategic	***I was suspicious of part of the route*** *as it took me through a small village,* ***so planned an alternative route***
	Adjusting map/routing preferences	strategic	*After arriving at the location* ***I made adjustments to my system maps…made the system make a new route*** *which then avoided the [small]village I had driven around using the roads I actually used*
	Regularly ignoring system advice in favour of individual preference	strategic/tactical	*My system always suggests going around the Rotterdam motorway ring in an anti-clockwise direction.* ***I know from experience that traffic moves very slowly... So I go clockwise****...saves at least 10 minutes.* ***I haven't made the adjustments to my map system to prevent this routing as I know this area so well.***
p17	Ignoring system advice in favour of individual preference	strategic	*auto routing…* ***does not always pick out my preferred route when multiple options exist…more prevelant near my home where I have a good understanding of traffic patterns and favourite roads****…the GPS will recalculate a few times until it is in agreement with my choices.*
	Preference for passive system usage in familiar areas	tactical	*I am very familiar with most of the roads* ***and mainly use the GPS as a monitor of where I am in map mode…I like the speed and timing functions of my unit to keep track of my driving***
	Re-checking calculated routes	strategic	***I still carry a paper map and use it for the high level view of my route planning***
	Favouring use of one system over another system and peers	strategic	*I was doing the driving and* ***always bring my Garmin C340 as my 'copilot' as I can't always rely on my peers map reading skills*** *and* ***I have found the Neverlost GPS system in Hertz vehicles to be cumbersome to use***
	Route planning before a trip	strategic	***I had preprogrammed the various addresses*** *that I knew we would be visiting before I left on the trip*

Participant	Behavioural adaptation	Level of driving behaviour	Diary entry extract
p17 (cont)	Minimising system use while driving and glances to display	tactical	***I like to have the passenger do these tasks when they can and usually only glance at the unit to provide some instruction****, but Garmin's menu makes it a quick learning curve*
	IVNS usage in unfamiliar areas	strategic	***I chose to let the GPS plot the course for most of the day because while I knew each stop as a radial from my house, I was not entirely sure of the best route between the points***
	Maximising system efficiency in future trips	strategic	*I like to add each search to my favorites list* ***to speed up the process for the next time***
	Using the system for situation awareness	strategic	***What was helpful from the system, though, was just seeing that there were or were not more cities on the island to visit that we hadn't been through yet.*** *Eventually,* ***once the map suggested we reached the end, we turned around***
	Passive system usage	tactical	*so I could* ***see the time progress*** *in the lower corner*
p11	Forcing alternative route due to previous experience	strategic	***I knew from previous experience that this would be a very busy route at this time of day*** *so wanted to force* ***the device to take an alternative route****…*
p3	Re-checking calculated route	strategic	*I was in a hurry… but* ***also used a paper map to confirm route*** *due to distrust of nav system routing*
p14	Preference for passive usage in familiar area	strategic/tactical	***As I knew the main area*** *it was in* ***I planned*** *to simply drive there and then* ***use the zoom and pan function on the GPS*** *to find the high school*
	Maximising system efficiency for future trips	strategic	*I had been at his house once 3 years before and as it* ***was a tiny place tucked away in a crowded part of the city I had logged it as a waypoint at that time with my Garmin Legend***
p7	Preference for passive usage in familiar areas	tactical	***I knew the way home so I just left the satnav running, without entering the address***
	Preparing for easy access to routing functions in case of congestion	tactical	*I had to pick someone up at the airport. I know where the airport is,* ***but turned the satnav on…I was a bit afraid if there are some roadworks on the M1 may have to find alternative route***
	Preference for passive usage in familiar areas **and** utilising extra functions	tactical	***I was driving to a familiar destination, but always use the SatNav to monitor time and distance to go as well as for speed cameras***

Participant	Behavioural adaptation	Level of driving behaviour	Diary entry extract
p20	Ignoring system advice due to system limitations	tactical	***It will not reset after my last input of a previous destination. I have to disobey a turn*** *for it to reset to my current location*
p5	Preference for passive usage in familiar areas	tactical	***Whilst making a normal journey I was using the device to give me an ETA***
	Preference for visual modality due to system limitations	tactical	***the device was issuing instructions some way behind where I actually was****...****I got round the problem by using the graphical display more then the spoken instructions***
p13	Route planning based on individual preferences	strategic	*I have set it to* ***toll roads and fastest time*** *which I find will* ***steer clear of back streets****…*
	Shutting system down to minimise glare/distraction	tactical	***The reason for turning the unit off all the time is so the glair doesn't shine in my eyes****…unit set on the lowest setting for brightness but can still be bright on the eyes*
	Preference not to use system at all in familiar area	tactical	***Then area was known so it was not needed***
	Preference not to use the system in familiar area	strategic	*Because* ***I know about 900 klm of the journey there is no need for the unit to run all the time***
	Using the system for increased situations awareness rather than guidance	tactical	***I keep the map on screen all the time so I can see the direction of the road all the time*** *so if it's a very built up road system and the voice is misunderstood I can follow the map markings which always works*
	Passive system usage for increased situation awareness	tactical	***Without entering the destination I used the map to show which direction the upcoming road was going.***

Please note: Bold text denotes reasoning for behavioural adaptation and level of driving behaviour columns

5.8 Discussion

This study was primarily concerned with collecting rich, detailed qualitative data concerning the contexts in which the previous studies have shown that behavioural adaptation to IVNS can occur. Similar to a case study, the objectives didn't concern generalising the results to wider populations, but instead concerned exploring and understanding the varied manifestations of behavioural adaptation to IVNS, which would have been particularly difficult to do using surveys or quantitative methodologies alone.

5.8.1 Sampling caveats

Section 5.3.2 described how potential participants initially expressed interest in this study by completing a short eligibility questionnaire, which asked about their age and other demographic details. Since the previous surveys demonstrated significant associations between age and both system interaction while driving and following inaccurate route guidance instructions (i.e. two forms of behavioural adaptation that this study aimed to investigate further), it was important to recruit participants of all ages. So based on responses to the eligibility questionnaire, invites to participate in the study were sent out to drivers representing every age band from 17-20 years to 70+ years.

The eligibility questionnaire also collected details concerning the frequency with which drivers reported travel in unfamiliar areas. The IVNS user-survey described in the previous chapter, showed that the vast majority of participants used their IVNS in an active manner while travelling in unfamiliar areas. In order to collect high volumes of rich qualitative data concerning IVNS use over a 2-week timeframe, and due to the limited sample size used in this study, only those drivers who indicated that they drive frequently (once a month or more) through unfamiliar areas were invited to participate.

5.8.2 Sample characteristics

Both surveys reported in the previous chapters were piloted to ensure they were short enough to be completed by participants in less than 10 minutes. This was because several researchers have suggested this strategy to attract high volumes of participants and to minimise dropout (Reips, 2002; Van Selm and Jankowski, 2006; Sheehan and Mcmillan, 1999). Since this study was longitudinal, it was not feasible to minimise its length this way, so to avoid dropout and to attract participants, they were offered payment for participation.

Despite this, several participants who initially expressed interest in participating failed to reply to emails inviting them to do so, therefore figure 5.1 shows that although all driver age bands were represented, very young drivers and those over 46 years were somewhat under-represented in the sample. Figure 5.1 also shows that only 10% of the sample was female IVNS users. A higher proportion of female drivers were invited to participate but only two replied agreeing to.

As expected, most participants were experienced or very experienced drivers, but it was surprising that 1 participant was an inexperienced driver[1]. Although most participants used nomadic IVNS, figure 5.2 shows that PDA/mobile phone, integrated and laptop-based IVNS users were all represented in this study. Figure 5.3 shows that while most participants had been using an IVNS for less than 2 years, a significant proportion has been using one for much longer. This suggests that participants had a wide range of IVNS experience. The various tables reported in the previous section also suggest the present sample frequently used their IVNS in several diverse ways.

Although participants were recruited based on the frequency with which they reported travel in unfamiliar areas, figure 5.4 shows that in most cases diary entries concerned a range of familiar, unfamiliar and only partially familiar journeys. The previous chapter showed that passive usage in familiar areas can also provide insights about behavioural adaptation to IVNS, and clearly these journeys were not neglected in this study.

5.8.3 System interaction while driving

Figure 5.5 compares different forms of system interaction that three groups of participants (i.e. those in the IVNS user survey, those who completed the eligibility questionnaire and those who participated in this study) thought should be allowed while driving. It shows that a similar proportion in all three samples thought that access to quickly executed destination entry features (i.e. by POI and stored location) and other IVNS functions (i.e. change volume and change view) should be allowed while driving, and a similar proportion thought no form of system interaction should be allowed while driving. However, allowing access to more time consuming destination entry tasks and other forms of system interaction was clearly much more popular among participants and potential participants in this study. This may be

[1]Based on Rothengatter et al`s (1993) driving experience classification scheme

partly due to the sampling frame used for this study (i.e. worker drivers who use an IVNS and frequently drive in unfamiliar areas) as well as the significantly larger sample size in the IVNS user survey.

The IVNS user survey showed that even though a third of participants thought that no form of destination entry should be allowed while driving, only a quarter reported that they never entered destinations while driving themselves. As discussed in the previous chapter, this suggests a mismatch between intentions and actual behaviour. In the IVNS user survey it would have been inappropriate to have speculated further about why people opposed to this behaviour might still engage in it themselves, but the extra contextual information provided in this study provides some clues.

While two participants indicated that no form of system interaction should be allowed while driving, table 5.3 shows that one of these participants (p18), did use their system while driving during the diary study. The contextual information accompanying this diary entry shows that although it was performed in heavy rush-hour traffic, it was only a quick interaction entailing just a couple of key presses, and that it was performed because the participant suddenly realised he didn't know the way home, so interrogated the system for this information.

Participants 9 and 10 indicated that only quick and easily executed IVNS functions such as change view and change volume should be allowed while driving. Table 5.3 shows that participant 9 only attempted to zoom on the map while driving on several occasions, but despite his views on the matter, at one point during the diary study participant 10 entered a destination while driving (i.e. postcode entry). However, the contextual information shows that this was specifically because his system fell to the floor and it was too difficult to pull over in the vehicle he was driving. He was also driving in an unfamiliar area which may have made it more difficult to find an appropriate place to pull over. This participant also reported using his system while driving when prompted to press the "ok" button, but that due to a system malfunction was forced to repeat this action several times for approximately 2-3 minutes. Although participant 18 was opposed to any forms of system interaction while driving, and participant 10 was opposed to anything but menial forms of system interaction while driving, these diary entries show that there are sometimes unusual circumstances when even for them, this behaviour appears justified (although the diary extract suggests that participant 10 was not comfortable behaving this way but felt he had little choice in the prevailing circumstances).

Interestingly, this study also showed that this mismatch between intentions and behaviour occurred in the opposite direction too. Although most diary study participants who indicated that every form of system interaction listed should be allowed while driving did interact with their system themselves while driving at some point during the 2-week timeframe, a third of them did not. The IVNS user survey reported in the previous chapter showed that although a high proportion of drivers did admit to destination entry while driving, a much smaller proportion (5%) did so frequently. Together these findings suggest that this behaviour may be somewhat situation specific, depending greatly on the prevailing circumstances at the time rather than a general propensity to use the system while driving (at least in the present sample).

Although relative to the IVNS user survey, destination entry by address and postcode were more popular among participants in this study, a cursory review of table 5.3 shows that these destination entry tasks were rarely employed. When destinations were entered while driving, most participants favoured destination entry by stored location, POI or postcode, and as a result most instances of destination entry while driving entailed minimal keystrokes (<10) and some took only a short time (<=15 seconds) to complete. There were some notable exceptions however. For example, 3 participants took approximately 2 minutes to complete destination entry tasks. Although this was probably acceptable for participant 4 as he was sitting in heavy traffic due to road works, and for participant 16 who indicated that the task caused no distraction in a manageable traffic situation, participant 11 indicated that this task was particularly distracting.

Chapter 2 described how as a rule of thumb, system interaction tasks should take no longer than 15 seconds to perform while the vehicle is stationary. This “15 second rule” is a recommended practice (J2364) in the Society of Automotive Engineers and is well known among system designers and manufacturers. It was proposed to ensure that if IVNS are used while driving, distraction potential is minimised. Although system interaction while driving is a dual task situation, so some tasks may take longer to complete while driving than while stationary, clearly two minutes is unacceptable. According to Green (1999) this practice rules out destination entry and other forms of interaction while driving. The accompanying contextual information for two of these cases also shows that both these destination entry tasks entailed more complex system interaction than simple key/button presses (e.g. "*touchscreen selection* ***and dragging****; typing destination entry* ***and scrolling through choices****)*.

The IVNS user survey showed that most IVNS users were prepared to enter destinations while driving at least occasionally, and from a road-safety perspective this is alarming as entering a final destination (and any route planning demands this entails) may be quite time consuming and attention demanding, particularly if drivers have preferences for certain road types etc. Although the present sample were not representative of ordinary drivers, a particularly important observation from the contextual information they provided was that destination entry tasks were most often performed to find locations en-route to satisfy prevailing moment to moment demands (e.g. *find petrol station*, *find* supermarket to buy sandwich, *looking for restaurant, lunch from favourite sandwich shop)* or due to congestion (e.g. *find alternative route due to heavy traffic).* Even though the sample consisted of worker drivers who would have been trying to reach a variety of destinations as part of their jobs, table 5.3 suggests that with some exceptions, final destinations were rarely entered and whole routes were rarely planned while driving. In several diary entries participants mentioned that they entered their final destinations and planned routes to these, either while stationary in their vehicle (e.g. *in my driveway, before setting off)* or completely outside of the vehicle (e.g. *in the office)***.** Several participants (particularly the LGV and HGV drivers) mentioned that route planning for the next day of driving takes place during the evenings wherever they sleep that night.

Table 5.3 shows that participants interacted with their systems while driving in familiar, unfamiliar and partially familiar areas. Surprisingly, two instances of system interaction while driving in familiar areas concerned destination entry tasks, but unsurprisingly most instances of destination entry were performed while driving in unfamiliar or only partially familiar areas. The table also shows that participants interacted with their systems while driving in a variety of traffic situations. Encouragingly, most instances of destination entry while driving were performed during mild traffic conditions (e.g. *road quiet, relatively quiet road, traffic was tame enough not to cause any issues*), although it is unclear whether participants were coincidentally in these traffic situations when they entered destinations while driving or purposely chose to enter them in these circumstances. Similarly, participant 11 entered a destination using a stored POI while driving, but he had started entering it while stationary at traffic lights, and so only completed this task while driving because the traffic lights had changed. Participant 3 indicated that he entered a destination while driving on a residential road. This could be positive in terms of safety as residential roads are more likely to have a low speed limit, but could also be negative as there may be a much greater chance of encountering pedestrians on these roads.

One thing particularly striking in table 5.3 is the frequency with which participants felt that various forms of (sometimes quite complex) system interaction while driving caused little or no distraction, or failed to compromise safety in any way. Only in a minority of cases did participants acknowledge the potentially detrimental effects of system interaction while driving on safety and performance. Since this study relied completely on participants' self-reports of these situations, it would be impossible to confirm or deny their safety perceptions, but chapter 2 described how many previous studies have shown that destination entry tasks can and do disrupt driving performance even during mild traffic conditions and on straight roads (e.g. Nowakowski et al., 2000; Dingus et al., 1995; Tijerina, Palmer and Goodman, 1998; Zwahlen, Adams and DeBald, 1988). In future studies of this type, it would be useful to accompany the diary study methodology with observational techniques. For example, recording equipment could be placed in vehicles giving researchers the opportunity to determine the extent to which participants' perceptions of both the traffic situations they encounter and the level of distraction caused, correspond with the video feed.

Without such additional objective measures it is impossible to speculate whether diary study participants' subjective perceptions were accurate or justified, but in the traffic psychology literature drivers' tendency to over-estimate their own driving abilities compared to other drivers is also a well documented finding, originating with a study by Svenson (1981) in which participants were asked to rate how safe they were at driving and how skillful they were compared to the "average driver". Svenson found that over three quarters of participants considered themselves safer, and 65% considered themselves more skillful. Since it is unlikely that most drivers are more skillful than the average driver, this tendency is probably an illusion (Taylor and Brown, 1988). It is commonly referred to as optimism bias, which is a belief that negative events are more likely to happen to others, while positive events are more likely to happen to oneself (Dalziel and Job, 1997). According to Job (1999, p.32):

"we see ourselves as less likely than our peers to suffer an early heart attack, have cancer, AIDS or a drinking problem but more likely to live past 80 years, own our home, and have gifted children".

Since Svenson`s (1981) original study, several other studies have demonstrated that most drivers view themselves as more skillful (Goszcynska and Roslan, 1989; McKenna et al., 1991; Sivak et al., 1989) and less likely to be involved in an accident than the average driver (Finn and Bragg, 1986; Greening and Chandler, 1997; Matthews and Moran, 1986). Recently, Wolgater and Mayhorn (2005) found evidence of an optimism bias when they examined drivers' perceptions of the safety implications of using a mobile phone while driving. Participants rated other drivers using a mobile phone while driving as more dangerous than they rated themselves behaving this way, and on average these participants also disagreed that people in general can use a mobile phone safely when driving. These findings suggest that participants in the Wolgater and Mayhorn (2005) study were at least aware that it could be dangerous when other drivers use a mobile phone while driving even if they failed to observe it in themselves. In the present study too, there was also evidence that some participants were at least aware of the potential for distraction as several diary entries described various attempts to minimise the distraction of interactive tasks performed while driving (e.g. *slowed down to 50mph and performed tasks in stages to minimise distraction, I did about 6 key presses while driving then pulled over to complete the rest while parked, picking my spot for the button presses to minimise any potential for compromising road safety*). Some participants were also aware of the differential impact on safety of different aspects of manual system interaction while driving (e.g. *minimal distraction as no data entry just selection, diverted attention a little from driving to touch the correct area of the screen, I found the second stage quite distracting...this involved dragging the map on the screen*).

That diary study participants were aware of the potential for interactive tasks performed while driving to cause distraction or degrade safety, but rarely acknowledged such effects when they performed them, would therefore be consistent with previous research (e.g. Svenson, 1981), although it is unverifiable in the present study as no additional objective measures were collected. Any misalignment between subjective perceptions of the performance/safety effects of system interaction while driving, and objective measures, could have serious implications for the design of any future strategies to remediate or mitigate this behaviour. Therefore, it would be advisable for future research to investigate the degree of correspondence between subjective ratings of the safety, risk, performance effects and distraction effects of system interaction while driving and objective measures of these parameters. Such a study could be implemented using the extended diary study methodology outlined above, where drivers record diary entries concerning their experiences, but they and the traffic situations they encounter are also observed using video recording equipment for later analysis and verification of diary entries by researchers. However, employing this methodology would likely be time consuming, expensive and would entail several ethical considerations. Fortunately these issues may also be safely explored experimentally using driving simulators as they allow researchers to examine several driving performance measures in significant detail. For example, a simulator experiment with a repeated measures design might examine the effects of destination entry on driving performance by requiring participants to drive a fixed route unaided or performing some baseline task (e.g. tuning a radio) and then driving the same route entering destinations while driving. It would be possible to calculate differences in objectively measured driving performance between these conditions. Through piloting, it would also be possible to design and administer to participants subjective rating scales concerning their perceived driving performance between these conditions. By correlating objective and subjective measures of the same performance effects it would be possible to assess whether subjective perceptions are appropriately aligned with objective measures of these parameters.

Although there is a need to be cautious in interpreting statistical findings from such a small sample size, this study also replicated the age effects reported in the previous chapter, as those who engaged in some form of system interaction while driving were significantly younger and had held their driving licenses for significantly less time than those who did not. Additionally, further analyses showed these differences achieved even higher levels of significance, when the characteristics of those who had specifically entered destinations while driving were compared to those who had not. The previous chapter discussed how past research has demonstrated that younger drivers take more risks and commit more driving violations than older drivers (Zhang et al., 1998; Aberg and Rimmo, 1998; Blockey and Hartley, 1995; Parker et al., 1995; Simon and Corbett, 1996), and in light of the age effects reported in this research, any attempt to either warn drivers about the dangers of system interaction while driving or to minimise the extent to which they behave this way, should be targeted primarily at younger drivers.

The previous chapter discussed how older drivers have been shown to compensate for age-related declines in attention, perception and motor skills by taking fewer risks (Hakamies-Blomqvist, 1994; Holland and Rabbit, 1992; Simms, 1992, 1993; Rackoff, 1974) and this may explain why older drivers were less likely to use their system while driving. Some research investigating confidence in older drivers (e.g. Marattoli and Richardson, 1998; Parker et al., 2001) have shown that it was associated with self-rated driving ability, and Parker et al. (2001) showed this relationship was not mediated by personality (i.e. unaffected by scores on neuroticism and extraversion scales of the EPQ personality test). This suggests that driving confidence does reduce as drivers get older, but only due to an awareness that their own skills are also deteriorating. There is evidence showing that younger drivers have a greater tendency to be over confident in their own driving ability (e.g. RoSPA, 2002; NHTSA, 2006), so it is possible that younger drivers are more likely to use their system while driving because they are more confident (or even over confident) in their own driving abilities, and therefore in their ability to sufficiently cope with potential distraction; so this study examined the relationship between confidence and this behaviour. Descriptive statistics suggested a tendency for those participants who used their system while driving (mean score on confidence scale=16) in the diary study to be more confident in their driving skills than those who did not (mean score on confidence scale=24.3), but this difference failed to attain statistical significance, possibly due to the limited sample size obtained in this study.

5.8.4 System reliability

In the IVNS user survey the majority of participants rated the degree of correspondence between system generated route guidance and their own individual preference when driving in familiar areas as moderate, with only about a third of participants rating it as high or very high. In this study, nearly half the sample rated it as high and just over a quarter rated it as moderate. These findings more closely resemble those of Svahn (2004)[2]. However, the majority of participants (90%) questioned the fallibility of system-generated route guidance instructions and as shown in tables 5.3 and 5.4, a high proportion has received instructions

[2] Although Svahn (2004) also used a 5-point scale for this item, this study and IVNS user survey used different labels for each point on this scale, as Svahn`s (2004) labels were written in German, but were less appropriate once translated into English.

that could be classified as dangerous/illegal both before and during the diary study. In the IVNS user survey about a quarter of those who have received these erroneous instructions had followed them on at least one occasion, but nearly half the participants in this study that had received these instructions before the study began had followed them at least once. Again, it is likely that the smaller sample size and the sampling frame used in this study probably contributed to this increase.

Although the statistics reported in this study and the IVNS user survey provide valuable insights into the extent to which IVNS users receive inaccurate or unreliable route guidance and the IVNS user survey provided some basic descriptions of these situations, they insufficiently describe the specific contexts in which this has occurred. Fortunately the rich, detailed qualitative data obtained in this study and illustrated in table 5.5 helps to fill some of these knowledge gaps.

About a third of the cases reported in table 5.5, concern route guidance that participants have received that can be considered poor or inefficient, and a similar proportion concern cases in which participants received inaccurate route guidance. Those classified as inaccurate were wrong but would not necessarily have been dangerous or illegal had participants actually followed them. In many of these cases participants were able to recognise the instructions were poor, inefficient or inaccurate because they had some degree of familiarity with the areas they were driving in and therefore had superior knowledge about routes through these areas:

- *I know there is a lot of construction work ...I therefore decided to ignore this part of the route, knowing there is major construction along this route, I chose to turn right instead*
- *I reached a roundabout at which I knew I needed to turn right...the device failed to recognise the roundabout and instead instructed me to bear left;*
- *I knew the route was wrong...I knew the reason why and ignored this instruction;*

Sometimes they had previous experience of using system-generated routes in these areas:

- *my system always suggests going around the Rotterdam ringroad...I know from experience that traffic moves very slowly ...so I go clockwise... this route saves at least 10 minutes*
- *having some knowledge of the area there were a couple of turns that didn't make sense to me...*
- *does not always pick out my preferred route when multiple options exist...more prevalent near my home where I have a good understanding of traffic patterns and favourite roads*
- *I knew from previous experience that this would be a very busy route at this time of the day so wanted to force the device to take an alternative route*[3]
- *ask it directions to a restaurant 5 miles away that I already know how to find...the system plotted an understandable but poor route*
- *it appears there are two key roads which do not appear on my navigation systems maps – and as I discovered last week without them you`ll just drive round in a big circle or two!*)

Sometimes participants were driving in unfamiliar or partially familiar areas but recognised contradictory road signs/other information:

- *it then asked me to turn left where no road existed...I realised what was happening and ignored this direction; satnav asked me to take the exit on to the A1. However I could see that I actually had to carry on to get to my destination as the signposts were clear*
- *the satnav believed these roads connected directly with a roundabout, while the reality is that the A310 passes over the A127 on a flyover*

Or they had concerns about using the suggested route in the particular vehicle they were driving:

- *the route my system suggested was...travel through part of the city....as I drive a large lorry...I ignored this part of the suggested route*

[3] This and the previous diary entry are from table 5.7

Other cases of poor/inefficient or inaccurate route guidance were related to database errors, some cases suggested that the database was out of date:

- *being a new area the system did not have the street in its memory*
- *with so many changes to the road I travel it sometimes does not recognise the new road*
- *the maps on my navigation system are not as up-to-date as the maps on Google ...a few of the roads were missing*
- *the general appearance of the roundabouts suggested they were fairly new...clearly the verbal instructions being delivered weren't consistent with a roundabout*
- *in this time the units map went off the road which happened all the time between...the unit gets back on track once back on the older road*
- *noticed several roads that need to be updated on the map due to alterations to traffic flow*
- *when entering the postcode at base I found it didn't exist*

Others suggested the database was incomplete:

- *was unable due to airport name not being in the database*
- *my friends address could not be resolved...because she lives on a small private road*
- *since my destination was a government office it wasn't recognised*
- *the navigation was unable to correctly inform me to board the channel tunnel connection*
- *tried to send me back to the channel tunnel*

While other cases also indicated a poor correspondence between the database map and the visual map shown on the visual display:

- *the icon on the screen then changed to display my position as being on a parallel road to mine; the GPS had us displayed in a field*
- *putting some of my intermediary waypoints in the middle of nowhere*
- *when I glanced at my sat nav screen it showed that I was travelling through empty space*).

Receiving and following poor/inefficient or inaccurate system-generated route guidance instructions like those outlined above, may be inconvenient or frustrating for drivers, but receiving and following dangerous/illegal route guidance instructions can have much more serious consequences including accidents, injury or even death. The IVNS user survey reported in the previous chapter and table 5.6 in this chapter show brief descriptions of dangerous/illegal route guidance instructions that participants have received and followed. Many of these are also represented in much greater detail in table 5.6, for example:

Drive through one-way streets – "*I was instructed to turn left and continue...halfway down the road there was a dead end sign followed shortly by a no-entry sign*"

"the satnav wanted me to take an immediate right turn...the junction is in fact blocked with bollards and has been for the last 10 years"

"told to turn down one way street the wrong way"

Drive in pedestrianised zones - "*I tried to exclude the Taconic state parkway but it didn't seem to want to do that...after a few miles it kicked in with a legal route*"

"informed by the satnav that I had to turn right again...it looks like the road had been converted into a pedestrian precinct"

Inappropriate vehicle dimensions – *"I noticed a weight limit sign which prohibited me from using the recommended road"*

"satnav directing me to turn into roads which are clearly unsuitable for any vehicle larger than a family car"

"tried repeatedly to route me along roads unsuitable for my vehicle size"

Drive in roads for specific vehicles - "*I was presented with a restricted time zone road...for buses and taxis during daytime operation*"

Drive on private road/farm tracks - "*my TOMTOM would attempt to route me along unmade roads such as farm tracks and very narrow roads*"

"*direct me onto a left turn which was quite obviously a farm track*"

In the IVNS user survey, relatively few participants reported having received dangerous/illegal route guidance instructions that directed them along routes for which their vehicle dimensions (e.g. width/length/height) were unsuitable. The previous chapter discussed how this was probably because the sampling frame used didn't specifically target LGV and HGV drivers, but some participants in this study did drive these types of vehicles, and the results shows that this is a prevalent form of inaccurate route guidance that affects these particular IVNS users. Some of the diary extracts in section 5.3.5 show that development of systems that incorporate vehicle dimensions in route planning algorithms is a key design consideration that many of these drivers would like to see addressed in future systems.

A limitation of this study is that participants weren't asked about the status of their system maps. The IVNS user survey showed that although most of those who had received inaccurate route guidance instructions had not recently updated their system maps, a significant proportion had updated them. In the IVNS user survey, most participants were dis-satisfied with the present costs of map updates and clearly some participants in this study were also disgruntled about this particular issue (e.g. participant 19). Other participants had concerns about how complete their system maps were, as well as the efficiency of route planning algorithms and mapping systems.

This study was primarily designed to collect qualitative data; the quantitative aspects of the study were only secondary concerns. Due to the small sample size, statistical tests performed would have lacked sufficient power to draw any reasonable conclusions. Individual difference variants in demographic data were only pursued in an attempt to replicate the findings from the IVNS user survey. Statistical analyses involving the various scales were even less powerful because these were just ordinal level (i.e. inappropriate for parametric analyses)[4]. They were only included as an initial step in identifying individual difference variants in experiences of behavioural adaptation to IVNS beyond demographic data alone, and potential areas of explanation that might be pursued in future investigations. The CPRS, CFQ and MAAS scales were used with the assumption that complacency or lack of attention during the diary study be symptomatic of complacency or lack of attention in everyday life or previous driving experience, although just two participants that followed dangerous/illegal route guidance instructions during the diary study indicated that they had also done so before the study began.

Concerning the demographic data, the results largely replicated the age effects demonstrated in the IVNS user survey (i.e. those who followed dangerous/illegal route guidance instructions were significantly older and had held their driving licenses for significantly longer than those who had received but not followed them). It was interesting that these drivers were also significantly less confident in their own driving ability. Chapter 2 outlined the relationship between automation trust/reliance and self confidence. In some of the early work concerning trust in automation, using a process control paradigm, Lee and Moray (1992, 1994) found that an operators' reliance on automation depends on self-confidence (i.e. their ability to perform the task themselves), such that when self-confidence was high, operators preferred to perform the task manually, but when it was low they were prepared to delegate responsibility to automation. However, in the present context, self-confidence would refer to confidence at navigating specifically (as this is the task which IVNS support) rather than general driving confidence which the Parker et al (2001)[5] scale measured, nevertheless the results indicate that navigational confidence may also be an important avenue of future investigation.

Based on the contextual information[6] provided by participants concerning situations in which they followed dangerous/illegal route guidance instructions both during the study and before the study began, table 5.6 suggests potential areas of explanation. Clearly some cases implicate both trust and attention based explanations whereas other implicate only trust based explanations. The results section showed that in general, most participants had a

[4] With the exception of the CPRS which used a 5-point likert type scale ranging from "strongly disagree" to "strongly agree"

[5] The Parker et al. (2001) scale was primarily included to examine differences in the confidence of drivers who used their system while driving compared to those who did not.

[6] Table 5.6 shows that these assumptions were only made when diary entries contained sufficient contextual information to reasonably suggest potential areas of explanation

high degree of trust in their IVNS, and trust is obviously a significant issue for IVNS users as many mentioned it explicitly in relation to their IVNS. However, some diary entries illustrated in table 5.7 also indicated distrust of system-generated guidance, in many cases participants reported re-checking system-suggested routes before embarking on their journeys (e.g. *I then check the route for anything unsuitable; I was suspicious of part of the route....so planned an alternative route; also used a paper map to confirm route due to distrust of nav system routing*)

The analyses revealed no significant differences between those who had and had not followed dangerous/illegal route guidance instructions in terms of the attentional self-report measures, and there were also no significant differences between these groups in terms of overall trust and distrust ratings, but an individual item analysis revealed that those who have followed dangerous/illegal instructions considered their system to be significantly less reliable (trust) and were significantly less wary of their system (distrust). Although at first glance these findings appear to be contradictory it is important to note that participants may have viewed the trust item in relation to overall system reliability (e.g. memory capacity, battery life, windscreen/dashboard grip)not just in terms of its routing performance. It is interesting that these participants were also less wary of their system, and the contexts illustrated in table 5.6 suggest some participants need to become more wary of guidance they receive.

Those who had followed dangerous/illegal route guidance instructions also had a significantly higher potential for complacency than those who had not followed them. This is consistent with some of the research outlined in the previous chapter which showed that older adults are more likely to be complacent in different contexts and to over-trust automation in general.

However, table 5.6 shows that there were some instances in which participants followed dangerous/illegal route guidance instructions but were completely aware that they were doing so (e.g. *one of the final roads turned out to be a bicycle path but on a motorbike it was fine; it was an illegal turn but I had to turn as it was a fast road; followed navs direction onto an illegal left hand turn too late to deviate to a legal turn further on; I have been guided down roads that are too narrow and found that I could not turn HGV around and had to keep going*). Clearly these explanations do not imply over-trust or complacency as participants were fully aware they were performing dangerous/illegal actions. In light of the research outlined in the previous chapter, it is possible that these participants had a significantly higher potential for complacency simply because they were significantly older than those who had shown restraint when they received dangerous/illegal route guidance instructions.

As mentioned previously in this chapter, it would be particularly useful for any future studies to also employ recording equipment so that researchers can make up their own mind about the situations encountered without having to rely solely on self-report data, which may be unreliable or prone to certain biases. This would also be particularly useful when trying to establish the reasons why some drivers have a greater tendency to follow inaccurate route guidance instructions. Several cameras could easily be employed so researchers could view the traffic situation as well as driver glances to the road and to the IVNS display. Although the CFQ purports to measure perception, attention, and memory, it would be useful for future research to also employ objective measures. Several valid, objective measures of attention and perception/visual acuity are available, and there is even evidence to suggest the sustained attention to response task (SART- Robertson et al., 1997) can be successfully delivered to participants online (Forbes, 2004).

Further research should also consider the role of other factors from the psychological literature that may explain why some drivers, particularly older ones, have a tendency to follow inaccurate route guidance instructions. For example, in social psychology several studies since Milgram`s (1963, 1974) famous experiments, have investigated obedience to authority figures. No research could be found which had linked trust in automation to this area of research, but it would be interesting to investigate the extent to which drivers view IVNS as authority figures, as the present research has shown that many have a high degree of trust in their systems, although it has also shown that most users do not believe their systems are infallible. In fact, a key concern in authoring the present thesis was how to refer the phenomenon in which drivers follow inaccurate route guidance. Chapter 2 described the similarities between this and the command-effect (Kramer and Reichart, 1989), and based on Kramer and Reichart`s (1989) article, Gestalter and Fastenmeier (1992) preferred the term “obey” rather than “follow”. The term follow was considered most appropriate for this study as (in the present author`s opinion) the term “obey” has too many trust-related connotations, and although a trust-based explanation is certainly plausible, the present thesis has shown that it is not necessarily the only plausible explanation.

Although explanations of [particularly older] drivers' tendency to follow inaccurate route guidance instructions still require much further investigation, this thesis has shown that it does happen, and is a significant behavioural adaptation issue that has so far received only minimal research attention. It would be advisable for future studies to thoroughly investigate this issue as although presently, the UK legal situation concerning IVNS is unclear, a UK Parliamentary Office of Science and Technology (2002) postnote refers to an EU RESPONSE project that examined the legal ramifications of the use of in-vehicle technologies in terms of accident liability. It showed drivers not manufacturers should be liable in cases of collisions that result from relying on automated vehicle systems. It would be advisable to fully explore tendencies to follow inaccurate route guidance instructions as soon as possible while drivers are still in charge of vehicle controls. As IVNS get more sophisticated, it is certainly conceivable that sometime this century, systems will be developed that completely replace the driving and navigation tasks. In 2004 the Defence Advanced Research Projects Agency (DARPA) held a challenge in which several teams of experts from the US armed forces and the artificial intelligence and robotics research communities, were required to design an autonomous vehicle that could traverse a 150 mile route along the Mojave desert in the US, that followed the highway route leading from Barstow in California to the California-Nevada border. None of the teams completed the task (the vehicle that travelled furthest only completed less than 7.5 miles). However, in the 2005 challenge only one vehicle failed to complete the course. The 2007 challenge required vehicles to traverse a sixty mile urban environment in under six hours, and to perform various manoeuvres (e.g. negotiating intersections, merging, overtaking and parking), and six teams completed the challenge. Recently, Larry Burns, vice president for research and development at General Motors, announced that his company planned to be testing driverless cars by 2015, and to make viable commercial products available by 2018 (http://www.dallasnews.com/sharedcontent/dws/bus/stories/010707dnbusdriverless.522d527.html accessed 24/10/08). In a recent Japanese article, Stanford University professor of computer science Sebastian Thrun, whose team won the 2005 DARPA challenge reported that although it is possible, he considered it unlikely that these vehicles will be commercially available quite so soon (ERA 008, date unknown), nevertheless due to the research effort so far, it is arguably only a matter of time before they are commercially available.

Although there have been no reported cases so far (just test cases), there is another potentially serious implication of drivers' tendency to follow inaccurate route guidance instructions that so far has not been discussed. A recent press article[7] described how two researchers from an organisation called Inverse Path had found a way to hack the traffic message channel of some IVNS using widely available, cheap off the shelf electronics products such as an RDS encoder, an FM transmitter and a hand-held antenna. Using this equipment, they have shown it is possible to broadcast fake travel information messages to IVNS in range of the transmitter. Fake messages could include informing drivers about a fake plane crash, a bomb alert or road closures. Sometimes inserted fake traffic information messages will pop up to the driver once received, but some systems may not even inform the driver about receiving this information, and proceed to include the information in route planning algorithms (i.e. hard automation – see Young, Stanton and Harris, 2007 in chapter 1). For example, a fake message concerning a road closure could be broadcast; an IVNS would receive this message and automatically re-calculate a route to avoid the road in question. According to the researchers who discovered this method, traffic management channels do use encryption but this is used for the purposes of discrimination rather than authentication, and besides, encryption keys can be easily broken. The researchers suggest for now that this technique would not work if the traffic management channel used a closed system with more complex encryption, but it is reasonable to assume that over time techniques will be discovered to exploit these too. Although this is clearly a worst case scenario, if this technique were exploited by terrorists or other organised criminal organisations, receiving and following these inaccurate guidance instructions could have serious consequences. It would also be likely in this potential scenario, that significantly more drivers would follow such guidance than have done so in the present research because the information would appear legitimate, and they may not be presented with contradictory guidance information such as road signs/markings (especially in situations where drivers used hard automation IVNS).

5.8.5 Other IVNS usage and user preferences

In addition to various aspects of behavioural adaptation to IVNS brought to light in the previous three chapters, in the participant information pack participants were also encouraged to write about the following:

[7] http://www.theregister.co.uk/2007/04/20/satnav_hack/ (accessed 24/10/08)

1. Aspects of IVNS usage both inside and outside their vehicle
2. User preferences (e.g. particular likes/dislikes)
3. Opinions and suggestions about their IVNS and IVNS in general
4. Any further user experiences that they thought should be noted

They were given some specific examples for each of the above points, but the participant information pack made it clear that as long as they wrote about their user experiences, they could write about anything they considered appropriate. It was anticipated that using a largely unstructured approach like this would yield rich and diverse qualitative data, especially since this approach worked so well for those items in the IVNS user survey which examined components of user-satisfaction and dis-satisfaction.

Interestingly although they were not prompted to do so, section 5.3.5 shows that some participants made direct comparisons between paper maps and IVNS. Chapter 2 outlined several studies which had objectively examined the effects of each on driving performance, but to the authors' knowledge, this is first study that has thoroughly examined drivers' subjective reports about this issue. These previous studies had directly compared driving and navigational performance using a paper map while driving with performance using an IVNS while driving. Participant 7 indicated that before acquiring an IVNS he used to use a paper map while driving, but found that using and even interacting with an IVNS while driving was considerably less distracting than following directions on paper maps. Similarly participant 9 described the additional difficulties of locating and tracking vehicle position in real time using paper maps, that are avoided when using a [correctly functioning] IVNS. Participants 9 and 13 both indicated that using paper maps they would previously have sometimes had to drive sometimes considerable distances to find a place to pull over to consult them, but that this was unnecessary using IVNS. This represents a form of strategic level behavioural adaptation that has largely positive effects in terms of efficiency and mobility (e.g. *with roads being so narrow, it was also very hard just to pull over and take a look at a map, so I found myself driving for miles just to have a look at a map*). Table 5.7 shows that participant 17 indicated that he always brought an IVNS, not because he finds it easier to use than paper maps but because "*I can't always rely on my peers map reading skills*". Table 5.7 also illustrates a variety of diary extracts which indicated other aspects of strategic and tactical level behavioural adaptation to IVNS. Many of these have already been discussed due to their relevance to system interaction while driving or system reliability, but there are many more interesting accounts which have not yet been covered in previous sections.

5.8.5.1 IVNS usage

The previous chapter showed that some drivers prefer to use their systems passively when travelling in both familiar and unfamiliar areas, and there was also evidence for this among the present sample. Several participants indicated that they particularly like, (and make extensive use of) extra IVNS functions not immediately related to route guidance (e.g. *I like the speed and timing functions of my unit to keep track of my driving; so I could see the time progress in the lower corner; I planned to drive there and use the zoom and pan function on the GPS to find the high school; always use the satnav to monitor time and distance to go as well as for speed cameras; I was using the device to give me an ETA*) and some described how they used their systems to increase general situation awareness (e.g. *I used the map to show which direction the upcoming road was going; I keep the map on screen all the time so I can see the direction of the road all the time; what was helpful...just seeing that there were or were not more cities on the island to visit that we hadn't been through yet; I just left the satnav running without entering the address*).

However, just as in the previous sample, some participants preferred not to use their systems at all when in familiar areas (e.g. *the area was known so it was not needed; because I know about 900klm of the journey there is no need for the unit to run all the time*). Interestingly, some participants described how using an IVNS has encouraged aspects of behavioural adaptation in everyday life rather than driving behaviour specifically (e.g. *when I arrived back at work I was able to view the destination distance which I used to provide my employer with the miles travelled; In the past I have used the unit for distance...this is very useful when I fill out a logbook)*.

A few participants' diary entries mentioned aspects of strategic level behavioural adaptation in which they had made updates to the system, to make future journeys more efficient or convenient (e.g. *I like to add each search to my favourites list to speed up the process for next time; as it was a tiny place tucked away in a crowde*d *part of the city I had logged it as a waypoint; after arriving at the location I made adjustments to my system maps...made the system make a new route which avoided the [small] village I had driven around using the* *roads I actually used*) and participant 7 indicated that although he was familiar with the area, he left his system turned on so he had the option to quickly access route guidance functions just in case he was faced with congestion during his journey.

Some diary entries also concerned methods that participants used for overcoming system limitations, for example one participant 5 indicated less reliance on the auditory modality and greater reliance on the visual modality because the system was too slow in providing auditory instructions, and although this doesn't specifically concern behavioural adaptation of driving behaviour (more like consumer behavioural adaptation), participant 19 indicated that he had bought separate memory cards for maps in different countries because his unit had insufficient memory to cope with the long journeys that he was used to making.

5.8.5.2 Minimising distraction

The discussions in the previous chapters noted that relatively few drivers acknowledged the distraction potential of their systems during normal route following (i.e. not system interaction), but table 5.7 shows that several participants indicated strategic and tactical level decisions to minimise any distractions. Most often they outlined strategies to minimise glare on the screen (e.g. *during daylight usage with bright sunlight the LCD screen is difficult to see…to avoid this satnav repositioning away from the windscreen and lower down to avoid direct sunlight; the reason for turning the unit off all the time is so the glair doesn't shine in my eyes*) but one participant also indicated adaptation of glance behaviour to minimise distraction (i.e. *usually only glance at the unit to minimise distraction*).

5.9 Summary and implications for behavioural adaptation

This chapter described a diary study which mainly collected qualitative information but also collected some quantitative data concerning potential individual difference variants in experiences of behavioural adaptation to IVNS. The discussion showed that it was unnecessary to recruit a representative sample of drivers and IVNS users as the diary study aimed to explore aspects of behavioural adaptation to IVNS already identified in previous survey research. The study recruited worker drivers who travel frequently in unfamiliar areas. Several participants also had HGV and/or LGV driving licenses, so this study was able to find out about their experiences in using IVNS, as this particular group of IVNS users was relatively neglected in the previous studies. The study failed to attract any drivers who use systems with vocal interfaces.

The results showed that several participants used their IVNS while driving and table 5.3 shows the range of contexts in which they did this over a 2-week period. Again, the majority of participants in this study, thought that some forms of system interaction should be allowed while driving, although a higher proportion of participants in this study, than the IVNS user survey, thought drivers should be able to access more complex system functions while driving (e.g. destination entry by address or postcode). The discussion described how despite these attitudes, most drivers only used their systems while driving to satisfy moment-to-moment requirements, they rarely entered final destinations as this kind of route planning was dealt with before commencing a journey, in most cases. This study also showed that those who used their system (and entered destinations specifically) while driving were significantly older than those who had not.

The discussion also considered participants' perceptions of the risks of using their system while driving and the potential impact on safety and driving performance. It showed that although some participants were aware that interactive tasks performed while driving can distract drivers and degrade driving safety, participants rarely mentioned that **they** had been distracted or had compromised driving safety while performing these tasks. Based on diary data alone it was impossible to assess whether these perceptions were justified, but several studies cited in chapter two have shown than manual and vocal destination entry tasks performed while driving can degrade driving performance and safety. Based on this evidence and diary study participants' awareness that interactive tasks performed while driving can cause distraction or degrade driving performance and safety, it is possible that their subjective perceptions were misaligned with reality. The discussion showed how this would be consistent with an optimism bias – a well documented finding in traffic psychology where drivers rate themselves as better and more skilful than "average drivers" (e.g. Svenson, 1981). Future studies were therefore proposed to further examine the objective driving performance effects of system interaction while driving and to assess the accuracy of subjective ratings of these performance effects. The discussion showed that due to the potential expense of naturalistic observational methodologies, there would be several advantages in using driving simulators to conduct these experiments. Such experiments would be consistent with the third aim of this thesis (i.e. to select a safety-negative behavioural adaptation to understand why some drivers behave this way, with a view to informing the design of future potential remediation or mitigation strategies). A poor degree of correspondence between subjective ratings and objective measures might for instance indicate a need to re-align these subjective perceptions through driver training or educational/media campaigns.

The results also illustrated the varied contexts in which participants had received and followed inaccurate and/or dangerous/illegal route guidance instructions both during the study and before the study began. Most situations encountered by participants could be broadly classified in similar categories shown in the IVNS user survey, but in this study participants provided much richer and more detailed accounts of these situations. This study also showed that inaccurate route guidance instructions which have guided drivers along routes for which their vehicle dimensions are unsuitable are also a significant issue for those with HGV and LGV driving licenses, these particular drivers were largely neglected in the IVNS user survey. Replicating previous results, this study also showed that those who followed dangerous/illegal route guidance instructions were significantly older than those who did not. Those who had followed them also had a significantly higher potential for complacency than those who had not, and although were no significant differences between groups in terms of overall trust and distrust ratings, there were significant differences in responses to two individual items from this scale. There were no significant differences between each groups' scores on the attentional scales. However, the discussion showed that these findings alone are insufficient to select a trust/complacency or attention based explanation due to methodological limitations of this study (e.g. small sample size and use of ordinal level scales).

Clearly this study has fully addressed the second aim of the thesis by exploring in detail some of the contexts in which behavioural adaptation to IVNS does occur. Despite their low power due to sample size restrictions, the quantitative analyses also revealed interesting individual difference variates in drivers' experiences of behavioural adaptation to IVNS. Concerning the variables age, driving experience and computing skill, the present study replicated many of the findings in the previous study which sampled a much higher volume of IVNS users.

Finally, in combination with the previous two surveys, this study has now fully addressed the first aim of the thesis by identifying several more instances in which participants appeared to have demonstrated strategic and tactical level behavioural adaptation to IVNS during the two-week diary study. Behavioural adaptations concerned several issues, including IVNS usage in familiar areas, strategies employed by drivers to minimise distraction and strategic preparations to aid the efficiency of future journeys.

Chapter 6 – Considerations for thesis direction

6.1 Introduction

The previous chapter showed how the last 3 studies have fully addressed the first two aims of the thesis. The remainder of this thesis will deal with the third aim, which involves selecting and further investigating a prevalent safety-negative behavioural adaptation to IVNS to understand why some drivers behave this way, with a view toward informing the design of potential strategies to remediate or mitigate this driver behaviour. This chapter begins to address the third aim of the thesis by outlining some important considerations in selecting an appropriate behavioural adaptation topic for further study, particularly since a key consideration in this decision will be to select one that will remain a salient issue for some time. The discussion will then go on to explain why the remainder of the thesis focused specifically on the tendency for young drivers to use their systems while driving instead other topics discussed up to this point.

6.2 Overcoming system limitations

Some forms of behavioural adaptation identified in the preceding chapters have been linked to limitations with current systems or other problems/ difficulties associated with IVNS. For example, in chapter 5 some diary study participants employed a range of strategies to minimise distraction caused by glare on the visual display. Also in chapter 4 most IVNS users surveyed reported that they have received inaccurate route guidance instructions at least occasionally and chapter 5 illustrated some of the varied contexts in which this occurs. Inaccurate route guidance instructions can be caused by problems with the system itself (e.g. erroneous/poor routing algorithms), but the data from chapter 4 suggests that the currency of the underlying map data is also of particular concern since inaccurate route guidance instructions were by no means exclusively received by IVNS users who had not regularly updated their maps - nearly half of those who had updated had still received inaccurate and dangerous/illegal route guidance instructions. Clearly a pre-requisite for drivers to over-trust and/or over-rely on inaccurate or dangerous/illegal route guidance instructions is that they must first have received them, and the data suggests they are caused by system/software problems or limitations.

Finally, chapter 2 showed that although vocal destination entry while driving has been shown to degrade driving safety and performance, they are typically degraded to a greater extent when drivers manually enter destinations while driving. Chapters 4 and 5 suggest that the majority of IVNS users manually interact with their IVNS at least occasionally and a significant proportion do so regularly. Manual system interaction is a standard feature on all IVNS, but it could be argued that a further limitation of present systems is that a much narrower range of them currently allow for vocal interaction.

Due to the increasing popularity of IVNS chapter 1 showed that the entire market is continuously expanding at a significant rate. Many problems covered in the present thesis, which had been largely unaddressed by the industry when the thesis was initiated three years ago, might rapidly becoming less serious due to a range of industrial and technological solutions and improvements to system design. As a result, it is possible that many of the issues raised in the thesis, where drivers have shown behavioural adaptation due to system difficulties or limitations, may become obsolete over time as these are continuously addressed by industry. Traffic law in the UK is also undergoing continuous development; it is inevitable that as IVNS become more popular, and are adopted by an increasing range and number of drivers, they will increasingly fall under the scrutiny of legislators. This chapter outlines some recent technological developments in the IVNS (and IVNS accessories) industries, as well as some legal issues which may significantly reduce the extent to which drivers show some forms of behavioural adaptation identified in this research.

6.2.1 Distraction due to glare on screen

Manufacturers have been aware of the potential for screen glare to cause distraction for some time, and industry appears to be taking steps to reduce or eliminate this particular problem. Different manufacturers have taken varied approaches to addressing it. For example, Boxwave have released an anti-glare screen protector for use with Honda Civic IVNS[1], several IVNS manufacturers (e.g. Pioneer, TOMTOM, SONY, GARMIN etc.) now have models which use anti-glare coatings on visual displays, the 2007 Lexus SC DVD IVNS[2] has a tilting screen, and other manufacturers (e.g. glarestomper, drumma,

[1] Source: http://www.boxwave.com/accessories/2006-honda-civic-navigation-system-screen-protectors_2653.htm (accessed 22/10/08)
[2] Source: http://www.who-sells-it.com/cy/lexus-u-s-a-2009/2007-lexus-sc-dvd-navigation-system-8643/page-1.html (accessed 22/10/08)

zunzun) have released anti-glare shades which fit around nomadic IVNS to prevent sunlight from reaching the display (see figure 6.1). It is likely that with an increasing range of products designed to reduce glare, that over time, drivers will have less need to employ strategies to minimise it.

Figure 6.1: showing one of many methods available to consumers, of reducing glare on screens of nomadic IVNS

Source: http://www.yournav.com/content/review/467/ZunZun_kill_glare_on_your_SatNav.html (accessed 22/10/08)

6.2.2 Inaccurate route guidance instructions

Given the frequency with which the press have reported instances in which IVNS users have received inaccurate guidance (see chapter 2 for some examples), it is not surprising that to avoid future embarrassment and damage to sales, manufacturers have expended great effort into finding methods of reducing inaccuracies and increasing the general reliability of system maps. For some time most of the major manufacturers, including those who manufacture the electronic maps, have had online error reporting systems, that allow drivers to report errors they encounter so that future maps (which are published several times a year) are more accurate. Additionally the two main electronic map manufacturers Navteq and Teleatlas have extensive survey teams who drive along roads throughout the world continually re-mapping them, to identify any structural changes that can be incorporated into new map editions. These efforts have been going on for some time, but according to TOMTOM (2007), it is estimated that 10-15% of road networks change each year, so it is unsurprising that presently IVNS users frequently receive inaccurate route guidance instructions (as also illustrated in the previous two studies).

It has already been mentioned that most participants in both the present study and the previous studies reported using nomadic or portable IVNS (indeed this was a primary motivation for this research, as many other IVNS user studies have concentrated solely on integrated IVNS users). Although participants used a variety of models, produced by a range of manufacturers, the vast majority of participants used TOMTOM or GARMIN IVNS. This is not particularly surprising, as the GFK (2008) surveys showed that TOMTOM is by far the most popular IVNS manufacturer in Europe, while GARMIN are most popular in the US, and as shown, the vast majority of participants in the present study and previous studies were from these parts of the world.

Previous chapters have also shown that most drivers are annoyed with the expense of map updates and the reliability of these, so recently both these manufacturers have designed and released innovative solutions to further address map inaccuracies, which may vastly increase the quality and reliability of electronic maps, decrease the frequency with which IVNS users receive inaccurate route guidance (and in turn, decrease the frequency with which some IVNS users follow inaccurate route guidance). The end result should therefore vastly increase consumer satisfaction with these products.

The GARMIN solution is most straightforward. They have begun to offer users free lifetime map updates, where, as of 15th October 2008, for a one-time fee (about the price they previously would have had to pay for an annually updated map) users receive 4 Navteq map updates each year for as long as they own the GARMIN device. Additionally, drivers who purchase their latest IVNS models will receive free new maps if these are released within two months of their purchase.

TOMTOM also allow consumers who purchase new systems to receive free map upgrades, if they are made available after their purchase, but they have also patented and released a technology called MAPSHARE (see TOMTOM, 2007). This allows drivers to correct any errors they discover while driving, on their system maps. Additionally, if users connect their TOMTOM to the internet (via their personal computer), they can download map corrections made by other users and share their own corrections, which over time should vastly increase the accuracy of these maps. They also have certain measures in place to guard against abuse of the system (e.g. editorial teams who check each correction against aerial imagery and alternative mapping sites and allowing users to set the level of trust they are prepared to accept, where the highest trust level only includes corrections specifically verified by TOMTOM).

Although TOMTOM and GARMIN are presently the market leaders, unsurprisingly several other manufacturers have also recently followed suit by offering their own innovative solutions (e.g. Navigon now offer consumers who purchase their latest model, free map upgrades every three months for a period of two years and Mio are also offering consumers free map updates). It is likely that to survive in such a competitive market place, most if not all other manufacturers will soon have similar offers in place.

The Yonhap news agency of Korea (2008) recently reported that an organisation called the Electronics and Telecommunications Research Institute (ETRI) have also developed a technology which relies on specialised servers and a database management system to allow IVNS users to download map updates directly to their mobile phone and then to transfer these across to their IVNS.

The previous chapter in particular also outlined the prevalence with which HGV and LGV drivers have received route guidance instructions that were inaccurate because they directed participants along routes for which their vehicle dimensions (i.e. width, height, length) were unsuitable. In their diary entries, many of these participants vented their frustration about these inaccuracies and mentioned their desire to purchase IVNS that take vehicle dimensions into account in route planning algorithms. Recently several manufacturers (e.g. Siemens[3], Syrius[4]) have released IVNS specifically designed for these drivers.

Due to all these recent technological developments and more, it is likely that over time, system-map inaccuracies will occur much less frequently, so the negative aspects of over-reliance (or following inaccurate guidance due to lack of attention/perception) will probably become a decreasingly salient issue.

[3] http://w1.siemens.com/press/en/pp_cc/2007/02_feb/sosep200702_20_(mt_special_mobility)_1434205.htm (accessed 22/10/08)
[4] http://www.navtronics.co.uk/epages/BT2505.sf/en_GB/?ObjectPath=/Shops/BT2505/Categories/%22Lorry%20Navigation%22 (accessed 22/10/08)

6.2.3 System interaction while driving

Chapter one described how many early IVNS restricted drivers from performing certain functions like destination entry, while driving. Many models, particularly integrated systems still do, but with the increasing availability and decreasing price of nomadic devices and PND, more and more systems are becoming available which do not limit such interactions. Additionally, despite concerns about aspects of the external validity of online research, the present research and previous studies in the literature (e.g. Svahn, 2004) have shown that the majority of IVNS users rate their computing skill as moderate or higher. It is a relatively simple task for even moderately computer literate users with internet access to find several published online articles, providing instructions to circumvent safety protocols and access these functions on systems that previously restricted access to them while driving[5].

This suggests that system interaction while driving is likely to remain a significant behavioural adaptation issue for some time. However, so far the UK has not officially banned IVNS use while driving, but there are some reasons to suggest this may change in the future. In 2003 in the UK, legislation was passed banning the use of mobile phones (except mobile phones with handsfree options) while driving or even to use a mobile phone while supervising a driver with only a provisional license. The penalty for offenders was a fixed penalty of £30 or a fine of up to £1000 if the case went to court. In 2007 the legislation was updated so that offenders now receive a £60 fixed penalty fine as well as three points on their license (penalties are even more severe for drivers of goods vehicles or those carrying passengers – see ROSPA, 2007). This legislation is based on a significant volume of research investigating the effects of using a mobile phone while driving on driving performance (see Goodman et al.,1997; Young, Regan and Hammer, 2003; and Horrey and Wickens, 2006). Chapter 2 showed that in many papers that have examined mobile phone use (and engagement in other distracting secondary tasks) while driving, the topic of IVNS interaction is also often mentioned. This is not surprising as using both IVNS and mobile phones while driving involves entering data using buttons or touch screens, and many IVNS models allow vocal destination entry which has similarities with conversational aspects of mobile phone use. Chapter two discussed the implications of destination entry while driving (including systems which allow

[5] http://www.hybridchat.com/forums/toyota-camry-hybrid-audio-electronics/1116-2007-camry-navigation-modification-enter-destinations-while-driving.html (accessed 22/10/08); http://www.navigadget.com/index.php/2006/05/24/hack-your-toyota-prius-gps-navigation-system (accessed 22/10/08) http://www.wikihow.com/Override-Toyota-Prius-Navigation-Gray-out (accessed 22/10/08)

vocal interaction) and some of the similarities between this and using a mobile phone while driving, so they are omitted here.

The present (and some previous) research (e.g. privilege, 2006) has shown, that many drivers admit to interacting with their systems at some level while driving at least occasionally. Although using an IVNS while driving has not yet been banned outright in the UK, even presently there are some legal problems with this behaviour. Safermotoring (2008) report that until recently, engaging in distracting activities while driving fell under careless driving legislation, where, if drivers were found guilty of failing to drive in a competent and careful manner, they faced a maximum £5000 fine and penalty points on their license. However, since 2007, following a police revision, this behaviour (which includes using an IVNS) will be prosecuted under dangerous driving legislation, which carries up to a two year prison sentence (based on the assumption that offenders were avoidably and dangerously distracted).

Presently, the above legislation is most applicable to situations in which police can reasonably prove drivers have been using their system in a distracting manner, or where collisions or accidents have resulted from IVNS use while driving, but given their present stance on mobile phones, it is certainly conceivable that over time, as the popularity of IVNS increases and an increasing range of drivers adopt this technology, the UK government will adopt more stringent legislation concerning this issue. For example, in 2001 Spain submitted a proposal to the Economic and Social Council of the United Nations to amend the 1968 Vienna convention on road traffic (see economic commission for Europe, 2001), in which they proposed that IVNS (referred to as global positioning systems) should be viewed alongside mobile phones in considering the potential for driver distraction.

Although legislation wouldn't necessarily eradicate system interaction while driving (e.g. speeding is against the law and has strict penalties, but many drivers still drive over the speed limit), it is possible that it could reduce the extent to which some drivers behave this way.

6.3 Thesis direction

The above discussion outlines several arguments why different aspects of behavioural adaptation to IVNS may become less prevalent over the next few years. As mentioned at the start of this discussion, a key concern in selecting an aspect of safety-negative behavioural adaptation for further investigation, is finding one that will remain a salient issue for some time, so that the findings from the present thesis can usefully inform the design of appropriate future remediation or mitigation strategies.

Methodological factors must also be taken into account, as the aim of further investigation is to understand why drivers behave this way as an initial step towards designing future strategies to either prevent or reduce this driver behaviour to improve driving safety. It is important that studies investigating these issues don't lack validity and so are applicable to real IVNS users. Although the most appropriate methodological designs for these studies would be experimental or quasi-experimental on-road or test track studies, unfortunately such naturalistic approaches had to be ruled out as no funding was available for these final studies. Fortunately however, a fixed based driving simulator was available.

Due to the wealth of data collected on these issue in this thesis and the lack of previous research investigating them in this context, the potential topics for further investigation were narrowed down to either system interaction while driving or the tendency of some drivers to follow inaccurate route guidance instructions. System interaction while driving was selected as the topic for further investigation using the driving simulator for two main reasons:

Firstly, although over time various legal ramifications may somewhat affect the extent to which drivers use their IVNS while driving, such legislative decisions have not yet been made and their future introduction is presently only speculation. Additionally, even if the law does change, this will not necessarily eradicate this particular form of safety-negative behavioural adaptation, though it may reduce it. A significant proportion of individuals in most societies behave in ways prohibited by law (e.g. drug users), and a particularly high proportion of people, including many of those who are otherwise law abiding in other contexts, at least occasionally flout traffic laws. For example, a recent survey by Swiftcover insurance (2008) found that 79% of British drivers exceed the speed limit on motorways, and the privilege insurance (2006) survey showed that 23% of UK drivers claimed to drive when over the [alcohol] limit. Furthermore, Green`s (2000) analysis of accident data collected by the National Police Agency concerning accidents during 1999 for which IVNS were at least partially to blame, showed that 24% of accidents could be attributed to operating tasks, even though destination entry while driving is legally prohibited in Japan.

Section 5.8.4 in Chapter 5 described how a recent European review concluded that unless they could not reasonably have avoided them, drivers involved in collisions due to relying on system generated route guidance should be held liable for these actions (see UK Parliamentary Office of Science and Technology postnote, 2002). This is also a clear argument in favour of investigating tendencies for [particularly older] drivers to follow inaccurate and dangerous/illegal route guidance instructions, as this behaviour may increasingly carry certain legal ramifications. However, due to the various technological developments outlined above, it is likely that the overall reliability of IVNS maps will significantly increase over the next few years. Although some companies are offering to increase distribution of regular free map updates, and this will help improve overall accuracy, it is likely that TOMTOM`s mapshare system will also make an even more significant contribution, as no matter how many survey teams map manufacturers employ to travel routes throughout the world and find map inaccuracies, there will always be significantly more drivers with IVNS in their vehicle who between them all can perform this task more efficiently, quickly and completely. It is worth noting here that although TOMTOM have patented this technology, there are only two main electronic map suppliers for the wide range of available IVNS. TOMTOM IVNS predominantly uses TeleAtlas maps (TOMTOM, 2007), but so do many other systems produced by other manufacturers. While it is conceivable that this technology may significantly improve TeleAtlas`s maps compared to those of their main competitor, (which could lead to TeleAtlas establishing a more dominant market position in the electronic map sector); it is also conceivable that over time, drivers who use IVNS produced by other manufacturers will be able to download and therefore benefit from the mapshare system. Whether this is done with TOMTOM`s backing or not (e.g. the range of "cracked" hardware/software applications readily available on the internet for a range of purposes, suggests these technologies will also be "cracked" relatively soon) it is certainly a plausible (not too distant) future scenario.

Secondly, although the approach to system interaction while driving taken by the present thesis has received scarce previous research attention, several previous studies have investigated other issues concerning system interaction while driving, and several of these have been conducted in driving simulators, which suggest that it is at least possible (in terms of validity) to investigate this issue further. However, very few studies have investigated driver`s response to inaccurate and dangerous/illegal route guidance information in the way described in the present thesis. As shown previously, some studies have investigated drivers' response to varying levels of reliability (e.g. Kantowitz et al., 1997; DeVries, 2004), but these have mainly been geared towards examining the effects of system reliability on trust. Therefore, it is difficult to establish precedent for investigating this issue using this methodology.

Due to concerns about the appropriateness of investigating drivers' tendency to follow inaccurate route guidance instructions using a driving simulator, a simple scenario examining this issue was piloted. It revealed serious concerns about the validity of simulator research investigating this issue, which if this line of research had been pursued would seriously have brought the validity of the second half of this thesis into question.

The pilot is outlined below:

6.4 Method

6.4.1 Participants

Table 6.1 below illustrates some of the main characteristics of participants in the pilot. 8 participants (7 male, 1 female) took part. All participants were right handed. They had driven an average of 9250 miles in the past year and had held a full UK driving license for an average of six years. Participants drove a car for an average of 4 days each week. 3 participants had previously used an IVNS.

6.4.2 Design

The independent variable was the accuracy of route guidance instructions received (accurate/inaccurate) and the dependent variable concerned participants' response once they received an inaccurate route guidance instruction (follow/ignore an instruction to turn right into a street signposted as no entry). A repeated measures design was used, in which all participants received several accurate route guidance instructions and one inaccurate instruction in the same order (i.e. counterbalancing was not employed). Participants also completed the CPRS and trust in automation scales (see chapter 5), but no statistical analyses were performed (only descriptive statistics were obtained).

6.4.3 Materials

The pilot was carried out using a STISIM fixed base driving simulator (see appendix T). Participants also completed printed versions of the CPRS (Singh et al., 1993) and trust in automation (Jian et al., 2000) scales (see chapter 5). Since participants were only driving in a simulated environment, it was not feasible for them to use an IVNS currently on the market. A pseudo-IVNS was produced using Microsoft Powerpoint, and by pre-recording spoken route guidance instructions. The Powerpoint presentation (see appendix U for screenshots) was displayed on a screen located on the centre console of the vehicle cockpit.

Table 6.1: showing main characteristics of participants in the pilot[6] (N=8)

Item	Categories	No. of participants/descriptive statistics
Gender	Male	7
	Female	1
Age	Mean	25 years
	Median	25 years
	SD	3.5 years
	Range	21-31 years
No. years with full driving license	Mean	6 years
	Median	5.5 years
	SD	3.9 years
	Range	2-13 years
Approx. mileage past 12 months	Mean	9.3 thousand miles
	Median	8 thousand miles
	SD	7.8 thousand miles
	Range	1-22 thousand miles
Approx. number of days driving per week	0	0
	1	1
	2	1
	3	1
	4	1
	5	1
	6	1
	7	2
Previously used IVNS	Yes	3
	No	5

[6] All participants were UK nationals

6.4.4 Procedure

Before entering the simulator participants were asked to complete the CPRS scale. An urban scenario was authored using the STISIM software. A route was designed which took approximately fifteen minutes to complete. Following a 1km practice route, the urban scenario encompassed 10 turns in both directions. Two hundred metres before each turn the pseudo-IVNS was designed to advise participants to turn either left or right at the next junction. This instruction was repeated when they reached the junction. Turns 1-9 were legal turns, but for the final turn, participants were instructed to turn right into a street that was signposted as no entry. Once participants had either turned or continued driving for fifty metres, the program terminated and they were asked to vacate the simulator. They were then asked to complete the trust in automation scale in relation to the IVNS they just used. After they completed the questionnaire, participants were fully debriefed about the nature of the study. As the pilot was mainly designed to establish the validity of using this methodology to investigate this particular issue, a semi-structured interview was used to determine the face validity of the pilot.

6.4.5 Results and discussion

Three participants followed the inaccurate route guidance instructions by driving the simulated vehicle into the street signposted as no-entry. Participants were split into two groups depending on whether they followed inaccurate route guidance instructions. Table 6.2 below shows descriptive statistics for each group concerning driver characteristics and scale scores. It suggests slight tendencies for those that turned to be older, more experienced drivers (based on years holding a full driving licence and number of days driving per week), who trust the system more and distrust it less than those who did not turn. However, due to the small size and because this was only a study to pilot a particular methodology, it was inappropriate to subject these differences to statistical analysis.

Table 6.2: showing descriptive statistics of driver characteristics and scale scores for those who turned into the street signposted as no entry and those who did not (N=8)

	Those who turned (N=3)		Those who did not turn (N=5)	
	Mean	Standard deviation	Mean	Standard deviation
Age	26 years	3.6 years	22 years	1.5 years
Mileage (past 12 months)	9000 miles	6708 miles	9667 miles	10969 miles
Yrs with full driving license	7 years	4.5 years	4.3 years	2.5 years
No. Days driving per week	5.2 days	2.2 days	3 days	2 days
Mean CPRS score	3	0.9	2.9	1
Mean trust score	4.9	0.4	3.5	1.3
Mean distrust score	1.4	0.4	3.4	1.5

Although some of the descriptive statistics suggest similar trends as have been identified elsewhere in the present thesis, the semi-structured interviews revealed several concerning issues about the validity of this particular study. These are briefly each discussed in turn below:

1. All participants were fully aware that they were using a pseudo-IVNS. Most observed that graphical fidelity and level of detail were far inferior to their prior experiences or expectations of commercially available IVNS. Additionally, all but one of the participants brought up the issue that since they drove a simulated vehicle and therefore never actually moved, the instructions they received could not have come from a GPS-informed IVNS.
2. Following from the previous point, since participants were largely aware they were using a pseudo-IVNS, they had also guessed that the suggested route would have been pre-programmed by the experimenter. This could lead participants to perhaps behave in ways that they think the experimenter want them to behave (i.e. demand characteristics – see Orne, 1962).
3. All participants were fully aware that their behaviour in the simulator would entail no legal problems or safety issues. Therefore their decision to turn in a simulated environment, may have nothing to do with decisions to turn in real driving environments where collisions and accidents are expensive, may cause injury or have legal implications.

The above points were the most frequently raised in the interview, but several individual participants also raised other concerns about the validity of this methodology (e.g. two found it more difficult to perceive road signs than they would have in real life). Based on these interviews, it was clear that it would not be viable to further investigate these issues using a driving simulator. The drawbacks of using driving simulators for some aspects of research in traffic psychology have also been discussed in the literature previously.

Driving simulators are appealing as a research tool as they provide a safe, convenient and comprehensive environment for research (Kaptein et al., 1996). In relation to the present work they also would allow researchers to study conditions which may otherwise be rare, but data collected may be confounded by learning effects (for both the simulator and the navigation system) and experimenter effects (NHTSA, 2000). Many participants, particularly older ones (i.e. the age group that would have been targeted for this kind of study), also suffer simulator sickness (Goodman et al, (1997). However, the main drawback (as this pilot has partially illustrated) concerns validity.

Several authors have questioned the extent to which simulated driving performance corresponds with real driving performance (e.g. Reed and Green, 1999; Carsten et al., 1997). Goodman et al. (1997) suggests that driving behaviour, particularly allocation of attention to in-vehicle tasks, may significantly differ from real world performance because no serious consequences result from driving errors in a simulator. Simulator participants may not observe legal or socially accepted codes of behaviour (e.g. turning into a one-way street) as stringently as they would in the real world. They are also unlikely to experience the same motivations, time constraints and other pressures as real drivers who may want to reach a destination for many different reasons.

6.4.6 Conclusion

In contrast to simulator studies, it would be most appropriate to further investigate drivers' tendencies to follow inaccurate route guidance instructions by observing real driving behaviour using longitudinal on-road research. However, these studies are often expensive and time consuming, so would not have been feasible for the present research, particularly as most IVNS users drive frequently in familiar areas and even if a sample was found who made mostly unfamiliar journeys, instances in which inaccurate route guidance instructions are followed are relatively rare events.

6.5 Chapter conclusion

The pilot showed that it would have been inappropriate to have further investigated older drivers' tendency to follow inaccurate route guidance instructions in this thesis. Due to these methodological difficulties as well as recent and future developments in the IVNS industry, this chapter has shown that it would be most appropriate to address the final aim of the thesis by further investigating the issue of system interaction while driving because it is most likely to remain a significant driving safety issue despite potential legal and technological developments in the wider IVNS industry.

Chapter 7 – Subjective VS objective driving performance when entering destinations while driving in a simulator

7.1 Introduction

The final aim of the thesis was to select and further investigate a prevalent safety-negative behavioural adaptation to IVNS to understand why some drivers behave this way and with a view toward informing the design of future strategies to remediate or mitigate this driving behaviour. The previous chapter explained why the remainder of the thesis will further investigate system interaction while driving only and chapter 5 outlined a particular need for further experimental research examining the degree of correspondence between subjective ratings of the performance effects of system interaction while driving and objective measures of these parameters.

In the diary study it would have been impossible to have determined whether participants' subjective perceptions were misaligned because objective measures were never collected. The data suggested that participants were aware that interactive tasks performed while driving could cause distraction and degrade driving safety/performance but rarely acknowledged these effects when they performed these tasks. The discussion in chapter 5 showed that since previous research has shown that destination entry while driving does degrade driving safety and performance, these diary study findings were also consistent with previous studies describing an optimism bias (e.g. Svenson, 1981) where drivers typically rate their own driving skills more favourably than other drivers.

It is plausible that some IVNS users who enter destinations while driving are largely unaware of the performance and safety effects of this behaviour. This thesis has shown that younger drivers enter destinations while driving significantly more frequently than older drivers, and previous studies have illustrated that younger drivers are more likely to be miscalibrated about their own driving skills (Matthews and Moran, 1986; Finn and Bragg, 1986; Harre, Foster and O`Neill, 2005; Freund et al., 2005; Garabet, Horrey and Lesch, 2007). Horrey, Lesch and Garabet (2007, p.59) proposed that drivers' willingness to engage in distracting tasks while driving may be influenced by their perceptions of the distractive effects of behaving this way. According to the authors (citing Wogalter and Mayhorn, 2005)

"*the willingness to engage in distracting activities may be a function of drivers' perceptions of performance decrements. As such, drivers may engage in distracting activities simply because they do* *not realise that their performance is degraded or they may be overconfident in their skills and their ability to deal with distractions behind the wheel"*.

The present study was designed to address the third aim of the thesis. Following Wolgater and Mayhorn (2005), it is plausible that some drivers enter destinations while driving simply because they are unaware it could be dangerous or are overconfident in their own ability to cope with distractions while driving. To determine how well calibrated young IVNS users who have previously entered destinations while driving were about their driving skills when performing this task in a simulator, the present study examined subjective ratings of the performance effects of destination entry while driving as well as the strength of associations between subjective ratings and objective measures of these parameters.

Establishing the strength of associations between subjective ratings and objective measures could also be a useful initial step toward informing the design of future remediating or mitigating strategies. For example, if subjective performance ratings and objective measures of these parameters were misaligned, further research might investigate methods of re-aligning or more appropriately aligning them, with a view to preventing drivers from behaving this way (i.e. remediation) or reducing negative consequences of this behaviour should they choose to behave this way (i.e. mitigation).

7.2 Experimental hypotheses

1. When participants enter destinations while driving, their driving performance will be significantly worse than it is during normal driving on the same stretch of road.

2. There will be a significant association between these objective driving performance measures and subjective ratings of these parameters, between these conditions.

7.3 Method

7.3.1 Participants

Table 7.1 below illustrates some of the main characteristics of participants in this driving simulator study. Twenty four participants (19 male, 5 female, mean age=25.2 years, SD=5.9 years) took part. All participants were paid £10 for participating and were recruited using advertisements placed around campus at the University of Nottingham, but only 5 participants were university students. All participants held a full driving licence[1] and had all previously used an IVNS.

Table 7.1: showing main characteristics of participants in the driving simulator studies (N=24)

Item	Categories	No. of participants/descriptive statistics
Gender	Male	19
	Female	5
Age	Mean	25.2 years
	Median	24 years
	SD	5.9 years
	Range	18-40 years
No. years with full driving license	Mean	5.9 years
	Median	4 years
	SD	4.7 years
	Range	1-17 years
Approx. mileage past 12 months	Mean	7.8 thousand miles
	Median	5 thousand miles
	SD	8.3 thousand miles
	Range	1-35 thousand miles
No. years using a computer	Mean	8.3 years
	Median	9 years
	SD	5 years
	Range	1-20 years

[1] 20 participants held UK driving licenses and 4 participants held international driving licences, but all participants had driven on UK roads for longer than 6 months.

Item	Categories	No. of participants/descriptive statistics
Self-rated computing skill	Expert	1
	Considerable skills	7
	Moderate skills	8
	Some skills	5
	Insignificant skills	2
	No skills	1
No. days driving per week	0	2
	1	1
	2	2
	3	1
	4	3
	5	5
	6	4
	7	6
Vehicle licenses held	Car	24
	Motorcycle	0
	Light goods vehicle	2
	Heavy goods vehicle	1
Presently own IVNS	Yes	13
	No	11

7.3.2 Materials

The present study was carried out in a fixed base STISIM driving simulator (see appendix T). Participants controlled the simulated vehicle from a real vehicle chassis, and the driving scene was projected onto two side screens, a front screen and a rear screen which could be viewed in the rear view mirror. The driver`s side wing mirror also had an LCD screen embedded in it, so this perspective could also be viewed. A working speedometer and rev counter was also presented on an LCD screen embedded behind the steering wheel (in the same location these gauges are typically found in vehicles). The simulator collected a range of data, but three video cameras were also used to aid coding and data analysis. One pointed towards the front projected driving scene, one pointed towards the participant`s face and one pointed towards the IVNS. Video data was used for coding destination entry time and to assist in identification of the distances between which, participants entered destinations while driving for purposes of comparison with normal driving on the same stretch of road.

Participants completed destination entry tasks using a TOMTOM GO nomadic IVNS. Vocal guidance options were disabled on the IVNS as it would not have been able to provide system-generated guidance to participants who were driving an imaginary route through a simulated environment. Instead vocal directions which corresponded to the route to be driven in the simulator were recorded before the experiment began, and were played to participants at appropriate times during their drive.

Once participants had completed the experiment, they were asked to compare their experiences entering destinations while driving with their experiences during normal driving and to answer a series of questions based on these experiences. This questionnaire was piloted to ensure items had satisfactory face validity, and could clearly be understood (see appendix V). It was defined by six items, each using ordinal level data. Participants were asked to base their responses to each item on their experiences in the present study only. For the first three items, participants were required to provide a rating on a scale ranging from 1 (much worse) to 9 (much better) concerning their ability to remain within lanes, to maintain an appropriate driving speed and their overall self-rated driving performance when entering destinations while driving. For the last three items, participants were required to provide a rating on a scale ranging from 1 (not at all) to 9 (extremely) concerning how safe and risky they perceived entering destinations while driving to be in the present study, and to rate how confident they were entering destinations while driving (see appendix W for rating scales).

Participants also completed a short questionnaire designed to collect additional demographic information (see appendix X). This questionnaire was defined by 16 items. It collected nominal, ordinal and ratio level data, and two items (i.e. IVNS manufacturer and model) required text entry. Ratio level items were age, number of years with full driving license, mileage over past 12 months, number of days they use their vehicle each week and number of years using a computer. Ordinal level items were driving confidence, self-rated computing skill, frequency of using an IVNS while driving and frequency of using the in-car stereo controls while driving. Nominal level items were gender, whether mileage over past 12 months was typical, whether participants were left or right handed, vehicle used most often and whether they presently own an IVNS, whether they have previously used an IVNS, and if so, whether they had ever previously used an IVNS while driving.

7.3.3 Design

The present study employed a within-subjects design. The independent variable was destination entry method (i.e. while parked or while driving). All dependent variables used ratio level data. The dependent variables were:

- Longitudinal driving performance measures (i.e. number of speed exceedences, longitudinal acceleration and longitudinal velocity)
- Lateral driving performance measures (i.e. number of lane departures, lateral acceleration and lateral velocity)
- Destination entry time

The longitudinal and lateral vehicle control tasks are the most important in driving, and each of the above measures of longitudinal and lateral control have been employed in previous driving research (e.g. see Green, Fleming and Katz, 1998; Gellatly and Dingus, 1998; Gartner, Konig and Wittig, 2001; Tsimhoni, Smith and Green, 2002; Itoh et al., 2004;). Longitudinal control refers to the control of a vehicle`s forward (and backward) speed, so that there are no collisions, and the vehicle progresses steadily along a desired route. It is based on acceleration (due to throttle) and deceleration (due to throttle and braking). The high volume of research that has associated accidents with increased speed confirms it as a valid measure of driving performance. It is of particular interest because driving is a self-paced task, so drivers may speed up or slow down due to task difficulty, workload etc. For example, Antin et al (1990) found that drivers adapted to task demands by adopting more cautious driving styles including reducing speed (see chapter 2).

Lateral vehicle control refers to the steering tasks in driving. The aim of lateral vehicle control is for the car to remain on the road, and most often within a specific lane. DeWaard (1996) particularly recommends examination of lateral control measures in driving studies concerning secondary task performance as well as in wider driving research, due to their sensitivity to driver workload. They also have high face-validity as measures of interference to the driving task (e.g. chapter 2 showed how a range of secondary tasks including IVNS use and mobile phone dialing can disrupt lateral task performance).

The number of lane departures and speed exceedences provide fairly useful, but crude measures of lateral control, as they are absolute measures (i.e. the driver did or did not leave the lane or did or did not exceed the speed limit), so do not illustrate variations in lateral/longitudinal position, which can tell a great deal about drivers' control over these tasks. Fortunately variation in task performance can be measured by examining the standard deviation of longitudinal and lateral control measures. For example, a low standard deviation of speed would indicate a constant driving speed (i.e. control over acceleration/deceleration), whereas a higher standard deviation of speed would indicate increased speed variation (i.e. reduced control). Similarly, a high standard deviation of lane position would indicate greater weaving within a lane and a lower standard deviation a more constant vehicle path (i.e. greater lateral control). The standard deviation of lateral velocity is a further measure of stability/instability within a lane, and lateral acceleration concerns aggressive attempts to correct lane deviations.

The standard deviation of longitudinal velocity is also a useful measure of speed variation. According to Monty (1984), these measures are sensitive to the attentional demands of secondary in-vehicle tasks. The standard deviation of longitudinal acceleration is also useful for understanding speed corrections based on throttle control. Hanowski, Kantowitz and Tijerina (1995) showed that longitudinal acceleration increased when drivers performed secondary tasks such as dialing a phone, reading text and tuning a radio.

7.3.4 Procedure

Participants volunteered for the present study by responding to advertisements placed around the University of Nottingham campus. When potential participants responded to the advert they were asked their age, whether they held a full driving licence, whether they had previously used an IVNS and whether they suffered from migraines, blurred vision or motion sickness[2]. Those who were aged below 40 years, had held a full driving license for longer than 3 months, had previously used an IVNS and who didn't suffer from these ailments were invited to participate.

When participants arrived they were asked to complete a short questionnaire collecting demographic data (see appendix X), then to sign a consent form (see appendix Y) and then to read the instructions (see appendix Z). As well as explaining their task, the instructions also explicitly informed participants they could withdraw from the study at any time, and to signal (by speaking through an intercom system) the experimenter if they start to feel unwell in any way. Once participants had formally agreed to

[2] These symptoms feature on the simulator sickness questionnaire (SSQ- Kennedy et al., 1993). Kennedy et al (1993) showed that older individuals and those suffering from migraines, blurred vision or motion sickness are most likely to experience simulator sickness (i.e. nausea and disorientation).

continue with the experiment, they were asked to make themselves comfortable in the simulator. They could adjust the driving seat and mirrors to whichever position felt most comfortable. Based on responses to item B7 in the questionnaire, right handed participants had the IVNS set up on the dashboard to the right of the steering wheel and left handed participants had it set up on the dashboard to the left of the steering wheel[3].

They were told to use vehicle controls as they would when driving normally. Although all participants had previously used an IVNS, they were all shown how to enter destinations using this particular model, and were given three destinations to enter as practice. They were also told that during the task, as soon as they had entered the destination, and the system began performing a route calculation, to ignore the resulting on-screen visual guidance, as they would receive auditory guidance delivered via speakers installed in the vehicle. Additionally, they were told that they would receive all experimenter instructions through the same speaker system.

Once participants had practised entering destinations, they were told about each phase of the experiment to come and then the experimenter left them alone in the vehicle. Participants drove a one mile practice route to get accustomed with the simulator and its controls. There were two phases to this experiment, and in each phase participants had to enter 2 destinations. In each phase both destinations were printed in upper case letters (Arial font, 30pt size) at the centre of an A4 white sheet of paper in landscape orientation (see appendix AA). All destinations contained an identical number (N=16) of alphanumeric characters and their [correct] entry required an identical number of screen touches (N=23). Participants kept these destination cards on the passenger seat for reference purposes, but before starting the experiment, they were asked to read the destination names aloud a few times, until they felt they were familiar with them.

In both experimental phases, participants were instructed not to stop when they reached the first destination, but to continue driving straight ahead (they were also prompted vocally to "continue straight ahead" at these times). They were asked to pull over to the side of the road when they reached the second destination (and were also promoted vocally to do this). They drove exactly the same route in each phase (but destination names differed). Both scenarios began with the vehicle parked at the side of the road. In each phase participants received no route guidance instructions from the IVNS, they were always told to "continue straight ahead" once they had entered each destination. Phases 1 and 2 are

[3] Participants were also told they could re-position the IVNS to the opposite side if they preferred.

described below. For purposes of counterbalancing, 12 participants were randomly selected to complete phase 1 first, and then phase 2 and the other half of the sample completed these phases in the reverse order.

7.3.4.1 Phase 1

In phase 1, participants were required to enter destinations while stationary and parked at the side of the road. They were asked to enter the first destination while parked before setting off, and to enter the second destination when prompted (after driving 7000 feet), by pulling over at the side of the road as soon as it was safe to do so. Once they had completed each destination entry task, they were vocally instructed to “continue straight ahead”. When they arrived at the first destination (5100 feet) they were vocally instructed to “continue straight ahead”, and when they arrived at the second destination (10,940 feet), they were vocally told “you have reached your final destination, please pull over now”.

7.3.4.2 Phase 2

In phase 2 participants were required to enter both destinations while driving. They had been previously instructed to begin entering the destination as soon as they felt it was safe to do so, once prompted. After driving 580 feet they were vocally prompted to “please enter destination 1 now”. When they had driven 7250 feet, they were vocally prompted to “please enter destination 2 now”. Once they had completed entering each destination, they were vocally instructed to “continue straight ahead”. When they arrived at the first destination they were vocally instructed to “continue straight ahead” and when they arrived at the second destination, they were vocally told “you have reached your final destination, please pull over now”.

Participants took 8-10 minutes to complete each phase. Once they had completed both phases, they were asked to vacate the simulator and were offered refreshment (a glass of water). They were not debriefed however; as after a short rest period (approximately 5 minutes) they went on to complete a second study, which is described in chapter 8.

7.4 Results

7.4.1 The nature of the sample

A table showing all driver characteristics can be found in appendix AB. Participants had held their driving licenses for an average of 5.9 years (SD=4.7 years, range=1-17 years) and had driven an average of 7.8 thousand miles in the past 12 months (SD=8.3 thousand miles, range=1-35 thousand miles). For 18 participants, this represented their typical annual mileage. Participants drive for an average of 4.6 days each week (SD=2.2 days, range=0-7 days), and all participants were licensed to drive a car, 2 were also licensed to drive light goods vehicles and 1 was also licensed to drive heavy good vehicles. 22 participants were right handed and participants had been using a computer for an average of 8.3 years (SD=4.9 years, range=1-20 years). Most participants (33.3%) thought they possessed moderate computing skills and only 12.5% thought they possessed insignificant or no computing skills. General driving confidence was rated on a scale ranging from 1 (very unsure) to 7 (very confident). All but one participant (who rated themselves at scale point 1) rated themselves at scale point 5 or higher. All participants had previously used an IVNS, and they had all previously used one while driving, 13 participants presently used an IVNS. All these participants used a TOMTOM nomadic IVNS, and they all enter destinations while driving occasionally or more frequently. 22 participants frequently or very frequently use their in-car stereo controls while driving.

7.4.2 Actual driving performance

The simulator output data provided a reading of several driving performance measures as well as distance travelled at approximately one second time intervals (the timer started when participants first accelerated). The video data was reviewed, to determine the times at which participants entered each destination while driving. By comparing these times with the simulator output data it was possible to determine the distances in the scenario between which participants entered destinations while driving. For each destination, performance measures were collected from the destination entry start distance to the destination entry end distance in phase 2, and these were compared to the performance measures collected in phase 1 within each of these distance ranges using parametric tests (descriptive statistics concerning each participant's performance data are shown in appendix AC).

A series of within subjects t-tests showed that when participants entered destination 1 while driving:

- They made significantly more lane departures ($t(23)=-2.892$, $p<0.01$)
- They drove significantly slower ($t(23)=4.067$,$p<0.01$)
- Their longitudinal acceleration was significantly lower ($t(23)=3.752$, $p<0.01$)
- The standard deviation of longitudinal acceleration was significantly lower ($t(23)=-3.051$, $p<0.01$)
- The standard deviation of lane position was significantly higher ($t(23)=2.991$, $p<0.01$)
- The standard deviation of lateral velocity was significantly higher ($t(23)=2.840$, $p<0.05$)

A series of within subjects t-tests also showed that when participants entered destination 2 while driving:

- They made significantly more lane departures ($t(23)=-3.542$, $p<0.01$)
- They committed significantly fewer speed exceedences ($t(23)=-4.978$, $p<0.01$)
- They drove significantly slower ($t(23)=5.046$, $p<0.01$)
- Their longitudinal acceleration was significantly lower ($t(23)=2.372$,$p<0.05$)
- The standard deviation of lane position was significantly greater ($t(23)=2.756$, $p<0.05$)
- The standard deviation of lateral acceleration was significantly greater ($t(23)=2.274$,$p<0.05$)
- They took significantly longer to enter the destination ($t(23)=-3.840$, $p<0.01$).

Figure 7.1: showing standard deviations and the mean number of lane departures and speed exceedences on the same stretch of road, when participants drove normally and when they drove while entering destination 1 (N=24)

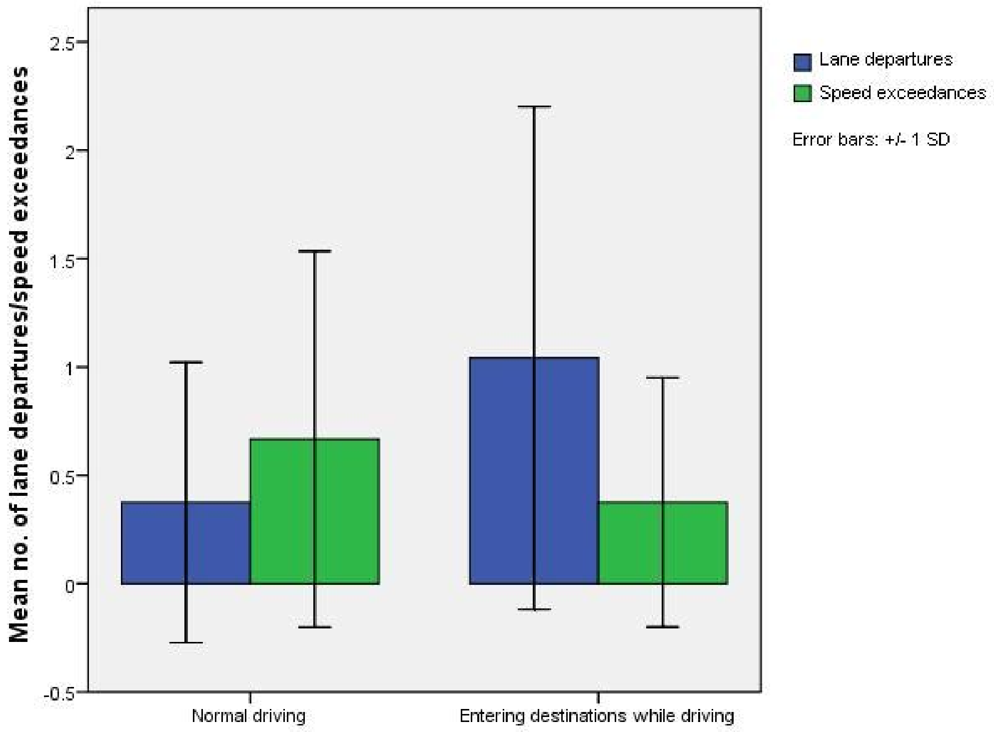
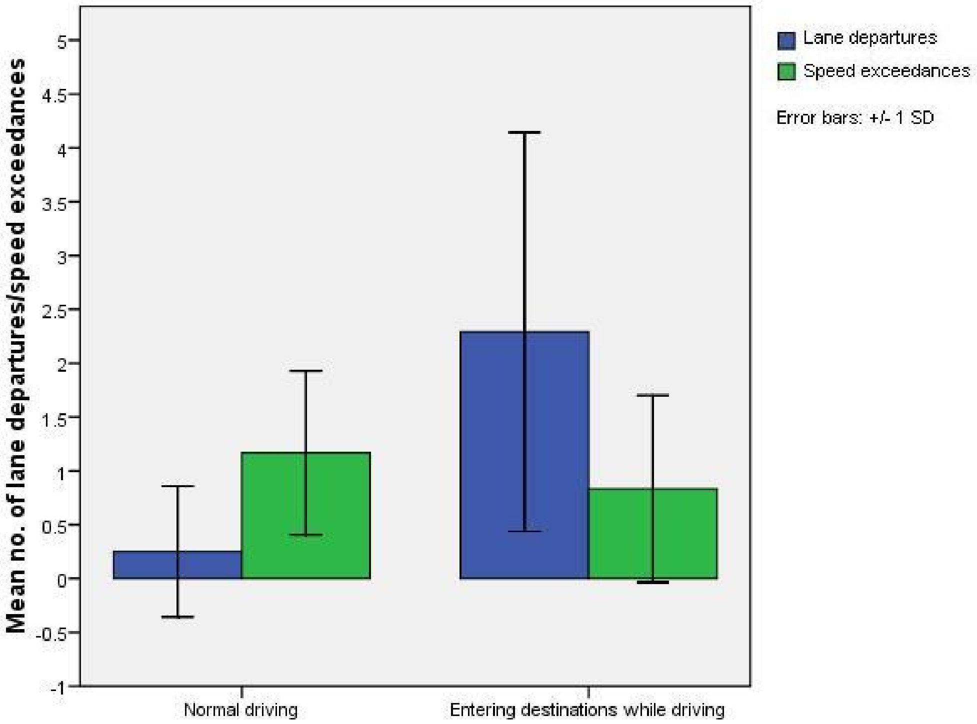


Figure 7.2: showing standard deviations and the mean number of lane departures and speed exceedences on the same stretch of road, when participants drove normally and when they drove while entering destination 2 (N=24)



7.4.3 Subjectively rated driving performance

Figure 7.3 shows the subjective ratings of the effects of entering destinations on driving performance, relative to normal driving in the simulator. Figure 7.4 shows perceived safety and risk of entering destinations while driving as well as confidence in their driving ability when performing this task (relative to normal driving in the simulator). Perceived risk was reversed so it could be compared with perceived safety and confidence (i.e. 1= extremely risky, 9=not at all risky).

There were no significant correlations between subjective ratings of driving performance when entering destinations while driving and any of the demographic variables examined, with the exception of a highly significant negative correlation between general driving confidence and the perceived risk of entering destinations while driving relative to normal driving (Spearman`s rho=-0.567, df=23, p<0.01).

Following figures 7.3 to 7.4 below, the next section considers the degree of correspondence between perceived and actual driving performance during destination entry while driving.

Figure 7.3: showing perceived driving performance when entering destinations while driving, relative to normal driving (N=24)

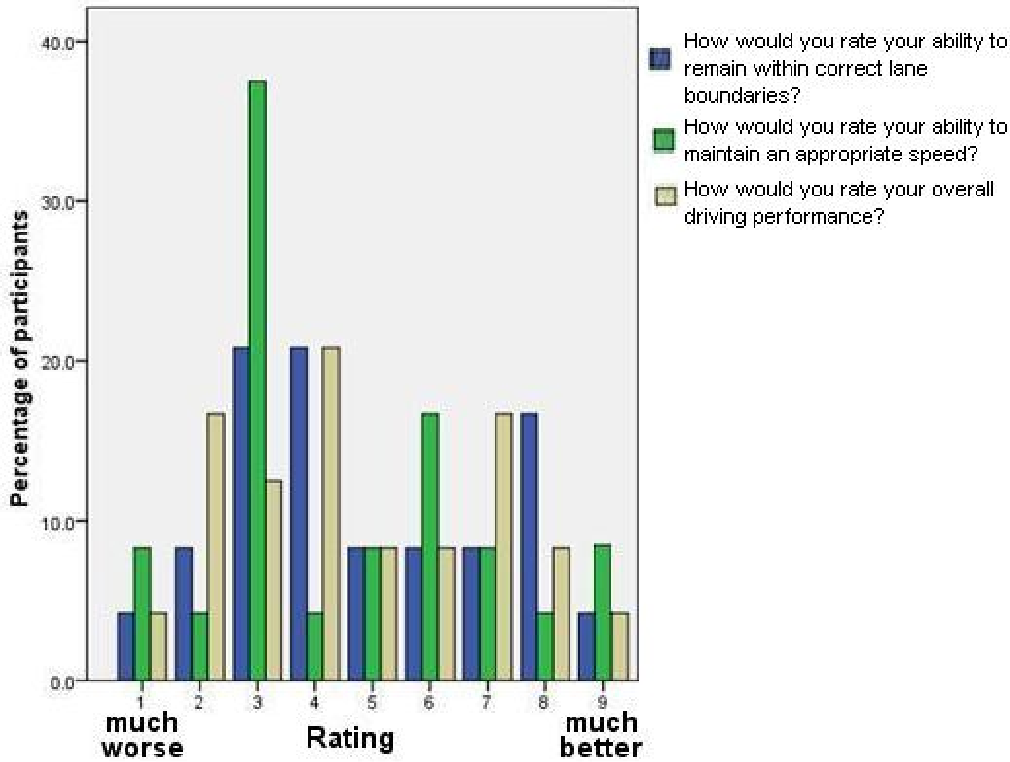
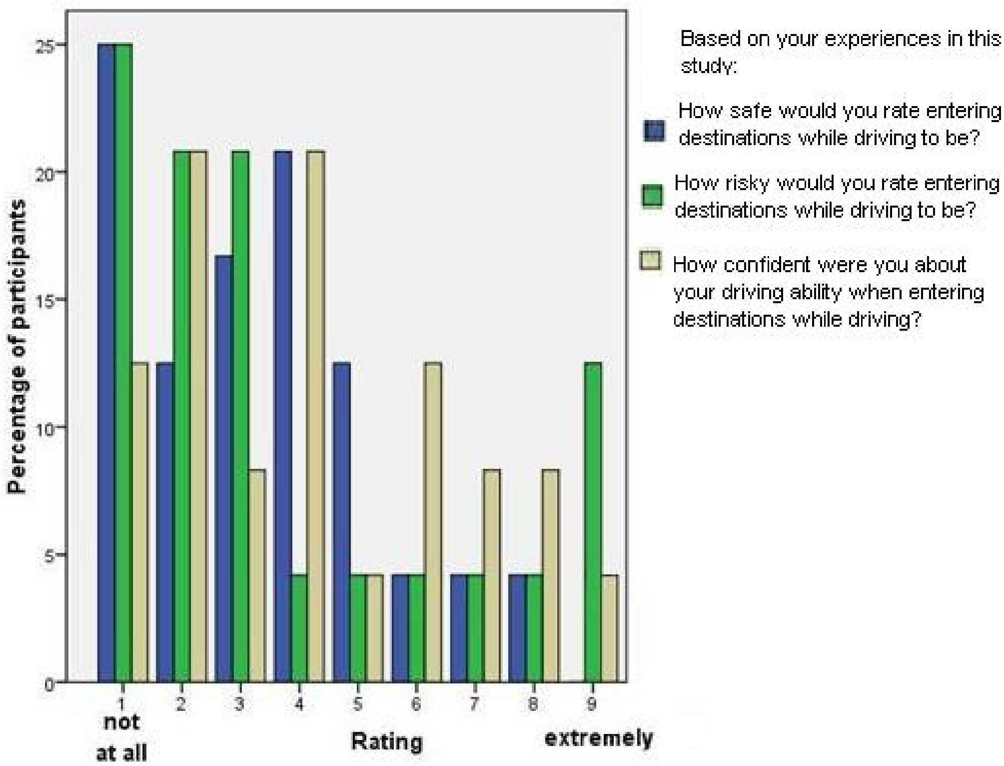


Figure 7.4: showing perceived risk, safety and confidence of entering destinations while driving, relative to normal driving (N=24)



Responses to the perceived risk item were reversed in Figure 7.4 so they were in the same direction as ratings of perceived safety and confidence entering destinations while driving (i.e. 1= extremely risky and 9= not at all risky).

7.4.4 Association between perceived driving performance and actual driving performance

7.4.4.1 Recoding actual driving performance

A central aim of the present study was to examine the correspondence between perceived driving performance when entering a destination while driving and actual driving performance (relative to normal driving on the same stretch of road). So for each destination, the means and standard deviations of longitudinal and lateral driving performance measures recorded when participants entered destinations while driving, were compared to those of the same performance measures recorded when participants drove along the same stretch of road during normal driving. Section 7.3.3 outlined why the mean of some driving performance measures are useful, but for others it is the standard deviation that is most interesting due to the information they provide about control over longitudinal and lateral tasks. Calculating differences in the mean and standard deviation of driving performance measures, shows whether performance improved, got worse or remained the same when participants entered each set of destinations while driving, relative to normal driving on the same stretch of road. When this difference was a positive number, it indicated that performance during destination entry while driving was worse than performance during normal driving, as the mean number of lane departures and speed exccedences was higher, and there was greater standard deviation in the performance measures. Similarly when this difference was negative, it indicated that driving performance was better during destination entry than normal driving, and a zero indicated no difference in performance. These differences were converted into Z-scores, in order to create a standardised scale of driving performance during destination entry while driving relative to normal driving, for this particular sample. A table showing the procedure used to convert driving performance measures into z-scores, using example participant data is shown in appendix AD.

In the subjective scales participants were asked to rate their performance during destination entry while driving, relative to normal driving based on their experiences in the simulator. These scales ranged from 1 (much worse) to 9 (much better), and as shown above, scores on the standardised scales ranged from better to worse, so a negative correlation would have indicated that perceived performance increased with actual performance.

Shapiro-Wilks normality tests revealed that for both destinations, the longitudinal control variables (i.e. speed, longitudinal acceleration, longitudinal velocity) significantly differed from a normally distributed population (i.e. violating the assumption of standardisation, that all raw scores were drawn from a normally distributed population), despite non-significant tests of skewness and kurtosis. As a precaution, to verify all the correlation analyses, differences between the standard deviations of longitudinal performance measures, recorded when participants entered destinations while driving, and drove normally on the same stretch of road, were also recoded to 3 point scales[4]. These were also correlated with the subjective ratings, and in all cases, correlations were similar and in the same direction as those based on z-scores.

For each destination:

- All cases in which variation in these performance measures was greater (i.e. poorer control) when they entered destinations than when they drove normally were recoded to 3 (worse).
- All cases in which there was no difference in the standard deviation of performance measures between these conditions were recoded to 2 (no difference).
- All cases in which variation in performance measures was smaller (i.e. greater control) between these conditions were recoded to 1 (better).

7.4.4.2 Objective vs subjective performance

In most cases there was no apparent association between subjective ratings and objective measures of actual performance, with many extremely weak correlations, particularly concerning associations between perceived lane keeping and speed performance and lateral/longitudinal control measures, but there were some interesting exceptions, these significant correlations are highlighted in table 7.2. Table 7.3 also shows significant correlations between demographic variables and the objective scale.

[4] 1= worse 2= no change 3= better

Table 7.2: showing correlations between perceived performance and z-scores of performance during destination entry while driving relative to normal driving on the same stretch of road (N=24)

Driving performance measure Z-scores All scales range from positive to negative	Perceived ability to remain within appropriate lane boundaries when entering destinations 1 (much worse) – 9 (much better)			Perceived ability to maintain an appropriate speed when entering destinations 1 (much worse) – 9 (much better)			Perceived overall driving performance when entering destinations 1 (much worse) – 9 (much better)			Perceived risk of entering destinations 1 (not at all) – 9 (extremely)			Confidence in driving ability when entering destinations 1 (not at all) – 9 (extremely)		
	Dest1	Dest2	Both	Dest1	Dest2	Both	Dest1	Dest2	Both	Dest1	Dest2	Both	Dest1	Dest2	Both
Mean number of lane departures	-0.11	0.06	0.02				-0.2	-0.05	-0.09	0.04	-0.02	0.07	-0.5*	-0.31	-0.47*
SD of lane position	0.02	-0.03	0.28				0.11	0.34	0.31	0.41*	0.11	0.22	-0.17	0.11	0.05
SD of lateral acceleration (ft/secsq)	-0.05	-0.06	-0.09				-0.2	-0.13	-0.23	0.07	0.06	0.06	-0.01	-0.03	-0.04
SD of lateral velocity (ft/sec)	0.07	0.39	0.29				-0.08	0.44*	0.2	0.33	-0.02	0.24	-0.38	0.08	-0.27
Mean number of speed exceedences				0.13	-0.02	0.1	0.13	-0.15	0.03	-0.49*	0.05	-0.33	0.25	0.15	0.31
SD of speed (mph)				0.24	0.26	0.31	0.14	0.25	0.2	0.097	-0.28	-0.09	-0.46*	0.2	-0.12
SD of longitudinal acceleration (ft/secsq)				0.25	0.02	0.16	0.25	0.09	0.2	0.031	-0.05	-0.05	-0.23	-0.25	-0.11
SD of longitudinal velocity (ft/sec)				0.24	0.02	0.13	0.1	0.01	0.01	0.142	0.06	0.06	-0.48*	0.01	-0.26

All correlations used Spearman`s rho.

Shaded cells were non significant

*correlation is significant at 0.05 level

Table 7.3: showing correlations between demographic details and z-scores of performance during destination entry while driving relative to normal driving on the same stretch of road (N=24)

Driving performance measure Z-scores All scales range from positive to negative	Age			Number of years with full driving license			Annual mileage			Number of days driving per week			General driving confidence 1 (very unsure) to 2 (very confident)			Frequency of using stereo controls while driving 1 (never) to 5 (very frequently)			Self-rated computing skill 1 (no skills) to 5 (expert)			Number of years using a computer		
	Dest 1	Dest 2	Both	Dest 1	Dest 2	Both	Dest 1	Dest 2	Both	Dest 1	Dest 2	Both	Dest 1	Dest 2	Bot h	Dest 1	Dest 2	Both	Dest 1	Dest 2	Both	Dest 1	Dest 2	Both
Mean number of lane departures	0.32	0.46	**0.42**	0.03	0.2	0.05	-0.43	0.01	-0.28	-0.25	-0.34	-0.22	-0.38	-0.23	-0.43	0.01	-0.41	-0.29	-0.29	**-0.52**	**-0.52**	-0.34	-0.38	**-0.5**
SD of lane position	0.17	-0.1	0.01	-0.12	0.06	0.08	-0.07	0.05	-0.02	0.3	**0.63**	**0.64**	-0.45	0.34	-0.13	0.3	0.36	0.34	0.12	0.34	0.3	-0.26	-0.48	-0.41
SD of lateral acceleration(ft/secsq)	-0.37	0.06	-0.03	-0.08	0.09	0.05	0.03	0.01	0.03	0.03	0.19	0.11	-0.22	0.03	-0.02	0.23	-0.01	0.08	0.16	0.16	0.16	0.05	-0.47	-0.43
SD of lateral velocity (ft/sec)	0.15	-0.09	-0.05	-0.04	-0.07	-0.47	0.12	-0.01	-0.01	0.12	**0.52**	0.38	**-0.55**	0.03	-0.35	0.23	0.34	0.28	-0.01	0.23	0.16	-0.37	0.12	-0.49
Mean number of speed exceedences	0.36	0.01	0.3	0.48	-0.05	0.3	-0.01	-0.03	-0.02	0.02	-0.21	-0.11	0.25	0.02	0.11	-0.04	0.01	-0.03	0.15	-0.01	0.09	0.15	-0.01	0.21
SD of speed (mph)	0.08	-0.08	0.01	0.17	-0.1	-0.04	-0.15	-0.05	-0.18	0.05	0.04	0.13	-0.25	0.05	-0.23	0.14	-0.02	0.14	0.22	-0.05	0.16	-0.35	-0.01	-0.22
SD of longitudinal acceleration (ft/secsq)	-0.22	0.12	-0.17	-0.24	-0.21	0.27	0.09	0.14	0.1	0.01	0.34	0.42	-0.3	-0.02	-0.13	0.04	0.05	-0.02	0.09	0.24	0.21	-0.23	0.05	-0.08
SD of longitudinal velocity (ft/sec)	0.08	0.17	0.14	0.06	0.07	0.1	-0.16	0.11	-0.1	0.06	0.21	0.25	-0.22	-0.05	-0.19	0.11	0.08	0.21	0.26	-0.05	0.44	-0.33	-0.13	-0.25

Age, no. years with full driving license, annual mileage and number of days driving per week were ratio level variables, so Pearsons test was used. Spearmans rho was used for all other correlations.All shaded cells were non-significant, ***bold text*** *denotes correlations significant at the 0.01 level, all other correlations shown were significant the 0.05 level*

all correlations were verified used Spearmans rho for comparative purposes

7.5 Discussion

7.5.1 The sample

The sample characteristics show that despite all being under the age of forty, participants with a range of driving experience took part in the present study. So far in the thesis, it is clear from the results of both the IVNS user survey (reported in chapter 4) and the diary study (reported in chapter 5) that young drivers use their IVNS and perform destination entry tasks while driving, more frequently than their older counter parts, so this age group was specifically targeted for the present study. It was also important that all participants had previously used an IVNS, and had previously interacted with one while driving so that performance effects could not be attributed to the novelty effect; but despite their previous IVNS experience, it was particularly important that participants based their performance perceptions on their experiences in the simulator only, and participants were reminded of this throughout the study. This thesis has also reported significant associations between computing skill and the frequency with which drivers enter destinations while driving. Although most participants had moderate or higher computing skills, they varied in their degree of computer literacy and in the number of years they have been using a computer.

7.5.2 Objective performance effects of entering destinations while driving

By examining the correspondence between subjective and objective ratings, this study also looked at the effects of destination entry while driving on longitudinal and lateral driving performance and vehicle control measures. Chapter two described several previous studies which had examined the performance effects of manual destination entry while driving. It showed that many studies have reported degraded longitudinal (e.g. Srinivasan and Jovanis, 1997; Chiang et al., 2001; Zylstra et al., 2004) and lateral (e.g. Nowakowski et al., 2000; Dingus et al., 1995; Tijerina, Palmer and Goodman, 1998; Zwahlen, Adams and DeBald, 1988) driving performance, when participants entered destinations while driving.

Chapter two discussed some of the difficulties in comparing studies over time due to methodological differences between them. Citing previously reported findings concerning destination entry time as an example, the discussion demonstrated that in earlier studies, participants typically took much longer to enter destinations than in later studies, and that this was probably largely due to technological advancements, for example, in interface design. As well as increasing the ease of destination entry tasks, newer interfaces have reduced the number of steps required to complete them. In many early studies, participants took between 1 and 4 minutes (and sometimes up to 9 minutes) to enter destinations while driving, but in a more recent study, Chiang et al (2004) found that participants took an average of just 34 seconds to complete this task. In the present study, participants took an average of 40 seconds to complete destination entry tasks.

Similarly, contrary to many previous findings, Chiang et al (2004) also found that participants' lateral performance was acceptable when they entered destinations while driving, although they did also find that they drove slower than normal at these times. Due to differences in the findings of destination entry studies over time, the present study aimed to examine the performance effects of entering destinations on an extremely popular, cheap and affordable nomadic IVNS easily available to most drivers in Europe.

7.5.2.1 Longitudinal driving performance measures

Just like in Chiang et al. (2004), in the present study, participants also drove significantly slower when entering both destinations while driving, compared to their speed on the same stretch of road during normal driving. During destination entry tasks (relative to normal driving), they also exceeded the speed limit significantly less frequently. This is consistent with previous work discussed in chapters two and four concerning behavioural compensation. Then, the discussion showed how older drivers have been shown to drive more slowly, and that this may be a compensatory response to an awareness of deteriorations in physical, perceptual and cognitive abilities. Similarly, it is possible that in the present study, participants reduced their speed to compensate for the high workload demands of entering the destinations while driving (see Zylstra et al., 2004; Haigney et al., 2000).

Although from a road safety perspective, reductions in speed are largely positive (due to the well known associations between traffic accidents and high speed), it can also have negative implications in terms of both safety and efficiency. From a wider societal perspective, it is important for the smooth running of road networks that traffic flows throughout the network at constant and at highly predictable rates. If a driver suddenly reduced in speed while entering a destination on a busy highway, this could also lead to traffic accidents and/or road network disruption. When they compared the driving performance of drivers navigating using paper maps and those using IVNS, Pohlman and Traenkle (1994) also observed that participants drove more slowly when using an IVNS, and that some even stopped completely. They noted that participants reduced their speed without any consideration for traffic regulations or the right of way of other road users.

7.5.2.2 Lateral driving performance measures

Participants also made significantly more lane departures when they entered both destinations while driving. Chapter two showed that most previous studies have also reported similar findings (e.g. Nowakowski et al., 2000; Dingus et al., 1995; Tijerina, Palmer and Goodman, 1998; Zwahlen, Adams and DeBald, 1988). Some early dual task studies (e.g. Mcleod, 1977; Wickens et al., 1983; Sarno and Wickens, 1995) also noted that manual response tasks interfered with tracking task performance. The discussion in chapter two drew on multiple resource theory (Wickens, 1992) to explain why this task interference can occur, particularly with manual destination entry tasks.

Although degraded lateral performance is a consistent finding, surprisingly few studies that have examined the effects of destination entry while driving on these measures have also examined variation in lane position. Measuring these variables allows a more fine grained analysis of lateral performance, as it illustrates performance differences that did not necessarily result in lane departures. It is likely that these measures have been neglected in some studies because they used real vehicles on open roads or test tracks, where it is much more difficult to reliably and accurately measure variations in lateral position. This is an example of an occasion where use of a driving simulator to examine this issue can have advantages over more naturalistic methodologies.

In the present study, the simulator recorded significantly higher standard deviations of lane position (relative to normal driving on the same stretch of road), when participants entered both destinations while driving, indicating much greater variation in lane position during destination entry tasks. The main reason why performance effects were reported separately for each destination was to identify the most reliable performance consequences of entering destinations while driving. Since the standard deviation of lane position was significantly greater for both destinations, it was surprising that the other lateral performance measures were only significantly greater for one destination each.

A limitation of the present study was that driver glance behaviour was not coded and analysed. This is because the primary focus was to examine the correspondence between subjective and objective ratings/measures of driving performance. So to ensure the face-validity of the subjective scales it was important that only direct driving performance measures were addressed. Chapter two described several previous studies which had examined the frequency and duration of eyes-off-road time when participants manually entered destinations while driving, and Zwahlen, Adams and Debald (1988) reported a significant correlation between lane deviations and eyes off road time. Chapters 4 and 5 in this thesis have shown that the majority of participants have consistently reported minimal distraction when using their IVNS, so it would be interesting if future studies examined the degree of correspondence between perceived eyes-off-road time and differences in glance behaviour based on video coding data.

7.5.3 Subjective performance effects of entering destinations while driving

Even though all participants had previously used IVNS while driving before the study began, and half the sample that presently use one, use their system occasionally or more often; the present study, like many previous studies, has demonstrated degraded longitudinal and lateral vehicle control when participants entered destinations while driving. So it was particularly interesting to examine their subjective performance ratings.

Few previous studies could be found which had examined perceived driving performance during destination entry tasks. In Zylstra et al (2004), participants were asked to rate the perceived risk and perceived safety of a destination entry task performed while driving, relative to baseline tasks (i.e. mobile phone dialing and tuning a radio). They found that participants rated destination entry tasks as more risky and less safe than baseline tasks. According to their results, participants rated the risk of dialling a mobile phone or tuning a radio while driving on a motorway, to the equivalent risk of driving 10 miles per hour faster on the motorway, but for destination entry tasks they rated the risk as equivalent to driving 20 miles per hour faster on the motorway. Participants also indicated that IVNS destination entry issues should be urgently addressed by legislative bodies. (see section 7.5.4 for more on subjective ratings of performance when performing distracting tasks and driving).

Figure 7.3 illustrates extensive variation in subjective performance ratings across the present sample concerning in-motion destination entry tasks. It shows that a slightly higher proportion of participants acknowledged that they were worse at keeping in lane when entering destinations while driving, than during normal driving, though a significant proportion (46%) perceived no difference or even that they were better at this task, when entering destinations. Figure 7.3 also shows that although a significant proportion of participants thought they were better at controlling vehicle speed when entering destinations and driving, a higher proportion thought they were worse at this (relative to normal driving).

Overall just over half the participants thought they performed worse at driving when entering destinations, and just under half thought there was no difference or they performed better. Taken with the objective performance measures outlined above, these results could suggest that about half the sample were aware of the deteriorated longitudinal and lateral performance effects of entering destinations while driving that were objectively observed in the present study. However, only by correlating subjective and objective performance ratings, is it possible to assess the degree of correspondence.

Although Figure 7.3 illustrates extensive variation in subjective ratings of the performance effects of destination entry while driving, Figure 7.4 shows that the vast majority of participants acknowledged the potential negative safety implications of this behaviour. It is interesting that even though a much higher proportion of participants considered destination entry while driving to be very risky and unsafe, such a high proportion thought their own performance was better or that there was no difference when performing destination entry tasks. This was also apparent from an extract in the diary study reported in chapter 5. Participant 17 wrote:

...entering a few numbers into the satnav. (However I do not like the idea when other drivers don't keep their eyes on the road)

It is possible that the participant who wrote this diary entry was also aware of the negative safety-implications of entering destinations while driving, but thought it concerned other drivers, not himself. These findings are all consistent with an optimism bias as described in the previous chapter (e.g. Svenson, 1981; Finn and Bragg, 1986; Matthews and Moran, 1986; Goszczynska and Roslan, 1989; Sivak et al., 1989; McKenna et al., 1991; Greening and Chandler, 1997; Wolgater and Mayhorn, 2005) which refers to a well-documented tendency for most drivers to over-estimate their own driving abilities relative to other drivers. Interestingly, in light of the age effects reported previously in the thesis, there is some evidence that this tendency is most prevalent among young men (Matthews and Moran, 1986; Finn and Bragg, 1986). Similarly Garabet, Horrey and Lesch (2007) found that younger drivers consistently rated mobile phones as safer to use while driving than older drivers. A few other studies have also shown that younger drivers rate themselves as more skillful, safer and less likely to be involved in an accident, as well as more likely to pass a driving test, than other drivers of the same age (Harre, Foster and O`Neill, 2005; Freund et al., 2005). An optimism bias may also explain why despite a high proportion of participants in the present study being aware of the negative safety-implications of entering destinations while driving, a lower proportion thought ***they*** performed worse when entering destinations while driving, than during normal driving, although Figure 7.4 also shows that most participants weren't particularly confident about their own abilities to enter destinations while driving.

7.5.4 Subjective vs objective performance effects of entering destinations while driving

Tables 7.1 and 7.2 demonstrate the poor correlation between subjective ratings of performance when entering destinations while driving and objective measures. Clearly there were very low, non- significant associations between objective measures and subjective ratings of lane keeping performance and speed control. The only significant association was between overall perceived performance and objective lateral performance, but the direction of this association suggests that the better participants rated themselves at entering destinations while driving overall (relative to normal driving), the worse they actually performed on this particular measure of lateral vehicle control.

The difference between figures 7.3 and 7.4 was discussed in the previous section, the discussion showed that participants appeared to be much more pessimistic about the risk and safety implications of destination entry while driving, even though they were more optimistic about their own performance. Consistent with this, table 7.2 shows that there was a slightly greater correlation between subjective ratings of the perceived risk of entering destinations while driving and longitudinal and lateral objective measures. Interestingly, the correlations suggest that the more risky participants perceived destination entry while driving to be, the worse they performed at lateral vehicle control, but the better they were at regulating their speed so that it did not exceed posted speed limits.

It is likely that the fewer speed exccedences reported in this study can be explained by the slower speeds at which participants drove when entering destinations relative to normal driving. It is also worth noting, that being based on an absolute performance measure (i.e. speed exceedences), this correlation doesn't suggest an association between perceived risk and speed variation (i.e. an indicator of longitudinal control) during destination entry tasks, relative to normal driving.

Previous discussions have suggested a tendency for younger drivers to be over-confident in their driving skills, but the correlations shown in table 2 dispute these arguments. They suggest that the more confident participants were about their driving ability when entering destinations, the better they were at staying in lane when performing these tasks. This was also the only significant correlation consistent across both destinations. The findings also reveal a significant association between confidence entering destinations while driving and longitudinal vehicle control. Together, these findings suggest at least a degree of association between confidence and these aspects of longitudinal and lateral control, even if there is much less correlation between objective and subjective ratings of actual driving ability.

A limitation of the present study is that participants were asked only once to provide subjective ratings concerning both destinations. Figures 7.1 and 7.2 show that there were some differences in driving performance when entering destinations 1 and 2. It would have been more advisable to have collected subjective ratings for each destination entry task individually, as in the present study it is unclear whether participants based their ratings on one particular task or average performance across both tasks, and this may partially explain why most correlations weren't stable across both destinations.

Another limitation of the present study was that the sample size was relatively small. In addition to the requirement for non-parametric tests (as the subjective data was ordinal level), the small sample size reduced the power of the statistical analyses. It would be advisable for future studies of this type to employ a larger sample size as well as interval-level scales (such as 5-point likert-type scales that range from strongly disagree to strongly agree) that may be subjected to parametric analyses to enable more powerful statistical analyses.

It is also likely that the small sample size could explain why despite acceptable kurtosis and skewness, several of the longitudinal control measures were non-normally distributed (based on the Shapiro-wilk test). A larger sample size would have increased the likelihood of even greater variation in these performance measures, but it was reassuring that the coarse approach of recoding driving performance measures to a 3-point scale verified the correlations obtained with the z-scores. Standardised performance scales were considered most appropriate based on the primary objectives of the present study, but the small sample size and non-normality of some measures, would make it difficult to generalize these results beyond this sample. Standardized scales are most often employed in educational testing. Once a test has been designed, it is then trialed (usually on several thousand participants/students), to determine population means and standard deviation. Once the scores have been converted to z-scores, it is then possible to compare one student with another, based on their responses, relative to those of the general population. Since the present sample contained only 24 participants, it is unlikely that the range of scores collected, represent the same range that would be found when trialed on a larger population.

This wasn't a major problem for the present study however; as the primary purpose was to inform the design of the next study which describes an intervention tested on the same sample of participants. So the results of the present study can be generalized to the next study as they used an identical sample. It would certainly be useful if future research could trial a much more representative sample of participants, as it might then be possible to create a more representative standardized scale that reflects general population norms. Based on pilot data like the present study and the next study, future research could for example, test a range of tasks performed while driving (e.g. manual destination entry, vocal destination entry, mobile phone dialing, radio tuning etc.) and compare performance and glance behaviour while completing these tasks with these measures during normal driving on the same stretch of road. They could then produce standardized scales of objective differences in performance that could be employed by the wider research community to compare subjective and objective ratings for a varied range of contexts and potentially distracting tasks.

Despite some of the shortcomings of the present study it represents an important, original line of research. Horrey, Lesch and Garabet (2007) note that although a significant amount of research has examined the performance implications of engagement in a range of secondary tasks while driving, surprisingly few studies have considered drivers' awareness of distraction effects. The present study demonstrated a fundamental mismatch between subjective and objective measures of driving performance when entering destinations while driving, particularly since the only significant correlation that did occur, was in the wrong direction! (i.e. the better participants rated their overall driving performance, the greater the variation in lateral velocity when entering destination 2, relative to normal driving, which is suggestive of poorer lateral control during the destination entry task).

However, the results also suggest that these participants weren't particularly over confident in their driving ability when entering destinations, as table 7.3 shows that high confidence in this regard, was associated with better lateral performance for both destinations and better longitudinal performance for destination one. Although for other destinations, correlations were non-significant, these results suggest confidence may to some extent have been justified.

This finding conflicts with that of Lesch and Hancock (2004). In their study a sample of female drivers completed confidence scales then drove a test vehicle around a test track which included traffic signals. Occasionally, when visually prompted, they were required to perform a secondary memory task. At the same time as this, the traffic lights would change to red. Lesch and Hancock (2004) compared measures of stopping performance with confidence ratings and discovered a poor association. However, although the present study did find significant correlations between the z-scores of longitudinal vehicle control measures and confidence, it didn't examine braking behaviour or responsiveness to hazards (i.e. driving through a red light). Also their study concerned confidence in dealing with distracting tasks in general not IVNS specifically. Several studies that have examined the effects of IVNS and mobile phones on driving performance have used other potentially distracting tasks such as tuning a radio as baseline measures (see chapter 2), and have reported that IVNS use while driving disrupts driving performance to a significantly greater extent than these. This shows that there are big differences in the distracting potential of different activities while driving, and comparisons between findings should really only be drawn when both studies concern the same activity.

However, the present study represents an original line of research with few available studies for comparisons, but some recent studies have examined the degree of correspondence between subjectively and objectively rated performance/distraction while engaged in other distracting activities (e.g. using a mobile phone, map reading, grooming etc.). Although caution is advisable in comparing studies because they concern different distracting activities, as a whole, the present study and previous studies can still provide some insight into the reasons why some drivers behave this way, as well as potential interventions to remediate or mitigate this behaviour.

In a similarly designed study to Lesch and Garabet (2004) outlined above, Horrey, Lesch and Garabet (2007) examined the correspondence between subjective ratings of performance while participants performed an arithmetic task on hand held and hands free mobile phones while driving, and objectively measured performance decrements in terms of brake response time and stopping errors. They were interested in the degree of correspondence between subjective ratings of distraction and objective performance decrements. Both subjective and objective ratings were calculated based on the percentage difference in performance from the baseline task to the experimental task and these were correlated. They found no significant associations between subjective and objective ratings for any of the performance measures, and just like the present study, they found that some associations were significant but in the wrong direction. Of particular relevance to the present study, they also examined associations between age and calibration. They found that young males were the worst calibrated and suggested this group should be targeted for potential remediation or mitigation interventions. It was not feasible to examine such age effects in the present study, but this was precisely because young drivers were specifically targeted for both the present study and the next study, so that a potential remediation intervention could be tested on this driver age group in particular.

In a separate paper, concerning a different phase of the Horrey et al. (2007) study outlined above, the same researchers (Garabet, Horrey and Lesch, 2007) asked the participants to complete an arithmetic task, an auditory task and a conversational task (clearly the latter two bear resemblance to mobile phone tasks) on hand held and hands free mobile phones. This aspect of the study concerned examining age effects in the optimism bias hypothesis. They exposed older (mean age = 64 years, SD = 7 years) and younger (mean age = 23 years, SD = 5 years) drivers to distraction while driving, and examined the effect of this on their subjective ratings of ease of performing the tasks while driving and perceived safety. Younger drivers consistently rated the secondary tasks as easier and safer than older drivers, and for this age group, exposure to distraction decreased ease of use ratings, but had no effect on subjective ratings of safety.

It would also have been useful to have taken pre-task and post-task subjective measures in the present study. As all participants had previously used IVNS while driving, it would have been interesting to have compared subjective ratings based on their own prior IVNS experiences and their experience in the simulator. If this issue was examined in future studies, the degree of correspondence between these ratings could be useful in further validating the simulator methodology for this kind of research.

7.5.5 Individual differences in driving performance

Table 7.3 shows that there were several interesting associations between demographic variables and driving performance measures recorded during destination entry tasks relative to normal driving. It illustrates a significant association between increasing age and number of lane departures during destination entry tasks, and this could be due to deterioration in perceptual abilities typically associated with increasing age. As would generally be expected, the correlations suggest that those participants with greater driving experience (in terms of number of years with a full driving license) performed better at lateral vehicle control when entering destination 1 while driving. However, the table also shows that when entering destination 1, those who have had their license for longer, were worse at ensuring they drove under the posted speed limits. Interestingly, some of the strongest correlations were between the number of days that participants drove each week and lateral performance measures during destination entry tasks relative to normal driving. Counter-intuitively, they suggest that high frequency driving was associated with worse lateral and longitudinal control during destination entry tasks. Perhaps more frequent young drivers in this sample had more bad driving habits. Due to the contrasting findings in relation to different measures of driving experience (i.e. driving frequency vs number of years with a full driving license) it would be advisable for future studies to include a more robust measure of driving experience, such as Rothengatter et al`s (1993) classification scheme used in earlier studies in the thesis.

In addition to the findings concerning confidence entering destinations while driving reported above, table 7.3 also shows that was a significant association between general driving confidence and improved lateral vehicle control during destination entry tasks, which provides further evidence that the present sample were not over confident in terms of lateral driving performance. Following further examination of participants' subjective ratings, Garabet, Horrey and Lesch (2007) also reported that although younger drivers rated themselves as significantly more prone to distraction than older drivers, there were no significant differences between age groups in terms of confidence dealing with distracting tasks while driving, ability to effectively deal with distraction and perceived driving skill. For older drivers, there were also significant correlations between confidence in dealing with distracting tasks while driving and a range of other measures including perceived skill and vehicle control measures, but for younger drivers, confidence only significantly correlated with subjective ability to deal with distraction while driving, which Horrey et al (2007) reported (based on a different aspect of this same study), were completely unrelated to objective performance decrements. In the present study, there were no significant correlations between demographic variables and subjective ratings, although younger IVNS users were specifically targeted.

Throughout this thesis, computing skill has often been linked to the frequency with which people enter destinations while driving, but table 7.3 shows that it may also be associated with performance during destination entry tasks (relative to normal driving). It shows that self-rated computing skill was significantly associated with increased lateral control but decreased longitudinal control measures. Similarly, there was a significant association between the number of years using a computer and lateral vehicle control measures. These findings should be investigated further as the majority of participants that used IVNS in previous studies in this thesis, have also been skilled computer users. In conjunction with the findings reported above suggesting the present sample were not overconfident in their driving performance while entering destinations, it is possible that participants have not been over-estimating their own ability to cope during destination entry, but simply are better at these tasks because they are skilled at using computers in general, and this is why they have been shown to more frequently enter destinations while driving. Svahn (2004) found a significant negative correlation between "reduced awareness at system interaction" and computing skill, suggesting that more experienced computer users might be more confident that they can minimise the distraction associated with system interaction while driving. It is likely that skilled computer users will be more familiar with QWERTY format keyboards, as well as interface characteristics and menu navigation systems. Svahn (2004) also found that skilled computer users tended to access greater functionality in their IVNS. It is possible that drivers with high computing skill and general familiarity with computer characteristics have to glance at IVNS displays less frequently during destination entry tasks than those less skilled at computing. Unfortunately, correlation analyses only provide information about associations between variables, so it would be difficult to speculate further about this, but it would be useful for future research to investigate associations between computing skill and driving performance during destination entry tasks.

7.5.6 Future remediation or mitigation strategies

The final aim of the thesis was to single out a prevalent safety-negative form of behavioural adaptation for further study, with a view to informing the design of future remediation or mitigation strategies. In this context remediation strategies should ideally aim to prevent drivers from entering destinations while driving, whereas mitigation strategies should aim to reduce the risk of destination entry while driving, should drivers choose to behave this way.

In the wider field of distracted driving, some research has already begun identifying how such strategies might be designed. Llaneras (2000) reported an innovatively designed study run by NHTSA where several internet forums were set up to facilitate active interaction between both experts in the field and the general public concerning experiences using distracting devices while driving. Visitors to the site had the opportunity to download papers, engage in discussion, ask questions and share experiences over a five week period. During this time, the site received nearly 10,000 visitors and had over 2,000 registered users. Llaneras (2000) reports several topics of discussion. The most likely solutions to driver distraction that were proposed were system design, enforcement and legislation and education and training. These are discussed in more detail below.

7.5.6.1 System design

Llaneras (2000) reported that those who worked in the automotive and OEM (original equipment manufacturer) industries, were generally optimistic and confident that systems will be developed that are more in tune with driving practices. According to several authors (e.g. Young, Regan and Hammer, 2003; Burnett, Summerskill and Porter, 2004; Peters and Peters, 2002) ergonomically designed human-machine interfaces proven to be safe (or safer than the current design) would be the most effective solution.

In chapter 4 only a third of IVNS users surveyed thought that no destination entry features should be allowed while driving. Given the widespread adoption of nomadic systems and PND (e.g. PDA, mobile phones) by drivers surveyed in this thesis[5], as well as these majority views about restricting destination entry while driving completely, clearly total remediation system design strategies have proved relatively unpopular with drivers.

Fortunately however, mitigation strategies in system design have had some success. Young, Regan and Hammer (2003) cite a recent European initiative (i.e. the European Statement of Principles for Driver Interactions with Advanced In-vehicle Information and Communication Systems) designed to set performance goals for manufactured IVNS in terms of distraction and visual demand, and despite recently proposed revisions, the Society of Automotive Engineers has also widely adopted the standard 15-second rule (see chapter 2) to limit the duration of IVNS tasks that can be performed while driving.

[5] Chapter 1 showed that many integrated IVNS do restrict manual destination entry and other manual interactive tasks while the vehicle is in motion, but that nomadic systems and PND typically do not restrict access to these functions while the vehicle is in motion.

Other mitigation strategies in system design include the development of novel manual destination entry methods as well as wider developments in interface design (e.g. vocal interfaces). In chapter 4 about a fifth of IVNS users thought that destination entry by postcode and address should be allowed while driving but a much higher proportion (60%) thought that destination entry by stored location should be allowed while driving. Destination entry by stored location can be expected to cause less of a distraction to drivers because this destination entry function typically requires much shorter duration interactions than other methods. While presently still in the minority, many drivers also now have IVNS with vocal interfaces. Although previous research has shown that vocal destination entry while driving can also degrade driving performance and safety, in most studies manual destination entry tasks performed while driving cause greater task interference. In recognition that vocal interfaces can also interfere with driving task performance and safety, some researchers (e.g. Prynne, 1995; Burnett and Porter, 2001) have even emphasized the feasibility of tactile interfaces for future developments in system design.

A great deal of work has also considered the development of driver monitoring systems or workload management systems which could potentially help to deal with distraction issues, although they are presently still in developmental phases. Green (2003) suggests these systems may be a more useful long term alternative to legislation in the reduction of distraction related accidents. Wood and Hurwitz (2005) described one such system, for suspending mobile phone conversations. They reported positive effects of the system on driving performance and positive system evaluations from drivers. Donmez, Boyle and Lee (2007) describe a system which monitors driver behavioural and performance measures, and in real time "decides" the appropriateness of engagement in any distracting activities, any deemed inappropriate would be signalled to the driver by an alert. However, Horrey, Lesch and Garabet (2007) suggest that the system may provide frequent "false positives" (i.e. frequently identify distracting situations that the driver does not feel would warrant an alert), and that the mismatch between the drivers' perceptions and those of the system, could violate the drivers' mental model of the system. They cite previous research described in chapter 2 (Lee and Moray, 1994; Parasuraman and Riley, 1997), showing how disruption to a drivers' mental model, could decrease trust in the system to the point of disuse (where operators reject the capabilities of automation), which is the opposite to misuse (i.e. over-reliance) discussed in previous chapters.

It is also likely that drivers would also not evaluate positively, any system that suspended interactive tasks, particularly if this occurred frequently or on occasions when the driver particularly needed to use the IVNS (e.g. due to congestion). A further difficulty with technological design solutions, particularly those that attempt to prohibit access to certain functions, is that many drivers could argue that they should be allowed to access the IVNS while driving so passengers can perform interactive tasks. In the diary study, some extracts indicated that participants had asked passengers to perform interactive tasks while they were driving, and according to a recent US survey conducted by Jenness et al (2008), 59% of participants indicated that they ask passengers to control or get information from the IVNS, while they are driving, occasionally or more frequently. Chapter 5 also discussed how forcing drivers to pull over to complete destination entry tasks can also have negative safety implications. For example, particularly in unfamiliar areas, drivers might pull over to enter a destination, in a spot that would make them a hazard for other road users (Burnett, Summerskill and Porter, 2004).

Although systems can and have been designed to remediate (e.g. integrated systems that restrict manual interaction while the vehicle is in motion, workload managers that suspend interactive functions during periods of high driving workload) and mitigate destination entry while driving (e.g. alert-based driver monitoring systems, non-manual interaction functions), system design solutions are only really useful in the long term. This thesis has shown that presently, a much higher proportion of drivers use nomadic devices and PND and only a minority have access to vocal interfaces. Although over time it is likely that vocal interaction will become standard, appropriate remediation or mitigation strategies are needed for drivers today.

A further difficulty with relying on system design strategies to remediate or mitigate destination entry while driving was also discussed in the previous chapter. Section 6.4 described how methods to circumvent technologically-induced restrictions are easily and readily available to most people via the internet.

7.5.6.2 Enforcement and legislation

Several authors (e.g. Llaneras, 2000; Young, Regan and Hammer, 2003) advocate the use of legislative attempts to restrict engagement in distracting activities while driving. According to Llaneras (2000), legislative changes should be introduced initially followed later by other intervention strategies, although he also stressed that not all problems necessarily require legislative solutions, and there was a limit to what could be practicably enforced.

Chapter 2 described how Lerner (2005) had conducted two studies (a focus group study and an on-road study) to examine willingness to engage in distracting tasks while driving. Based on the findings from that study, Lerner, Singer and Huey (2008) formulated a matrix with potential solutions to address many of the issues raised. They proposed legal as well as potential licensing implications for many of their main findings. For example, they also found a negative association between driver age and willingness to engage in distracting tasks while driving, and advise licensing restrictions for teens and young drivers, preventing them from using in-vehicle systems. They suggested that licensing restrictions would also be useful in relation to other distracting activities more frequently performed by young drivers while driving, such as text messaging.

Section 6.5 considered the current and potential future legal climates concerning system interaction while driving in detail. It explained that in light of evidence showing the extent to which a high proportion of drivers disobey speed limits or drive while intoxicated, it is unlikely that legal interventions would provide a definitive solution. In the NHTSA internet forum reported by Llaneras (2000), several discussions concerned bans and other legislative efforts. Many of those in favour of regulation argued that legislation was the only effective way to reduce engagement in distracting activities while driving. However, those opposed labeled it impractical, arguing that drivers will still break laws, particularly those which are difficult to enforce.

7.5.6.3 Education and training

Across most papers and articles, the preferred solution is education and/or training. Consistent with utility maximisation approaches to behavioural adaptation (e.g. Hoyes et al., 1996; Janssen and Tenkink, 1988), Lerner, Singer and Huey (2008) found that drivers try to increase productivity by maximising use of their personal time and that driving time was viewed as “wasted time”. They suggested educational awareness campaigns similar to those previously used for drunk driving and speeding, in which drivers are encouraged to take responsibility for their own risk.

Although nationwide campaigns concerning the risks of using mobile phones while driving are well underway in the UK already, IVNS are presently used by a substantially smaller proportion of the driving population, so large-scale campaigns have not yet been initiated. Presently, IVNS users are only really educated about the safety-implications of destination entry while driving in user manuals and on IVNS start-up screens, but Burnett, Summerskill and Porter (2004) refer to these as the lowest priority method of remediation intervention. Using a survey, Jenness et al (2008) investigated strategies employed by drivers when learning to use four in-vehicle technologies, including IVNS. They found that

IVNS users were more likely than users of the other technologies, to learn to use their systems based on advice from friends or relatives, but that due to their complexity also adopted other learning methods. Overall, about two thirds of participants indicated that they learned using the manual, although they also found that younger drivers (those shown by the present research to most frequently interact with their systems while driving) were less likely than older drivers to refer to the manual. About half the participants also indicated that they learned based only on advice from dealerships and brochures, and just over half learned from trial and error based on-road experience[6]. According to Sanders and McCormick (1994) warning messages included in product documentation or displayed during IVNS start-up are notoriously ineffective because in some cases users will not notice them or understand them properly, but in the majority of cases they will simply be ignored.

Based on the NHTSA online driver distraction discussion forum data described above, Llaneras (2000) found that the majority of respondents polled (56%) thought that education or safety campaigns could have a positive impact, although 43% believed the impact would probably be minimal. Those that were unconvinced cited the relative failure of existing similar campaigns, and suggested they wouldn't necessarily result in behavioural change. However, Llaneras (2000) reported that some participants indicated that they would change their behaviour based on educational or safety campaigns, and 40% indicated that they had changed the way they use mobile phones while driving having seen or heard a safety tip. Based on this evidence, Llaneras (2000) advocated the use of education and safety campaigns as part of a multi-modal approach to addressing safety concerns associated with in-vehicle technologies.

The proceedings of the NHTSA (2000) driver distraction working group meetings identified several key issues concerning education based intervention strategies. These include:

1. There may be public confusion over safe behaviours in using devices
2. Programs that change unsafe behaviours need to be developed. Some drivers don't see a difference between using these devices and other distractions
3. It is important to find out the baseline level of knowledge the public has about risk, and find out what they believe they know. Knowledge gaps can be closed through education
4. What you think drives what you do, unrelated to what you know. Focus in on what people think
5. Promote the safe use of electronic devices as an alternative to bans

[6] Participants could choose several learning methods so responses added up to greater than 100%

7.5.7 Implications for the design of remediation or mitigation strategies

The above discussion highlights the importance of education and training based remediation or mitigation strategies due to the limits of contemporary system design and the likely ineffectiveness of present legislative approaches. Each of the key issues identified in the NHTSA (2000) driver distraction working group meetings above are relevant to the present study and to the third aim of the thesis.

7.5.7.1 Remediation

Consistent with the first and third issues in the previous section, this study has demonstrated a poor degree of correspondence between subjectively rated performance effects of entering destinations while driving and objective measures of these parameters. This suggests a degree of confusion among participants about what is safe and illustrates what these drivers think they know about the risks of destination entry while driving. As shown at the beginning of this chapter, Wolgater and Mayhorn (2005) suggested that drivers may enter destinations while driving simply because they think it is safe to do so. If this is the case, issue four above suggests that correctly aligning subjective perceptions with reality may be sufficient to drive behavioural change. According to Young, Regan and Hammer (2003), although much is known in the research community about the risks of performing distracting tasks while driving, these findings must also be brought to the attention of the general driving public.

Recently, Kramer, McCarley and Geisler (2003) conducted a study examining the efficacy of an educational intervention designed to influence engagement in distracting activities while driving. An online sample of drivers (N=1423) was randomly assigned to experimental and control groups. Control group participants received no educational intervention, but those in the experimental group viewed an introductory and concluding segments, as well as a brief set of 3 random educational clips from a pool which concerned distracting activities performed while driving, like eating, tending to children, reading a map, using a phone etc. All participants also completed a survey concerning their past engagement in distracting activities while driving, and their future intentions to behave in these ways. Consistent with the present thesis, they also found that the frequency of distracted driving decreased and the perceived danger of distracting driving increased, with increasing age. They also found that men engaged in distracting tasks while driving significantly more frequently than women. The intervention failed to influence participants' intentions concerning future behaviour, but did affect the perceived danger of distracting activities. In particular five distracting activities (including reading a map, using the stereo and grooming) were perceived as more dangerous by the experimental group than by the control group.

Garabet, Horrey and Lesch (2007) proposed that research concerning the correspondence between subjective ratings and objective measures of performance, could usefully inform the design of insight training. As the name suggests, insight training involves providing drivers with insight into their true driving behaviours and performance, when engaged with distracting activities while driving. Senserrick and Swinburne (2001) effectively used this approach to train young drivers. In a simulator study, Creaser, Lees and White (2004) randomly assigned young drivers to one of three conditions. In one condition, participants received verbal insight and error feedback, in another condition participants received just error feedback and in a control condition they received no feedback. They found a significant increase in time headway for those who received insight and error feedback.

Insight training could form part of a future educational intervention strategy to inform drivers about the risks and performance effects of entering destinations while driving. Participants could for instance, be told about studies which have demonstrated a poor degree of correspondence between objective measures and subjective perceptions of risk, performance, distraction and safety. Since prior simulator studies in this thesis have employed recording equipment, it would also be possible to provide video data illustrating poor driving performance during destination entry tasks. Although destination entry while driving affects both longitudinal and lateral vehicle control measures, it would be preferable to use video footage to illustrate poor lateral control, as it may be difficult to perceive poor longitudinal control from the video data alone. This video data (edited to obscure the participants' face) could usefully accompany presentations of research findings. The advantage in using video data from the present study in future research like this would be that subjective performance ratings were collected, so it would be a relatively simple task to locate the video data of those who thought they performed well, but had poor lateral vehicle control. Therefore, in addition to showing future participants the lateral performance effects of destination entry while driving, describing this particular study in conjunction with the video footage would also re-enforce the message that subjective ratings and objective ratings can be very poorly related.

Although findings from the present study did not suggest that IVNS users were particularly over-confident in their abilities to enter destinations while driving, a safety-related remediation intervention like this could also enforce the message that younger people are more likely to enter destinations and perform other distracting tasks while driving more frequently than older people, because younger people have been previously shown to be over-confident. Safety presentations should also include information about legal implications. For example, they could state that although it is not yet outright illegal to enter destinations while driving, it is still possible to be punished for doing so, if the behaviour could be interpreted as dangerous driving. Providing information about other distracting activities that have now been outlawed (e.g. using a mobile phone, smoking) could also encourage them to view destination entry while driving as an equally serious safety issue.

7.5.7.2 Mitigation

Although remediating interventions would clearly be the preferred strategy, this chapter has shown that there is mixed evidence concerning their potential effectiveness (e.g. Kramer et al., 2003; Llaneras, 2000). Outside of traffic psychology in other domains such as public health, mitigation strategies (referred to in this context as harm-minimisation or harm-reduction strategies) have achieved some success complementing remediation strategies (e.g. full treatment) in addressing high risk individual behaviours, such as needle exchanges for drug addicts, contraceptives for teenagers etc. (see Marlatt, 2002). Marlatt (2002) reported on harm-reduction strategies from across Europe, and based on the Dutch model of implementation commented that these strategies can also be extended to address other high risk individual behaviours. For example, Marlatt (2002) suggested that these strategies could also be applied to address high risk driving behaviours at the individual level (by teaching safer driving behaviours), the environmental level (by implementing changes to the road infrastructure) and the societal level (by implementing legislative changes). For the purposes of this thesis an individual level mitigation strategy could be used to help improve driving performance when participants enter destinations while driving or to teach them strategies they can use to minimise distraction and maximise performance/safety when completing these tasks.

The other two key issues outlined by the NHTSA (2000) driver distraction working group meetings described above were:

- Programs that change unsafe behaviours need to be developed
- Promote the safe use of electronic devices as an alternative to bans

A well designed mitigation intervention strategy could address each of these issues. Previous studies in this thesis have shown that drivers skilled at using computers enter destinations while driving significantly more frequently than those less skilled and the present study showed that computing skill/experience was associated with increased control over longitudinal and lateral performance measures. This discussion has already outlined that this is probably because these people are more familiar with modern technological interface characteristics. Therefore, it could be useful for an intervention to provide training in computing/typing skills. For example, a simple dual task scenario in which drivers complete a data entry task and a tracking task simulating aspects of lateral vehicle control (See Matthews, 2000) could easily be run on most desktop computers. With appropriate validation, this might provide drivers with an inexpensive way of improving their ability to enter destinations while driving safely. Such an approach could also demonstrate to drivers, the importance of employing other strategies to minimize the distraction caused by in-motion destination entry tasks, such as chunking or only entering destinations during periods of low driving workload.

7.6 Summary

This chapter described a driving simulator study which examined objective longitudinal and lateral performance effects of entering destinations while driving, subjective ratings of these performance effects and the degree of correspondence between objective and subjective measures. The results suggested that although participants did not appear to be over-confident in their driving performance while entering destinations (relative to normal driving), there was generally poor correspondence between subjective performance ratings and objective measures.

This finding addressed the third aim of the thesis by further investigating young drivers' tendency to enter destinations while driving in an attempt to understand why they behave this way. As shown above, previous authors (e.g.Horrey, Lesch and Garabet, 2007; Wolgater and Mayhorn, 2005) have suggested that some drivers may engage in distracting activities while driving simply because they are unaware of the safety and performance implications of behaving this way. This study is the first to demonstrate that subjective ratings of the safety and performance effects of destination entry while driving can be miscalibrated. It is now possible for future research to examine the effects of re-aligning subjective perceptions with objective measures of these parameters.

The main findings in this study were also discussed in relation to those from similar studies which had considered driver engagement in other secondary tasks (e.g. using a mobile phone) while driving. The discussion showed how a key aim of many of these studies was to inform the design of potential future remediation intervention strategies, as this approach is most likely to be more effective in addressing the extent to which drivers enter destinations while driving than legislative approaches and system design considerations alone. The implications of the present study to the design of such an intervention were discussed in detail.

The next chapter reports a final simulator study designed to test the hypothesis that simply informing young drivers about the potentially negative safety/performance effects of destination entry while driving will prevent them from behaving this way or reduce the extent to which they do. It will also examine the effects of training participants to enter destinations while driving more safely on subsequent performance measures or strategies employed to reduce distraction. The findings could have important implications for the design of future remediation or mitigation intervention strategies. The above discussion showed how the findings from the present study and the design strategy for the next study were also consistent with recommendations from an NHTSA (2000) expert panel concerning potential future educational and training intervention strategies to address distracted driving.

Chapter 8 – Simulator study testing safety and training related interventions

8.1 Introduction

This chapter describes the final study in the thesis - a driving simulator study that further addressed the third aim by designing and demonstrating a potential educational intervention strategy to prevent drivers from entering destinations while driving (i.e. remediation) and/or encourage them to behave this way safely (i.e. mitigation). In the previous chapter the discussion showed how some previous authors (e.g. Horrey, Lesch and Garabet, 2007; Wolgater and Mayhorn, 2005) have hypothesised that drivers may engage in distracted driving simply because they are unaware of the potentially negative safety/performance effects of behaving this way. Consistent with this, the previous study demonstrated that young drivers' subjective ratings of the performance effects of destination entry while driving were poorly aligned with objective measures of these parameters. The present study primarily aimed to test this hypothesis by informing some young IVNS users about the potential dangers of destination entry while driving and training others in dual task scenarios. The effects of these intervention strategies on several dependent measures (including longitudinal and lateral driving performance measures, frequency of entering destinations while driving, destination entry time, strategies employed to minimise distraction) were examined when participants completed post-intervention trials in which they were motivated to reach four destinations in a simulated unfamiliar urban environment within a specified time. Any significant findings could have important implications for the direction of future research concerning the potential design of intervention strategies.

8.1.1 Remediation intervention strategy

In chapter 7 the discussion outlined previous research concerning remediation intervention strategies and showed how some authors have proposed that drivers may enter destinations while driving simply because they are unaware of the performance effects of behaving this way (Wolgater and Mayhorn, 2005; Horrey, Lesch and Garbet 2007). Consistent with this, the previous study illustrated a poor degree of correspondence between objective measures of the performance effects of entering destinations while driving and participants' subjective ratings of these parameters. The previous discussion showed how a potential educational intervention strategy might incorporate insight training to inform drivers about previous research concerning the performance/safety effects of destination entry while driving and ideally, to illustrate that their subjective perceptions of these performance parameters and safety issues may be misaligned with objective measures. Therefore the remediation intervention strategy that was used in the present study was designed to:

1. Inform participants about previous research findings showing that destination entry while driving can degrade driving safety and performance.
2. Show participants video footage from previous studies in which drivers have displayed poor lateral vehicle control when entering destinations while driving.
3. Inform participants about the current legislative implications of this behaviour (see chapter 6).

8.1.2 Mitigation intervention strategy

The previous chapter explained that in other domains outside of traffic psychology, mitigation strategies have complemented remediation strategies in addressing high risk behaviours (e.g. Marlatt, 2002). In the previous study computing skill/experience was associated with increased control over longitudinal and lateral driving performance measures. The previous discussion also referred to Svahn (2004) who found a significant negative correlation between "reduced awareness at system interaction" and self-rated computing skill. It suggested that those drivers skilled at using computers will most likely be more familiar with QWERTY format keyboards, as well as interface characteristics and menu navigation systems. Although few previous studies have investigated associations between computing skill and driving performance while entering destinations, these findings suggest it may be possible to improve driving performance when drivers behave this way by training them to use computers or perhaps training them in other dual-task scenarios resembling in-motion destination entry tasks. Such a mitigation approach might also inform drivers about various strategies they could adopt to minimize distraction. Therefore the mitigation strategy that was used in the present study was designed to:

1. Train participants at performing computer-based tracking and data entry tasks and examine the effects of this training on driving performance measures.
2. Inform participants about various strategies that can be used to minimise distraction when entering destinations while driving (e.g. chunking).

The effectiveness of potential remediation and mitigation strategies was examined in this simulator study. Specifically, it aimed to examine:

1. The effect of a remediating intervention on the frequency with which drivers subsequently enter destinations while driving.
2. The effect of a mitigating intervention on destination entry time, driving performance measures and use of strategies to minimise distraction during destination entry while driving.
3. The effect of a combined safety and training intervention on these driving behaviours.

8.1.3 Methodology issues

Since the design of interventions in the present study is fundamentally related to the data provided by the previous study (i.e. the findings may not necessarily be applicable to another sample of drivers), it was also most appropriate to conduct this study in the driving simulator using the same participant sample. In addition to the logistical difficulties of organizing more naturalistic studies (e.g. test-tracks or on-road studies), to have conducted the present study in a more naturalistic setting would have also required validation studies to assess the degree of correspondence between performance measures provided by STISIM simulator and data recording equipment in real vehicles when participants performed destination entry tasks while driving and drove normally. In short, the validation procedures alone would probably have constituted an entire PhD thesis! The previous discussion mentioned that future studies of this type could examine performance norms of a much larger and more representative sample of drivers. In light of this, the present study and the previous study should primarily be viewed as pilots for a much larger multi-modal study concerning subjective and objective performance measures, the degree of correspondence between these, and the development and evaluation of remediating or mitigating interventions based on this data.

The present study used exactly the same participants as the previous study for two main reasons. Firstly, a limitation of the previous study was that the objective, standardized scale was developed based on this sample. The previous chapter discussed how this could lead to problems in generalizing the results of the study to the wider driving population, as the standardization was dependent upon the means and standard deviations of the population tested. The second reason for employing the previous sample in this study was that these participants had all received equal experience entering destinations on the TOMTOM IVNS, in this driving simulator. In each phase of the previous simulator study, participants were asked to enter destinations while driving and to do so while pulled over at the side of the road. So participants were made explicitly aware that it was appropriate to pull over at the side of the road to perform destination entry tasks while stationary in the simulator. Novel participants may for example, have only looked for designated spots to pull over, and so may have entered destinations while driving following an intervention not because they particularly wanted to, but because they felt there was nowhere appropriate to pull over for this.

The diary study showed that although participants sometimes entered final destinations while driving, they much more frequently used their IVNS while driving, to satisfy intermediary demands (e.g. hunger) based on prevailing circumstances. So in the present study, the effects of interventions on both scenarios were investigated (i.e. when drivers received destination information before setting off, and during their journey).

As the present study was conducted using a driving simulator, a key consideration was to motivate participants to want to reach destinations, but not to break the law doing so. To achieve this, they were told they would receive a small monetary reward for reaching destinations within specified time limits, but that the reward would be negatively affected if they broke the law[1]. The effects of time constraints on subsequent driving behaviour were also examined by providing participants with reasonable and less reasonable time limits in which to reach destinations[2].

8.2 Experimental hypotheses

1. The group participants are assigned to will significantly affect the frequency with which they enter destinations while driving, destination entry time or strategies employed to minimise distraction, whether they receive the destination before setting off or during their journey.
2. Time constraints will significantly affect the frequency with which participants enter destinations while driving, destination entry time, or the number of attempts to complete the destination entry tasks, whether they receive the destination before setting off or during their journey.

[1] Despite this all participants actually received exactly the same financial compensation for participating in this and the previous study, regardless of task performance.
[2] The reasonable time constraints condition was labelled “low time pressure” and the less reasonable time constraints condition was labelled “high time pressure”.

8.3 Method

The present study used the same sample as was described in the method section of chapter 7. Therefore, the participants section, and parts of the materials and procedure sections in the present study are identical to those in the previous study, so to avoid repetition, they were omitted here.

8.3.1 Materials

The simulator, IVNS and driver questionnaire were described in the previous chapter. In the present study, participants were randomly assigned to one of four groups. The materials these groups received were based on principles for remediation and mitigation strategies outlined in the previous chapter.

Control group – These participants received no intervention.

Safety group (i.e. remediation) – These participants watched a presentation concerning the safety implications of entering destinations while driving. In the style of a safety campaign, it presented an argument that entering destinations while driving was unsafe. It demonstrated this by summarising research findings on this issue in a recorded Microsoft Powerpoint presentation and showing video footage from previous simulator studies run at the University of Nottingham. The video shows the view from four separate cameras, two of which capture the driving scene, one is focused on the driver and one is focused on the IVNS. The videos clearly show two drivers weaving about in their lanes while attempting to enter destinations while driving. (see appendix AF for screenshots from this presentation). This presentation also outlined the present legal implications of destination entry while driving.

Training group (i.e. mitigation) – These participants were given 5 minutes to practice a divided attention task in which they had to enter letter and number strings into a spreadsheet using the numeric section of a computer keyboard (destination entry component) and perform a tracking task in which they were required to move a square around on a computer screen using a mouse, to keep an erratically moving dot contained within its boundaries. This task was run in a java-enabled web browser, and is one of many highly configurable online attentional tests, always available at the following website hosted by John Krantz of Hanover College:
http://psych.hanover.edu/JavaTest/CLE/Cognition/Cognition/dualtask_instructions.html (accessed 28/10/08).

Chapter 2 showed that tracking tasks are often used in conjunction with another task in dual-task studies. According to Matthews et al (2000) the driving task also has central tracking components (e.g. staying in lane), so this dual task setup is somewhat applicable to destination entry while driving investigations. After 5 minutes at both tasks participants were presented with performance statistics representing their tracking and data entry performance. They were then shown a short presentation (a recorded Microsoft Powerpoint presentation) in which they were explicitly told about the similarity between tracking tasks and aspects of the driving task (see appendix AG), and were made aware of two strategies that can be employed to improve tracking performance. These are:

1. Perform the data entry task in small discrete chunks
2. Choose your moment to complete the data entry task. When the driving task is much easier, it is also much easier to perform data entry

Since the online task was highly configurable, it was possible to alter certain aspects of it such as the size of the square and the speed of the moving dot. The square was enlarged to double its original size (i.e. from number 25 to number 50 on a scale ranging from 0 to 200). They were asked to perform the task again, and were explicitly reminded that the larger size of the square could also represent an easier driving situation.

Safety and training group – These participants first watched presentation combining elements from both the above presentations (see appendix AH), and then completed all the same tasks (including watching the training presentation) as those in the training group, also outlined above.

8.3.2 Design

The present study employed a mixed within and between subjects design. The within subjects factor was time pressure and the between subjects factor was group. Participants were randomly assigned to one of the four groups outlined above. Dependent variables were number of times IVNS was used while driving, number of attempts for each destination entry task, destination entry time, and driving performance measures (i.e. number of lane departures and number of speed exceedences). All dependent variables used ratio level data. No subjective measures were included in the present study.

8.3.3 Procedure

After a five minute refreshment (following the previous study), participants were asked to read a brief description of the present study (see appendix Z), and to sign a further consent form if they agreed to participate (identical to previous consent form). In these documents participants were also explicitly informed they could withdraw at any time and this would not affect their financial compensation for taking part in the previous study, and if they still agreed to participate, to signal the experimenter if they felt unwell in any way during the study. Once they had formally agreed to participate in this particular study, those participants assigned to the control group received no intervention, those assigned to the safety group watched the safety presentation, those assigned to the training group completed the training exercises and watched the training presentation and those assigned to the safety and training group watched safety and training presentations and completed the training exercises (as outlined above).

Once they had completed the interventions, participants were told about their current task in the simulator. They were asked to imagine they had a busy day, driving in an unfamiliar town, and had to reach four destinations within a specified time limit, and that the only source of navigational assistance available to them was the IVNS. For motivation, they were told they would receive a greater reward for participating if they reached each destination within the specified time limit (an extra 50 pence per destination in this study[3]). They were also explicitly told that they had to obey traffic laws including speed limits and traffic light signals as failure to do so would negatively affect their monetary bonus.

The diary study described in chapter 5 showed that some drivers rarely entered final destinations while driving but were prepared to enter intermediary destinations along their route. Both scenarios were investigated in the present study, so there were two phases, with two destinations per phase. Each destination was printed in upper case letters (Arial font, 30pt size) at the centre of a sheet of A4 white paper in landscape orientation. All destinations contained an identical number (N=16) of alphanumeric characters and their entry required an identical number of screen touches (N=23). Below the destination name, text with the same properties as the destination name, also showed the average speed limit

[3] A monetary reward was only used as motivation. All participants received exactly the same compensation for participation, regardless of task performance.

along the routes they would be travelling, the distance from start position to end position, the number of traffic light signals along the route and the time limit within which to reach the specified destination[4].

Table 8.1: showing the main characteristics of each route in the present study

Route characteristics	Phase 1		Phase 2	
	Low time pressure	High time pressure	Low time pressure	High time pressure
Length	1.2 miles	1.5 miles	1.5 miles	1.4 miles
Direction of turns	No turns	One right turn	No turns	One left turn
No. of junctions	1	2	1	3
No. sets of traffic lights	1	2	1	3
No. of curves	4	5	4	5
Average speed limit	40 mph	30 mph	50 mph	30 mph
Time limit	2 mins 30 secs	3 mins	3 mins 45 secs	2 mins 40 secs

Each piece of additional information was placed on a separate line (see appendix AI). Before beginning scenario 1 (in which they received destination information before setting off) participants were asked to read each destination aloud a few times until they were familiar with them. However, they were not given this opportunity before beginning scenario 2, but for both scenarios, they were given the opportunity to read the time, speed and distance information to decide for themselves how reasonable each time limit was. In each scenario, participants had to reach one destination within a very reasonable time limit (i.e. low time pressure) and another destination within a less reasonable (but still possible) time limit (i.e. high time pressure).Time limits for high/low time pressure conditions were calculated based on the average times that it took pilot participants to reach each destination (see appendix AE).

8.3.3.1 Scenario 1

Participants were asked to take the role of a driver who knows their destination before setting off, they were told that for each destination, the experiment would begin as soon as the scenario loaded and the graphics were on screen.

[4] No timing information was presented to participants as part of the experiment, but the IVNS did have a clock displaying hours and minutes only in the bottom right corner of the screen.

8.3.3.2 Scenario 2

Participants were asked to take the role of a driver who only becomes aware of the destination during their journey. Once the scenario had been loaded, participants were vocally instructed to "continue straight ahead". Before beginning phase 2, participants were told they would be prompted to enter the destinations at some point during their journey, and that they should complete this task whenever they felt it was appropriate to do so, as long as it was after they were prompted. Participants were vocally instructed to "please enter destination 1 now" once they had been driving for 500 feet, and were vocally instructed to "please enter destination 2 now" once they had been driving for 650 feet.

8.3.3.3 Counterbalancing

For purposes of counterbalancing 12 participants were randomly selected to complete phase 1 then phase 2, and the other 12 to complete each phase in the reverse order. Tables 8.2 and 8.3 below show the order in which 3 randomly selected participants from each group of 12 completed the simulator tasks, and table 8.1 illustrates the main characteristics of each route.

Table 8.2 showing further counterbalancing procedures employed for those participants who completed phase 1 then phase 2

Participants	Phase1		Phase 2	
	Destination 1	Destination 2	Destination 1	Destination 2
3 randomly selected participants	Low time pressure	High time pressure	Low time pressure	High time pressure
3 randomly selected participants	High time pressure	Low time pressure	High time pressure	Low time pressure
3 randomly selected participants	High time pressure	Low time pressure	Low time pressure	High time pressure
3 randomly selected participants	Low time pressure	High time pressure	High time pressure	Low time pressure

Table 8.3: showing further counterbalancing procedures employed for those participants who completed phase 2 then phase 1

Participants	Phase 2		Phase 1	
	Destination 1	Destination 2	Destination 1	Destination 2
3 randomly selected participants	Low time pressure	High time pressure	Low time pressure	High time pressure
3 randomly selected participants	High time pressure	Low time pressure	High time pressure	Low time pressure
3 randomly selected participants	High time pressure	Low time pressure	Low time pressure	High time pressure
3 randomly selected participants	Low time pressure	High time pressure	High time pressure	Low time pressure

8.3.3.4 Debriefing

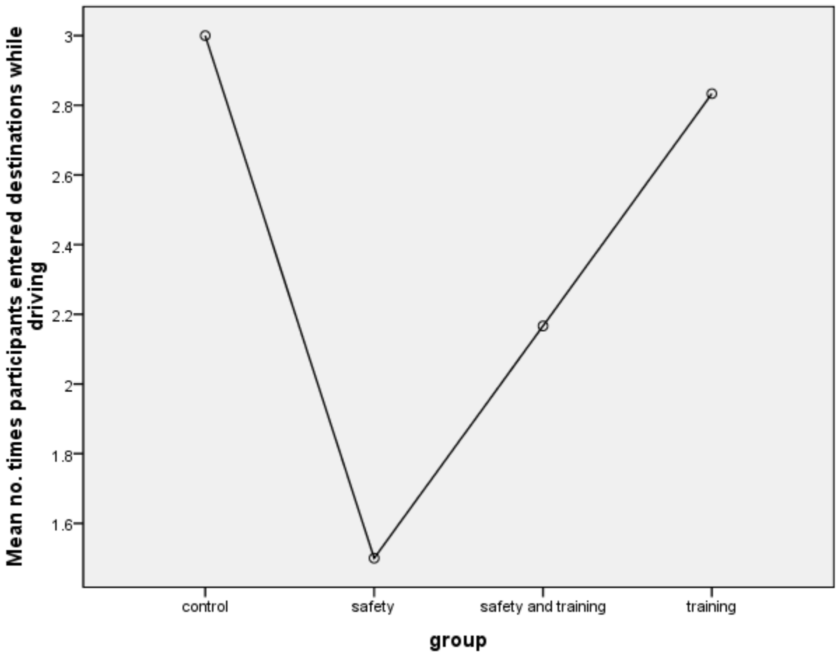
Once participants had completed scenarios 1 and 2, they were thanked for participating and offered a glass of water while they were debriefed about the true nature of the study. They were told that their performance had never affected their monetary compensation, and the reason why they were misled about this. They were asked to sign and date a form to show they had received their £10 monetary compensation for participating in this and the previous study. They were also asked to read and sign/date a pre-written statement which explicitly stated that they just took part in an experimental study and any actions taken or decisions made in this environment should not be repeated when using IVNS or any other in-vehicle equipment in a real vehicle, on real roads any time in the future. They were reminded that a driving simulator is a highly controlled research environment primarily used because it allows researchers to investigate issues that would be too dangerous to examine in real vehicles on real roads, due to the wide range of uncontrollable extraneous variables that could affect their driving performance. They were asked to sign and date the form to show they agreed with this text, as well as to show that they were feeling no ill-after-effects (e.g. headaches, dizziness, nausea) after using the simulator, and that they felt safe to leave the experiment and drive in a real vehicle (see appendix AJ).

8.4 Results

The results section in the previous chapter described the sample, so to avoid repetition this data was omitted from this chapter. The previous section described how the present study examined two scenarios (i.e. situations in which drivers received destination information before setting off and situations in which drivers received destination information during their journey). Most analyses were performed separately on results from each of these scenarios, and significant results are reported in the appropriate sections below.

However, as there were only two destinations in each scenario, the dependent variable, frequency of entering destinations while driving, would have been dichotomous in a mixed model ANOVA with time pressure as the within-subjects factor, and trichotomous in a univariate ANOVA collapsed over both destinations. Dichotomous and trichotomous data violate the normality assumption. So, a series of independent samples t-tests were performed to compare the total number of times each experimental group of participants entered destinations while driving with controls. The only significant difference was between safety and control groups ($t(10)=3.0$, $p<0.05$). Figure 8.1 shows the mean number of times, participants from each group entered destinations while driving over the four trials following interventions. It shows that participants in the safety and training group also entered destinations while driving less frequently than controls following the intervention, although this difference was not significant.

Figure 8.1: showing the mean number of times participants in each group entered destinations while driving over four trials, following an intervention (N=24)



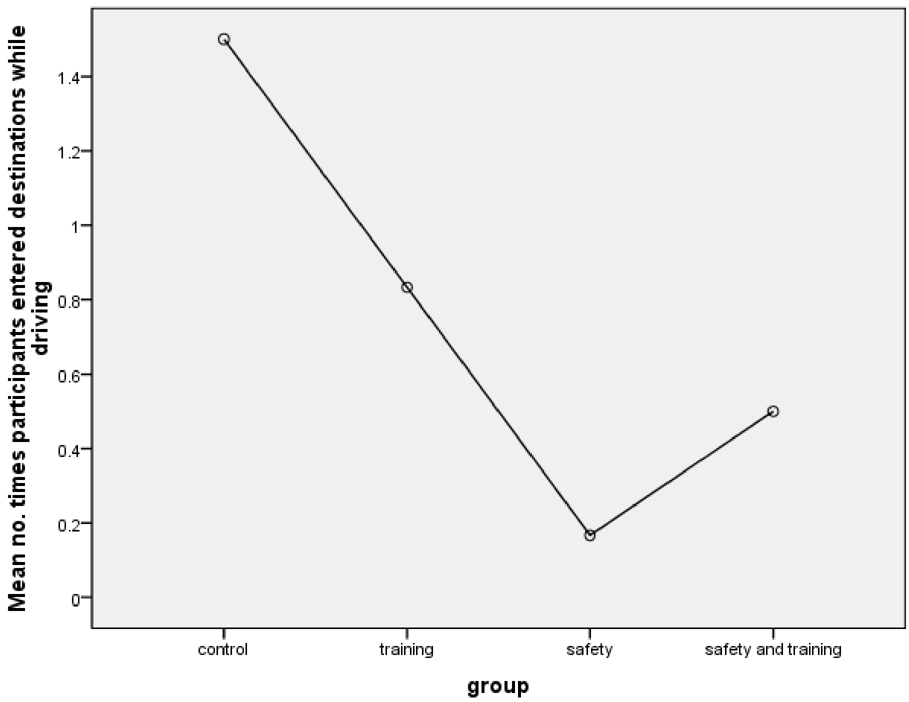
The majority of analyses, concerning most of the dependent measures were non-significant. In the following sections, only significant findings are reported.

8.4.1 Scenario 1 - Receiving destination information before setting off

Figure 8.2 shows the mean number of times, participants from each group entered destinations while driving, following the intervention, in scenario 1. Mann-Whitney U tests revealed significant differences between safety and control groups (Mann-Whitney U(10)=1.5, Z=-2.815, $p<0.01$) and between safety-training and control groups (Mann-Whitney U(10)=6, Z=-2.031, $p<0.05$).

In a mixed model ANOVA with time pressure (reasonable vs less reasonable) as the within-subjects factor, group as the between-subjects factor, and destination entry time as the dependent variable, there was a non-significant main effect of time pressure ($F(1,20) = 0.043$, MSE=214.321, ns) and a non-significant group*time pressure interaction ($F(3,20) = 0.415$, MSE=214.321, ns), but there was a significant main effect of group ($F(3,20)=3.558$, MSE=281.988, $p<0.05$). A post-hoc Tukey`s HSD test showed that the training group took significantly less time to complete destination entry tasks than the control group (mean difference=20.92 seconds, $p<0.05$).

Figure 8.2: showing the mean number of times, participants in each group, entered destinations while driving in scenario 1 following an intervention (N=24)



Destination entry time was also recorded in the previous study (i.e. before intervention). In a mixed model ANOVA with test time (before intervention vs after intervention) as the within-subjects factor, group as the between-subjects factor and mean destination entry time (before intervention regardless of destination VS after intervention regardless of time pressure) as the dependent variable, there was a significant group*test time interaction ($F (3,20) =3.136$, $MSE=59.642$, $p<0.05$). A post-hoc Tukey`s HSD test showed that the greatest mean difference was between training and control groups, but this difference failed to attain statistical significance.

There were no significant results from any of the analyses concerning scenario 2 in which participants received destination information during their journey.

8.5 Discussion

The sample was discussed in the previous chapter, so that discussion is omitted here. The present study aimed to test the effectiveness of safety and training based remediation and mitigation interventions. In particular, it aimed to test the effect of a safety intervention on the frequency with which participants entered destinations while driving, and of a training intervention on destination entry time, driving performance measures and use of strategies to minimise distraction (e.g. chunking), when they were given the destination before setting off, and during their journey.

The study also informed participants they would receive a small monetary reward if they reached destinations on time. The aim of this measure was to motivate participants to want to reach their destinations on time, just as for a variety of reasons; it is likely that many real drivers would be motivated to reach destinations by specified deadlines frequently during everyday driving. To further address ecological validity, participants were also told their reward would be negatively affected if they broke the law to achieve their goals. A monetary reward also provided the opportunity to test the effect of time constraints on the frequency with which participants entered destinations while driving and other performance measures. The use of a monetary reward to motivate participants has been employed in several previous laboratory studies (e.g. Bacharach and Gambetta, 2001; Berg, Dickhaut and McCabe, 1995; De Vries, 2004). For instance, DeVries (2004) examined trust and reliance in an automated route planner (see chapter 2). He motivated some participants to perform well at this task by offering a small monetary reward each time they reached the destination on time, and showed that motivation can affect trust and reliance. As shown however, participants were actually deceived, as they all received the same compensation for participating in both studies regardless of performance.

8.5.1 Main findings

Individual significant findings from each scenario are summarised and discussed in more detail below, but before that, some general findings applicable to both scenarios as well as a lack of significant findings in the present study, will be briefly discussed first.

It was interesting than none of the analyses revealed significant main effects or interactions concerning the effects of time pressure on decisions to enter destinations while driving, as well as on any performance effects of entering destinations while driving (e.g. lane departures of speed exceedences).

In the diary study, diary entries also rarely mentioned that destination entry tasks (or other forms of system interaction) were completed while driving due to time constraints, though it is reasonable to assume that they can, and probably sometimes do, affect drivers' decision making. It is possible that participants were unable to make accurate mental calculations concerning how reasonable the time limits were, based on journey characteristics (i.e. length, average speed, number of traffic lights), as they were never explicitly told that one was reasonable and one was less reasonable in each scenario, due to the confounding effects this could have had.

It is also possible that they viewed the less reasonable time limit as perfectly reasonable, as it was still achievable. As shown, these time limits were calculated based on the time taken for pilot study participants to reach the destinations. It was important that the less reasonable time limit was still achievable; as participants were motivated to adhere to traffic laws (otherwise they might have simply broken the speed limits and driven through red lights to reach destinations on time). Perhaps future studies should develop a more appropriate method of informing participants how reasonable time limits are, but without explicitly informing them that their behaviour in response to time constraints is under investigation.

It was surprising that none of the interventions had any effects on either of the driving performance measures examined (i.e. lane departures and speed exceedences). It was expected that providing training in dual task situations, might have improved driving performance, particularly in lateral control tasks, as the training procedure included practice at a tracking task. It would be appropriate for any future simulator investigations into distracted driving to include fine-grained vehicle control measures also, like those employed in the previous study. However, due to several further points addressed further on in this discussion, it would be most appropriate to further these investigations in more naturalistic settings, and to use the present study and previous study to inform the design of them. Unfortunately however, it is much more difficult to accurately and reliably measure these variables in naturalistic settings. The present study was never designed to even collect this data, so it was not possible to analyse it later. This was because the primary focus of this study was to examine the effect of interventions on higher-level driving behaviours.

8.5.1.1 Both scenarios

As shown, a univariate ANOVA was used to examine the effect of group on the frequency with which participants entered destinations while driving in both scenarios. The main effect of group failed to attain statistical significance, and it is likely that this was due to the small sample size. Figure 8.1 shows that participants in both safety and safety-training groups entered fewer destinations while driving than those in control or training groups, but this difference was only significant for those in the safety group.

8.5.1.2 Scenario 1

In scenario 1, when participants received destination information before they set off, both the non-parametric analyses, and figure 8.2, show that those participants exposed to safety and safety-training interventions, entered destinations while driving, significantly less frequently than control groups. It was particularly interesting that this difference was also significant for those who received the safety-training intervention, as there was a danger that these participants might have perceived both safety and training interventions as delivering conflicting messages (i.e. the safety presentation was designed to show participants that destination entry while driving can negatively affect performance and the training presentation and exercises encouraged participants to behave this way safely). The previous chapter outlined Wolgater and Mayhorn`s (2005) hypothesis that some drivers engage in distracted driving simply because they are unaware of the potential dangers of behaving this way. Consistent with this, the present study has demonstrated that informing young drivers that entering destinations while diving could be dangerous reduced the frequency with which they behaved this way in subsequent trials.

It would be particularly useful for future studies to use several post-intervention trials, so that a more accurate picture of destination entry while driving frequency may be obtained. In the present study it was inappropriate to use ANOVA to examine the effect of group on the frequency with which participants entered destinations while driving because the data failed to satisfy the assumptions. Although there is some convincing evidence in the literature that ANOVA techniques are robust enough to withstand violations of normality (e.g. several studies employing Monte Carlo techniques have demonstrated the robustness of ANOVA even for analysing dichotomous data - see. D'Agostino, 1971; Gaito, 1980; Lunney, 1970), opinion on the matter is divided, so as a precaution, this analysis technique was neglected for this particular aspect of the study in favour of the non-parametric Mann Whitney U test.

In the present study participants made very absolute decisions about entering destinations while driving. The diary study showed that on some occasions, drivers started entering destinations while driving, but pulled over to complete the task, and on others they began using their system while stationary (e.g. stopped at traffic lights or in traffic jams) and only entered them while driving, because traffic had started moving again. It is possible that they made these absolute decisions due to their experiences in the previous study, which directly compared destination entry while driving to normal driving. Participants were explicitly instructed to enter the destination while driving in phase 2 of the previous study, and if any had pulled over to complete the task (none did), their results would have had to have been excluded from analyses. This represents a limitation (beyond generalisability of the results as discussed in chapter 7), of using the same sample for the present study. If some participants had not made such absolute decisions, it might have been possible to have examined time spent entering destinations while driving as a dependent variable, and this would have resolved some of the problems associated with using ANOVA to examine the frequency with which participants entered destinations while driving.

A mixed model ANOVA also revealed the importance of group in terms of the length of time it took participants to enter destinations while driving, and in this case showed that the only significant mean difference in entry times was between control and training groups, which is also consistent with the first hypothesis. A further analysis examined the effect of group, on differences in mean destination entry in the previous study and in the present study. It also revealed a significant group*test time interaction, but the differences between experimental and control groups failed to attain statistical significance in this case. The interaction suggests that a significant proportion of the variance in destination entry time could be explained by a combination of the group participants were assigned to and the trial time. The group component of this interaction is self explanatory, the test time component is most likely indicative of practice effects.

An important point to note here however is that both the above analyses only considered destination entry time, regardless of whether participants entered destinations while driving. This was because about half the sample entered both destinations while stationary in scenario 1, and the analyses would have lacked sufficient power had they only been performed on these participants. Although a lack of power due to sample size is equally applicable to t-tests, for purposes of confirmation that training did also effect destination entry while driving time specifically, an independent samples t-test showed that participants in the control condition (N=6) took significantly longer to enter destinations while driving, than those who received the training intervention (N=3), the mean difference in time was 14.33 seconds ($t(3.8^{5}) = 3.855$, $p<0.05$).

8.5.1.3 Scenario 2

It was interesting that no significant main effects of interactions were identified for scenario 2. The diary study showed that in most situations in which participants used their IVNS while driving, it was to satisfy moment-to-moment demands (or point of need – see Burnett, Summerskill and Porter, 2004), and was rarely to enter final destination information, which was typically done before entering the vehicle. In the present study too, there was far less variation in decisions to enter destinations while driving (i.e. most of the time, the majority of participants entered destinations while driving) during scenario 2 than in scenario 1. With further replication, this finding could usefully inform future intervention approaches by for example, reminding drivers that despite their attitudes and intentions, decisions to use IVNS while driving can also be motivated by prevailing circumstances.

8.5.2 Evaluating the effectiveness of educational and safety-related transport interventions

There are several methodological difficulties that make evaluating the effectiveness of educational or safety transport interventions problematic. For example, several studies have shown that socio-economic status can affect responsiveness to safety campaigns (e.g. Klassen et al., 2000; Grossman and Garcia, 1999; McArthur and Kraus, 1999). To overcome some of these difficulties, in 2004 the UK Department for Transport published guidelines for evaluating the effectiveness of road safety interventions. These are less applicable to the present study given its size, scope and reach, but according to Rothengatter (1981) evaluation criteria for road safety education should depend on the educational objectives of individual programs. On this basis, the present study partially achieved its aims, as it demonstrated effectiveness for some, but not all dependent measures.

[5] Corrected for unequal variances, due to the small sample size and uneven number of participants in each group

The discussion in chapter 7 showed that the content of the intervention strategies used in the present study was consistent with several recommendations proposed by an NHTSA (2000) expert panel concerning the design of educational intervention strategies to address distracted driving. The discussion in chapter 7 also outlined an analysis of a massive online information exchange between experts and the driving public, which was summarised by Llaneras (2000). It showed that the majority of respondents polled (56%), thought that education or safety campaigns could have a positive impact on reducing distracted driving, although 43% believed the impact would probably be minimal, which is consistent with the findings from the present study. Llaneras (2000) also reported that 40% of respondents indicated that they had changed the way they use mobile phones while driving having seen or heard a safety tip. Based on this evidence, he advocated the use of education and safety campaigns as part of a multi-modal approach to addressing safety concerns associated with in-vehicle technologies. Chapter 6 described the shortcomings of legislative attempts, and the ways in which safety-educational programs would be more appropriate to cause behavioural change. Recently driving while using a mobile phone was banned in the UK, and at the time of writing it was also banned in more than fifty countries worldwide. In a study evaluating the effectiveness of this legislation in New York, McCartt and Geary (2004) found that immediately after the introduction of legislation, there was a significant decrease in the percentage of drivers prosecuted for using a mobile phone while driving, but a year later the percentage prosecuted increased to a proportion not statistically different from the pre-ban figures. The authors concluded that publicity in combination with vigorous enforcement campaigns were required to promote long term behavioural change.

Several studies and literature reviews are available concerning the effectiveness of wider national or large-scale road safety campaigns and other driver education programs (e.g. Tay, 2002; Tay, 2005; Delaney et al., 2004; Stead et al., 2006; Drgautinovic and Twisk, 2006). Unfortunately most of these studies deal with aggregated accident statistics not behavioural or attitudinal changes.

However, Clayton et al (1998) reported a British Institute of Traffic Education Research (BITER) survey of 1000 students before and after they attended a safety presentation run by the driving standards agency (DSA). They found that the intervention improved attitudes towards driving and risk awareness, but as previous studies in this thesis have shown, attitudes don't always predict driving behaviour (see chapter 4). Roberts et al (2001) also questioned the validity of this study as the questionnaire response rate was very low (36%) and no control group was employed. There is some evidence that safety or educational interventions can even be counterproductive and increase accident rates or driving violations (e.g. Vernick et al., 1999; Waylen and McKenna, 2002).

8.5.3 Insight training

Chapter 7 introduced insight training, which formed the basis of the present study as a means of better calibrating subjective performance during distracted driving with objective measures. The chapter described how insight training had previously been successfully targeted at younger drivers (Senserrick and Swinburne, 2001). Senserrick and Haworth (2005) defined insight training as:

"...training approach to poor, driving related attitudes and motivational orientations associated with greater risk-taking behaviour, including over confidence, overestimation of skills and underestimation of risk"

Clearly, based on this definition insight training was most appropriate for the present study, and this view is supported by Garabet et al (2007) concerning engagement in other distracting behaviours while driving. Gregerson (1996) added that the insight approach improves insight into the factors that increase accidents, and based on this perspective, several authors have argued that the level of skill a driver posses is less important than how the skill is implemented and the effect of skill-implementation on safe driving practices. Several studies support the theoretical basis of insight training (e.g. Twisk, 1995; Gregerson and Bjurulf, 1996; Lonero, 1999; Horneman, 1993), and it is also used as the basis of the GADGET matrix (Hatakka et al 1999) which has been incorporated as part of formal driver training in Finland. Chapter 2 showed how the GADGET matrix essentially extended Michon`s (1985) hierarchy by adding a level above strategic driving behaviour concerning motivations, attitudes and driver characteristics. The present thesis provides some support for this, as it has shown how various attitudes (e.g. trust) and individual difference variables (e.g. age, computing skill) can affect behavioural adaptation at the strategic, tactical and control levels (i.e. hierarchically lower levels). In an early study, Gregerson (1996) demonstrated how insight training (i.e. calibrating the new highest level of driving behaviour in the GADGET matrix) can be more effective than skill-based training (i.e. improving strategic, tactical or control level driving behaviours). Gregerson split participants into two groups. Both were told about basic driving theory for driving in icy conditions (i.e. there was no control group), but one group received skill based training (i.e. skid training on a closed course) while the other group received insight training (i.e. they were made aware that even though they had received basic training they couldn't necessarily rely on this in critical driving situations). Based on responses to a post-training survey, he found that those who received skill based training rated their skills as higher than those who received insight training, even though there were no differences between groups in terms of actual skills (i.e. the insight group were less likely to be over-confident in their driving skills). Nolen and Nyberg (2001) reported no significant positive effects of insight training (although descriptive statistics did suggest some positive tendencies), but did also find that skill-based training was counterproductive. Nyberg and Engstrom (1999) reported some positive attitudinal changes due to insight training but found no effects on behavioural measures (e.g. headway, speed), but the Senserrick and Swinburne (2001) study reported in chapter 7, did report positive attitudinal changes and [self-reported] behavioural changes due to insight training, particularly for young males. Chapter 7 also outlined a study which examined the efficacy of a brief safety-related educational presentation, on future self-reported intentions to engage in distracting activities while driving (Kramer McCarley and Geisler, 2003). Although the presentation affected participants' subjective ratings of distraction caused by various activities, it failed to affect their future intentions.

In the present study, although analyses concerning most dependent measures were non-significant, there were some behavioural and performance changes due to the interventions. For example, participants who received safety and safety-training presentations entered destinations while driving significantly less frequently than control participants, and participants who received a training intervention took significantly less time to enter destinations than control participants. It would have been particularly interesting to have collected subjective performance and attitudinal ratings in the present study too, as it would have been possible to have examined the effect of the interventions on these. Following Kramer et al (2003), it would also have been useful if the present study had examined behavioural intentions, as significant associations could have indicated the effectiveness of the present study beyond simulator performance alone, which is prone to validity concerns (see below). However, this data was deliberately neglected for ethical reasons. As shown, participants signed a consent form after completing the study stating their awareness they just took part in a simulator study, which is much more controlled than real-life driving, and that they wouldn't attempt to repeat behaviours performed in the study in a real vehicle. It was believed that asking them about future intentions might have invalidated this message.

8.5.4 Evaluating the effectiveness of insight training

According to Keskinen et al (1999) the effectiveness of insight training should be examined in the longer term, and several authors have suggested the same. Leutner and Bruenken (2002) suggest that while theoretical knowledge is quick and easy to acquire, attitude change can take much longer. Lonero (1999) also pointed out that young drivers (e.g. those who enter destinations while driving more frequently) have limited capabilities to adequately absorb information and/or training provided in the short-term. This is also consistent with behavioural adaptation. Behavioural change due to an intervention would be classified as behavioural adaptation. Chapter 2 outlined that behavioural adaptation effects should be studied in the long term or among long terms users, indeed this was the main reason why each study in the thesis targeted end-users of IVNS.

Although the present study reported some effect of training on destination entry time, the group participants were assigned to failed to independently explain the variance in the number of chunks in which participants completed destination entry tasks. In the training they received, they were explicitly reminded that chunking was a useful strategy to minimise distraction and were given an opportunity to adopt this strategy during the training exercises. However, the training exercises lasted only approximately ten minutes, and as shown above, insight training should be conducted in the longer term. Although there is a limit to the number of educational safety-related messages to incorporate in any intervention, training drivers to complete divided attention tasks, and demonstrating effective strategies to minimise distraction might, over time, result in more noticeable behavioural changes.

Due to the difficulties in generalising the results from the present and previous studies to the wider driving population, the discussion in chapter 7 suggested that these simulator studies should be appropriately conceptualised as pilots for more large-scale research. Future research of this type, should examine the effectiveness of providing training over multiple sessions. The present study used a dual task-training scenario set up cheaply and easily on a personal computer, without the need for a driving simulator or other expensive specialist equipment. Since a high proportion of people own computers, it would be feasible for a participant in a large-scale study to practice dual task scenarios at home, and for researchers to intermittently test their behavioural and attitudinal responses concerning destination entry while driving and any attempts to minimise distraction caused by this behaviour. Due to some of the limitations of performing the present study in a driving simulator (see below), it would also be advisable for future studies to use more naturalistic methodologies, such as in-car observations.

Adopting a similar methodology to Dingus et al`s (2006) 100-car study, in which several drivers were monitored using in-vehicle recording equipment, but were given no special instructions other than to go about their daily lives would be most desirable. If some of these drivers also received regular, long-term training in dual-task situations, as well as in strategies to minimise distraction, significant behavioural and performance changes may appear over time.

In the present study insight training involved presenting empirical findings to participants from previous studies which have revealed that destination entry while driving degraded driving performance and safety, showing participants video footage of other drivers' performance decrements when they entered destinations while driving and informing participants that while destination entry while driving is presently not yet banned outright in the UK, drivers can still be prosecuted for this behaviour under dangerous driving legislation. The presentations were designed to show participants that destination entry while driving can be dangerous. In the previous chapter, the discussion showed that it would be a relatively simple matter to identify participants from the previous study who thought they drove better when entering destinations while driving than objective measures revealed, so that future intervention strategies could demonstrate to young drivers that subjective perceptions may be misaligned with objective measures. As the present study was conducted immediately after the previous study it was not feasible to identify these participants to this sample, particularly since the same sample was used in both studies. However, by extending the methodology used in the previous study, in future research it may even be possible to enhance insight training further by demonstrating to drivers how well calibrated their own subjective ratings of the performance effects of entering destinations while driving are, relative to objective measures of these parameters.

8.5.5 Validity and methodological concerns

Several limitations of the present study have already been highlighted throughout this discussion, but an important limitation that has not yet been addressed concerns validity. Chapter 7 showed that due to issues with generalising findings from the previous study to the wider [young] driving population, it was necessary to test the remediation intervention on the same sample, particularly since the design of the remediation intervention was largely informed by the results of the previous study. Financial considerations aside, due to the small sample size, it would have been inappropriate to have tested the sample in a more naturalistic setting due to the difficulties in establishing comparable behavioural validity. Additionally, although participants varied in terms of their prior and current experience with

IVNS, all participants had received controlled levels of simulator exposure and IVNS experience while driving in the simulator.

Aside from on-road and test track studies, there are other ways that engagement in distracting driving activities such as destination entry, could have been examined. Some studies have employed self-report measures of future behavioural intentions (e.g. Kramer et al., 2003; Boyce and Geller, 2002). Thompson et al (2007) also used self-report measures to investigate engagement in risky driving behaviours by young drivers with ADHD. However, they noted several difficulties with relying on self-report measures, in particular that they were prone to certain biases (see discussion in chapters 3 and 4). Interestingly, citing Barkley, Murphy and Kwasnik (1996), Thompson et al (2007) suggested that driving simulators would provide a valuable tool for further researching these issues without the difficulty of bias, though they also warn that due to concerns about the ecological validity of laboratory based research in this area, it would be most useful for simulator studies to complement other studies with different methodologies. Fortunately, the present study has collected self-report data showing trends in a large IVNS-using sample, which due to the anonymity afforded to respondents, appeared to have reduced the influence of social desirability bias; as well as a high volume of rich and detailed self-report data in the form of diary entries, recorded over a 2-week period in the lives of worker drivers who frequently used their IVNS in unfamiliar areas. Although future intentions were not directly addressed in the previous chapters, they demonstrated a lack of full correspondence between attitudes (i.e. destination entry features and other forms of system interaction, that *should* be allowed while driving) and behaviour (i.e. the frequency with which IVNS-users entered destinations while driving).

Even though it was necessary and appropriate to collect the wealth and range of self-report data previously collected in the thesis to address the first two aims, there is little further self-report data could have contributed, particularly in relation to the final aim of the thesis. It was most appropriate to address this aim experimentally. In many ways, naturalistic, on-road studies are most suited to the present investigation, but there are several reasons why this was not feasible for the thesis. These include, but are by no means limited to:

1. **Financial considerations** – There was no financial support available for either this or the previous study, even when run in the simulator. It is likely that arranging an appropriate experimental naturalistic (i.e. road or test-track trials) investigation could potentially have run into thousands of pounds.

2. **High volume of work** – The level of detail required to plan an appropriate study to investigate this issue, would have called on several people, to devote a high proportion of their time and resources to this one project. Many previous studies that have taken a similar approach to that which would be most desirable for this investigation, have been conducted by large transportation institutions (e.g. NHTSA, TRL), who employ several experts and professionals to manage the varied logistical aspects of projects like this.
3. **Ethical considerations –** There would have been several ethical implications of conducting naturalistic experimental investigations. In the present study, ethical considerations were also addressed, and participants signed consent forms to signal their awareness that simulator behaviour should not be repeated elsewhere. However, even with signing consent forms, there is a danger that participants in a naturalistic study could repeat this behaviour elsewhere. For example, section 8.5.3 described how some studies have shown that skills training can be counterproductive (i.e. increase confidence and motivation to try skills learned in a study).
4. **Safety considerations –** This point is associated with each of the above three, as due to safety concerns, insurance costs would be extremely high. Also to adhere to legislation etc., project managers would have to establish several safety protocols and there are clear ethical implications of asking participants to complete tasks while driving that could potentially lead to accidents and injury or worse.
5. **Control –** There are a wide range of extraneous variables in naturalistic investigations that could potentially affect results. Even if all participants drove exactly the same route, there are several uncontrollable factors (e.g. traffic density, traffic behaviour, weather, pedestrians and pedestrian behaviour) that could affect driving behaviour and willingness to use an IVNS while driving. Although test-tracks offer a more controlled environment, there are still several uncontrollable factors such as the weather that could affect the validity of the results.

Although there are varying levels of implementation for on-road studies (e.g. Lerner and Boyd, 2005 examined wiliness to engage in potentially distracting tasks while driving, by taking participants out in a vehicle and asking them at pre-determined times, whether they would be prepared to perform them - see chapter 7), any kind of naturalistic study was infeasible for the present study, due to both financial considerations and the points raised in chapter 7. The previous chapter described how due to their size, and because they represent an original line of research, it would be particularly useful to view the present and previous studies as pilots for future, potential experimental or observational, naturalistic studies, which could investigate the effect of interventions, on willingness to use IVNS while driving and strategies employed to minimise distraction.

Conducting these studies in the simulator, therefore provided an initial opportunity to address some of the fundamental research questions, but to minimise some of the potential difficulties associated with naturalistic studies, described above. Although money was still needed to pay participants for completing the studies, this was the only financial consideration, as the computing department at the University of Nottingham has a fully functioning STISIM driving simulator that was available for this research. Although there were still several administrative and logistical issues in organising the study and using the simulator for this research, there was less need for a large highly co-ordinated team. There were still ethical considerations, and these were addressed, but there were much fewer ethical considerations than there would have been in a naturalistic investigation. Although there was still the potential for simulator sickness (despite screening potential participants based on this), participants were never in any real danger when they completed destination entry tasks. Finally, the simulator vastly increased the level of experimental control. All participants drove precisely the same routes, in precisely the same environmental and traffic conditions, in the same vehicle and with the same IVNS etc.

Although in most research, driving simulators are typically employed for examining performance effects rather than motivational behaviour (e.g. willingness to engage in distracted driving), there have been some exceptions. In one simulator study, Clifford et al (2005) examined the effect of the individual difference variable sensation seeking on engagement in risky driving behaviour, and also suggested using their research to inform the design of educational strategies aimed at targeting engagement in risky driving behaviour. Several other studies (e.g. Jackson and Blackman, 1994; Leung and Starmer, 2006) have also employed driving simulators to examine motivations to engage in risky driving behaviour. Pardillo (2008) advocates the use of driving simulators in investigating higher level variables from the GADGET matrix such as the effects of overconfidence on driving behaviour.

Although relative to performance-based simulator studies, the number of motivation-based simulator studies is low, the above research suggests there is some precedent for investigations like the present study to be conducted in driving simulators. There are several validity concerns about laboratory-based studies (e.g. demand characteristics – Orne, 1962) as well as driving simulator studies in particular (e.g. absolute vs relative validity – see Blana, 1996 or Young, Regan and Hammer, 2003 for reviews of several simulator validity issues); but for the present study, the key validity issue is that there was no way to replicate in the simulator, the range of motivations that real drivers experience when trying to reach real destinations. Drivers might be motivated to reach destinations quickly due to financial pressures or other time constraints. Individual differences aside, due to a whole range of other uncontrollable factors in normal driver's everyday lives, they might also differ in their motivation to obey traffic laws and the highway code, behave in socially unacceptable but not necessarily illegal ways while driving (e.g. violations), avoid accidents or injurious outcomes (i.e. safety), as well as in the level of risk they are prepared to accept on a given journey.

The difficulties with using driving simulators to investigate these issues can be easily illustrated by taking safety as an example. With the exception of simulator sickness, driving simulators eliminate many of the negative safety-implications of driving research. So in real driving, it is likely that participants are much more motivated to avoid injury due to the very real risks (in terms of personal injury and financial risks) associated with crashes or accidents, but it is unlikely that they would experience the same motivations in the simulator.

Although safety-based motivations could not be controlled in the simulator, which could to some extent cause concern about the validity of the results, the present study did attempt to at least partially address the motivation issue, by offering a monetary reward when participants reached destinations within a specified time, just as in real driving there may often be positive reward (though not necessarily financial) for doing this. Similarly in real driving there are potentially negative outcomes associated with breaking traffic laws, although these too, many not always be financial. By warning participants that their monetary reward would be affected by illegal driving behaviour, it was hoped that this also at least partially addressed this issue, particularly as the effects of time constraints on decisions to enter destinations while driving were also investigated (i.e. without this warning, participants may have tried to reach destinations on time by speeding or driving through red lights, in which case it would have been impossible to have understood if their decisions to enter destinations while driving were affected by time constraints).

Although the analyses showed that over both scenarios and in scenario 1, those who received the safety-intervention entered destinations while driving significantly less frequently than those in the control group, a limitation of the present study was that it didn't examine the differential impact of different messages presented in the safety intervention. As shown, it used statistics from previous research, a video from previous research demonstrating poor lateral control and provided information concerning current legal implications of this behaviour, in particular that it in some situations, it can, and has sometimes been prosecuted using dangerous driving legislation. It would have been useful to have interviewed participants who didn't enter destinations while driving, after the trial, to determine the extent to which this was because they considered it dangerous enough to be illegal (as they were told that illegal driving behaviour would negatively affect their monetary reward). Due mainly to financial constraints, it was only possible to include four conditions in the present study, but it would be more appropriate for future studies to examine different types of safety interventions each with very specific messages.

Similarly those in the training conditions could have been informed in different explicit ways about individual strategies, as well as different combinations of strategies, that might be used to minimise distraction; or could have received training in several dual-task scenarios, to show which results in the most appropriate, post-intervention, driving behaviour. In the present study, a dual task training exercise was chosen that could be easily implemented by most drivers on their home computer, so if it was found to significantly affect aspects of post-intervention driving behaviour, it would have been easily accessible to most IVNS users. However, future studies could investigate more elaborate training exercises that could be incorporated into formal driving training programs. The present discussion has already suggested that future studies should include longer term training interventions to achieve any noticeable behavioural effects; future research could also aim to examine the differential effectiveness of long term and short term training, as well as to determine the durations, between which, long-term training is most effective.

8.5.6 Summary and conclusion

This experimental driving simulator study, aimed to examine the effects of potential safety and training related remediation interventions on young drivers' subsequent willingness to enter destinations while driving, longitudinal and lateral driving performance measures and any strategies employed to minimise distraction when performing this task. It only modestly achieved its aims.

It did show that a safety-based intervention reduced the frequency with which drivers enter destinations while driving in scenario 1, but due to methodological difficulties this finding lacked adequate statistical power, although a univariate ANOVA did also show that regardless of within subjects variables like scenario and time constraints, those who received a safety-based intervention did subsequently enter destinations while driving significantly less frequently.

It also showed that those who received a training-based intervention took significantly less time to complete destination entry tasks in scenario 1 only, but failed to find any effects of training on strategies employed to minimise distraction in either scenario or longitudinal and lateral driving performance measures. Further analyses which compared data from the previous study with the present study, did also suggest an effect of training on destination entry time, but as this effect was only significant as part of an interaction with trial time (i.e. the previous study or the present study), it is likely this was also due to practice effects. Unfortunately the analyses were not performed for those participants who entered destinations while driving only, because this would have excluded about half the sample (N=13), seriously reducing the power of the analyses. For the purposes of confirmation only, independent samples t-tests were conducted to examine the effects of training and safety-training interventions on time taken to enter destinations while driving, and did confirm that those exposed to the training intervention took significantly less time to enter destinations than controls.

The discussion showed that educational and safety campaigns in general are notoriously difficult to evaluate in terms of effectiveness, and that insight training in particular should be studied over a much longer term. Throughout the discussion several other limitations were also described, and it went on to show that although some authors have positively evaluated simulator methodologies for this kind of research relative to other methods (e.g. self-report measures), there are also some key validity concerns that were unaddressed, although some attempts were made to address driver motivation.

Despite these limitations the present study and the previous study have fully addressed the third aim of the thesis by further investigating the tendency for some young drivers to enter destinations while driving and using the findings to suggest directions for future research concerning the design of potential intervention strategies. The previous study demonstrated that young drivers' subjective ratings of the performance/safety effects of destination entry while driving were poorly aligned with objective measures of these parameters and discussed Wolgater and Mayhorn`s (2005) hypothesis that young drivers might engage in distracted driving simply because they are unaware this behaviour may degrade driving safety/performance.

The present study showed that informing young IVNS users that destination entry while driving can be dangerous and showing them video footage to this effect, did reduce the frequency with which they subsequently entered destinations while driving in the simulator. It also demonstrated that participants trained in a dual task scenario took significantly less time to enter destinations. These findings suggest that outside of legislative changes or developments in system design, future intervention strategies to remediate or mitigate this behaviour should include some form of insight training to show young drivers that their own subjective perceptions of the performance effects of entering destinations while driving may be misaligned with objective measures of these parameters. They also suggest that it would be beneficial to provide training to young drivers in dual task scenarios.

Ideally these findings need to be replicated in future naturalistic studies outside of the driving simulator with a much larger and more diverse sample of drivers. It is possible that with an appropriate budget and project time-scale, further effects of these intervention strategies unidentified in the present study might also emerge. For example, a future study incorporating a longitudinal design in which participants receive multiple dual task training sessions might reveal subtle changes in driving performance over time when they enter destinations while driving that could not be observed in the present study.

Chapter 9: Thesis contributions and future work

9.1 Introduction

The previous chapters in this thesis have described and discussed a literature review, together with five main studies employing both quantitative and qualitative methodologies. The research has addressed the following specific aims, namely to:

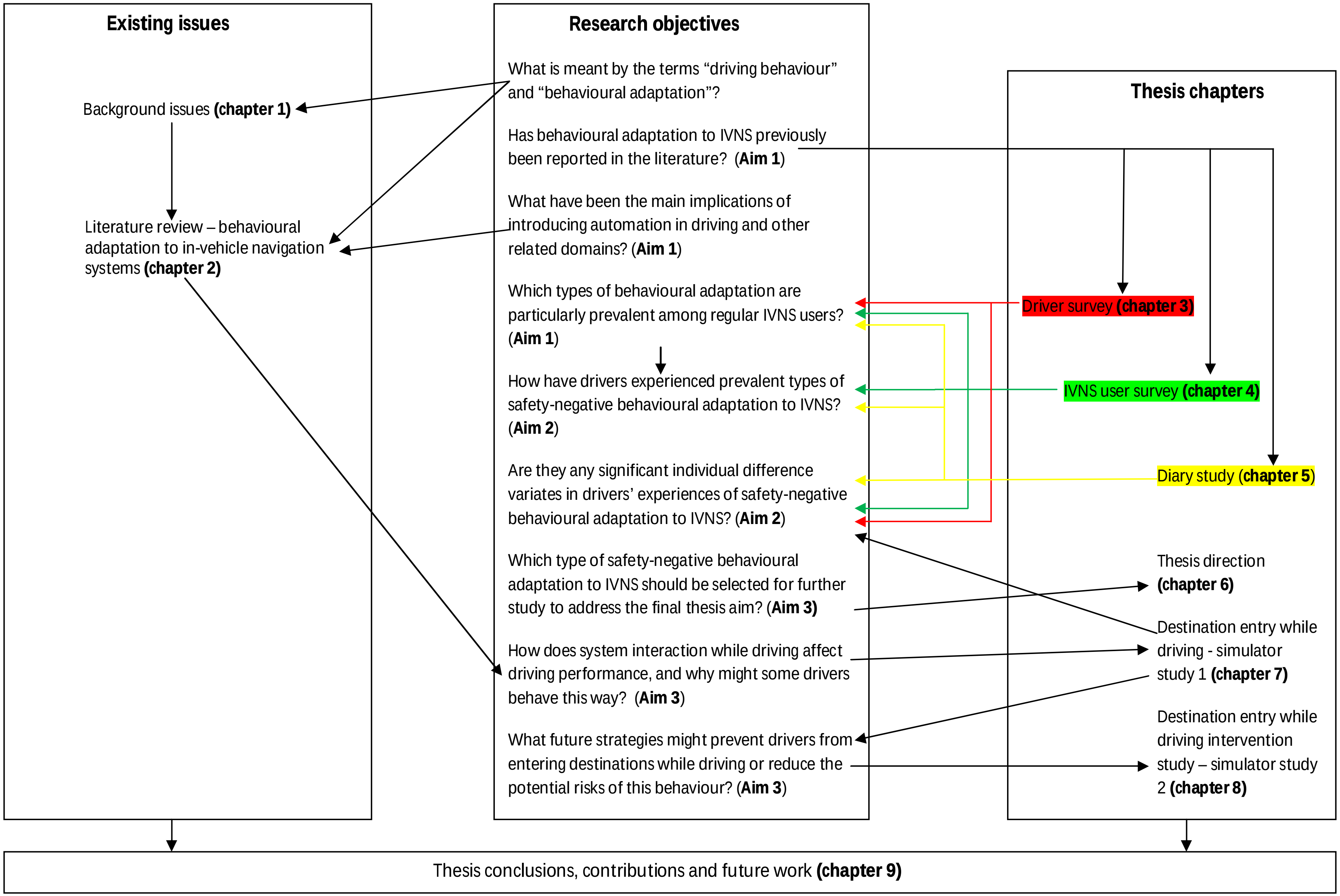
1. **Identify** the range of potential **types of driver behavioural adaptation** to IVNS including those which have a positive, negative and neutral impact on driving safety and navigational efficiency.
2. **Explore** those behavioural adaptations which have the potential to degrade driving safety, paying particular attention to any individual difference variates.
3. **Select** and **further investigate** a prevalent **safety-negative** type of behavioural adaptation to **understand** why some drivers behave this way. Use the findings to **highlight** potential strategies to remediate or mitigate this particular driver behaviour.

This chapter will begin by returning to the thesis structure diagram presented in chapter one to illustrate how each chapter in this thesis has contributed to addressing the above aims and the wider research objectives that were outlined in the diagram. Following this, several proposals for future research concerning behavioural adaptation to IVNS will be discussed and the chapter will close with a final statement briefly summarising how this thesis has addressed its aims and achieved its wider objectives.

9.2 Thesis contributions

Figure 9.1 on the next page shows the thesis structure diagram that was presented at the end of chapter one.

Figure 9.1 – thesis structure diagram revisited



9.2.1 Background issues

Chapter 1 began by introducing the reader to behavioural adaptation in a transportation context. It went on to show that automation can be implemented at different levels, and documented the ubiquity of automation in modern vehicles. It showed that IVNS as well as other in-vehicle systems represent a new level of sophistication in vehicle and driving automation.

What is meant by the terms "driving behaviour" and "behavioural adaptation"?

The literature review began by outlining several hierarchical models of driving behaviour. It showed that the Michon (1985) model provided a particularly useful framework upon which to base this thesis. This highly influential model was derived from a task analysis which broke the driving task into its constituent components. Michon (1985) viewed driving as a problem solving task comprised of three hierarchically related levels: strategic, tactical and control. Behavioural adaptations to IVNS were identified in this thesis as occurring at each of these levels. The discussion in chapter two also highlighted a recent extension to the Michon (1985) model called the GADGET matrix (Keskinen, 1998; Hatakka, Keskinen, Gregerson and Glad, 1999), which proposes a further level above the strategic level concerning driver characteristics (e.g. age, gender, personality, motivations) loosely labelled as "*goals for life and skills for living*". Hatakka et al. (1999) suggested that these driver characteristics can influence driving behaviour at lower levels, as they define how the driver functions as a person and this can affect how they solve tasks at the strategic level.

Chapter two also rigorously defined behavioural adaptation for the purposes of this thesis. It outlined in detail the OECD (1990) expert panel definition of this phenomenon and described how the term has been used elsewhere in the literature. This section showed that in the 1990`s behavioural adaptation and risk compensation were often referred to interchangeably in the literature, but the discussion showed that while it may also include risk compensation (or behavioural compensation), behavioural adaptation is a much wider and more far reaching concept. This is because risk compensation is limited to changes in the road/user/vehicle system implemented to affect driving safety. However, the OECD (1990) expert panel stressed that behavioural adaptations can occur in response to **any** changes in this system, regardless of whether they were initiated for the purposes of safety. Drawing on the original

OECD (1990) definition, the discussion also showed that behavioural adaptation refers to any behavioural changes, not just compensatory ones.

Chapter two explained that the original OECD (1990) definition of behavioural adaptation was adopted for this thesis with two caveats. The first caveat was that the thesis would focus specifically on driver behavioural adaptation and would not consider the behavioural adaptation of other road users and pedestrians as the original definition does. The second caveat was that the thesis would also report some behavioural changes intended by system designers in addition to those that are unintended. The discussion in chapter two explained how the original OECD (1990) authors had stressed that the precise operational definition of behavioural adaptation should also depend on the context of the research and that behavioural adaptations could have a positive, negative or **neutral** effect on driving safety. Since this thesis concerns IVNS, which are primarily purported to increase navigational efficiency and driver comfort rather than safety, it was appropriate in this context to also examine strategic and tactical level changes in navigational efficiency that occur when drivers use IVNS, regardless of whether these behavioural adaptations directly affected driving safety.

9.2.2 Aim one

Has behavioural adaptation to IVNS previously been reported in the literature?

The literature review went on to document behavioural adaptations that have previously been reported in response to a variety of non-automated (e.g. seatbelts, studded tyres, roadway changes) and automated (e.g. adaptive cruise control, intelligent speed adaptation) transportation interventions. It then discussed literature concerning behavioural adaptation to IVNS in detail. Initially it considered a range of studies which had compared the driving behaviour and performance of IVNS users and ordinary drivers using traditional navigation methods (e.g. spoken directions, paper maps). Behavioural adaptations at the strategic (e.g. overall navigational performance, trip preparation time, ability to anticipate congestion) tactical (e.g. driving speed, navigational errors, hazard detection) and control (e.g. lane deviation, brake usage, yaw rate) levels of driving behaviour were identified.

Although several studies were considered in this section of the literature review, table 2.1 illustrated the mixed and often contradictory findings that were reported (e.g. some studies indicated positive behavioural adaptation in terms of safety or navigational efficiency while others indicated negative or neutral behavioural adaptation for the same dependent measures). The discussion showed that there were also several problems which made it difficult to compare studies and draw firm conclusions from and between them. Aside from classification and methodological issues, the novelty effect makes it particularly difficult to generalise findings from these early studies, most of which examined the behaviour and performance of drivers who had no prior experience of using IVNS. However, early researchers observed that with increased system experience, drivers appeared to devote fewer attentional resources to the IVNS (Antin et al., 1988). For example, Dingus et al. (1997) observed that experienced IVNS users glanced less at the display and for shorter durations, and suggested this demonstrates the novelty effect wearing off. The novelty effect is a particularly salient issue for this thesis because many forms of behavioural adaptation to in-vehicle systems may not appear immediately, but will only become apparent after a familiarization period (Saad et al., 2004).

The discussion in chapter two also noted the wide variation in IVNS used across studies and throughout time. It showed that the majority of studies that had compared IVNS users with drivers using traditional navigation methods were conducted during the 1990`s or even before this (i.e. at or near the time that IVNS first became widely available to drivers). Many of these systems lacked key features that are standard in contemporary models. For example, chapter 1 reported that early systems simply provided a map displaying a start point and a destination point, with no turn by turn directions, route re-calculations etc. Similarly Antin et al. (1990) reported that the ETAK navigator that participants used in their study could only provide general route information beyond approximately half a mile radius of the current vehicle, and as such, drivers could only use the navigator effectively by repetitively glancing at the display to acquire important information as it was updated and presented. This was because this system used dead reckoning instead of GPS to calculate vehicle position. Furthermore the digital maps and operating system were stored on tapes. Due to the limited memory capacity of these tapes, maps for some cities were spread across several tapes, so when drivers reached map boundaries they had to change tapes to continue receiving route guidance support. Also the ETAK navigator presented route guidance information to drivers using green vector maps only. Contemporary IVNS are significantly more effective and efficient in presentation of route information primarily because they use GPS to determine vehicle position; they have significantly larger memory capacities and use much higher fidelity visual displays. Therefore many of Antin et al`s (1990) findings may have been over-estimations due to technical limitations of the early IVNS they used. These examples illustrate some of the problems in comparing studies throughout time as it is particularly difficult to generalise many of the findings from these early studies to contemporary IVNS users.

A further difficulty in generalizing from these early studies was that the majority of them had considered behavioural adaptation to integrated IVNS only. However, due to the present and future, affordability and availability of after-market IVNS (e.g. nomadic systems), as well as the continually expanding range of platforms on which the software and hardware is available (e.g. PDA`s, mobile phones, laptops), economic forecasts suggest that the after-market range of IVNS have achieved, and will continue to achieve, significantly greater market penetration than integrated models. Unsurprisingly, the majority of drivers sampled in each study in this thesis also used after-market IVNS models. The studies brought to light, several aspects of behavioural adaptation to IVNS, many of which have received scarce research attention to date, yet are presently affecting an increasing proportion of the driving population.

Due to the lack of research that had specifically investigated strategic level behavioural adaptation to IVNS, the literature review also considered strategic level behavioural adaptation to a much wider range of advanced navigational aids. It documented several reported changes in route and departure time, mode of transport and even decisions to travel, and emphasized a need for further research to investigate strategic level behavioural adaptation to IVNS specifically.

What have been the main implications of introducing automation in driving and other related domains?

The literature review also outlined some of the main reported implications of introducing automation in driving and other domains. The discussion showed that many of these issues (e.g. trust in automation, automation-induced complacency, situation awareness, workload) were particularly salient when investigating behavioural adaptation to IVNS and they provide a useful starting point for investigating behavioural adaptations previously identified in the literature as well as those that have received little or no previous empirical research attention (e.g. over-reliance).

Which types of behavioural adaption are particularly prevalent among IVNS users?

The studies reported in chapters 3, 4 and 5 all addressed the first aim of the thesis. The driver survey compared characteristics of IVNS users and non-users but found no significant differences between groups in terms of demographic factors (e.g. age, driving experience, annual mileage, SES), suggesting these groups of drivers were broadly similar. However, some significant differences in the self-reported driving behaviour of IVNS users and non-users were identified. The discussion noted that although self-report measures may be prone to several response biases (e.g acquiescence, social desirability, overconfidence) there were some important differences found between IVNS users and non-users that have implications in terms of behavioural adaptation to IVNS.

Concerning the DBQ items specifically related to driving safety, there were few significant differences in the relative frequency with which IVNS users and non-users reported engagement in a range of driving errors. For most safety-related DBQ items, where differences were found they suggested that IVNS users behaved more safely than non-users. The most notable exception was that IVNS users reported driving while distracted significantly more frequently than non-users, but this was a violation item (i.e. a deliberate action rather than an accidental one). Similarly in terms of navigational efficiency, responses largely indicated positive tactical level behavioural adaptation to IVNS, as IVNS users reported making fewer navigational errors (i.e. misreading signs on roundabouts and junctions) than non-users. Responses also indicated positive strategic level behavioural adaptation for more than a quarter of IVNS-using respondents who reported that since acquiring their system they have made more unfamiliar journeys than they used to. The driver survey results also showed that most IVNS users were satisfied with their systems, suggesting that system acceptance (a pre-requisite of behavioural adaptation) was probably quite high, so it was unsurprising that IVNS users also reported worrying about the consequences of getting lost significantly less frequently than non-users.

Clearly the driver survey indicated overwhelmingly positive behavioural adaptation to IVNS in terms of safety and navigational efficiency, but the discussion in chapter 3 also identified some limitations with this study. Although IVNS user and non-user responses suggested that respondents had not been biased towards socially desirable responding, insufficient respondent information was collected (e.g. it was unclear whether non-users sometimes used traditional navigation aids or drove completely unaided). Similarly IVNS usage was inadequately addressed. Following previous surveys reported in the literature (e.g. J.D. Power and associates, 2003) respondents in the driver survey were asked how frequently they used their IVNS. The results showed that on average respondents reported using their systems about 30 times each month. However, the contexts in which they used their systems were unclear. Perhaps some respondents interacted with their systems while driving whereas others used them to follow route guidance instructions or merely had them switched on. Given the significance of understanding IVNS usage when investigating behavioural adaptation to IVNS, it was clearly important to collect further usage information. Finally, aspects of automation-related behavioural adaptation to IVNS, for which some anecdotal evidence was reported in the literature review (e.g. over-reliance, system interaction while driving), were neglected in the driver survey to ensure it could be completed in less than ten minutes, as previous authors (e.g. Reips, 2002; Van Selm and Jankowski, 2006; Sheehan and Macmillan, 1999) have recommended this strategy to minimize dropout and maximize online survey attractiveness to potential respondents.

The IVNS user survey reported in chapter four focused in detail on behavioural adaptations to IVNS that were either neglected or insufficiently addressed in the driver survey. Fortunately a far higher number of IVNS users provided data for this survey. The results suggested most IVNS users in this study too were satisfied with their systems, but this survey went on to highlight some of the components of user satisfaction and dis-satisfaction. IVNS usage was also explored in much greater detail. Unsurprisingly, the results showed that most respondents used their system in an active manner while travelling in unfamiliar areas and passively while travelling in familiar areas. However, only about 15% of respondents reported that they had never engaged their IVNS in familiar areas. This shows that most respondents have made the strategic decision to use these systems beyond the scope of their originally designed purpose (i.e. to provide navigational assistance in unfamiliar areas). Interestingly, a similar proportion of IVNS users in this survey reported increased exploration of unfamiliar areas since acquiring an IVNS as in the driver survey (i.e. positive strategic level behavioural adaptation in terms of navigational efficiency).

The IVNS user survey also highlighted the prevalence with which IVNS users enter destinations while driving, as only a quarter of the sample reported that they **never** behaved this way. The literature review showed that although some studies have previously investigated the performance effects of destination entry while driving, there is much less available evidence concerning the extent to which IVNS users actually behave this way. A likely reason for this (as shown above) is that most previous IVNS user research has focused on drivers who use integrated systems only. Chapter one explained that integrated systems typically restrict many forms of system interaction while driving (including destination entry tasks), but that most nomadic systems, PDA and laptop-based systems have much less scope to restrict this form of system interaction because they are disconnected from other vehicle systems. The vast majority of IVNS user survey respondents used aftermarket systems. The results of this survey suggest that destination entry while driving is a significant behavioural adaptation issue affecting the majority of these contemporary IVNS users. Unfortunately the IVNS user survey failed to collect further data concerning other forms of system interaction that participants engage in while driving. Chapter 2 showed that destination entry while driving has been examined most frequently in the literature as this is one of the most complex forms of system interaction facing most IVNS users, and destination entry tasks typically violate the 15-second rule which has been adopted by the society for automotive engineers (see chapter 2). However, to fully address the first aim of the thesis it was also important to examine the prevalence with which drivers engage in other forms of system interaction while driving.

The IVNS user survey also documented the frequency with which IVNS provide unreliable, inaccurate and sometimes even dangerous/illegal route guidance instructions. Although most respondents simply ignored these erroneous route guidance instructions when presented with them, a significant proportion of respondents reported that they had followed them on at least one previous occasion, and some reported following them even more frequently than this. This was the first empirical study to document this form of behavioural adaptation to IVNS.

The diary study reported in chapter 5 also addressed the first aim of the thesis. By examining diary study participants' user preferences, several examples of strategic and tactical level behavioural adaptation to IVNS were identified. For example, participants mentioned a range of strategies they used to minimize distraction, overcome system limitations, maximize system efficiency in future trips and verify calculated routes (see table 5.7). The diary study also revealed the prevalence with which participants engaged in other types of system interaction while driving. The majority of interactive tasks performed while driving shown in table 5.3 concerned interactive tasks unrelated to destination entry. Only in a minority of cases had participants entered destinations while driving, but they had engaged in other forms of system interaction (e.g. browsing points of interest, zooming on the map) much more frequently while driving. This finding further demonstrates the importance of this issue when considering behavioural adaptation to IVNS, as based on this sample, other forms of system interaction while driving may be even more prevalent among contemporary IVNS users than destination entry tasks alone.

9.2.3 Aim two

The second aim of the thesis comprised two phases: exploration of prevalent safety-negative forms of behavioural adaptation to IVNS and identification of any significant individual difference variates in drivers' experiences of safety-negative behavioural adaptation. The studies reported in chapters 4 and 5 addressed this aim. Drawing on findings of the first driver survey, secondary sources and human-factors literature concerning the implementation of automation in the driving domain, the IVNS user survey and diary study explored in detail, two prevalent forms of behavioural adaptation to IVNS that have the potential to negatively affect driving safety. These were:

(1) a tendency for some drivers to have followed inaccurate or unreliable system-generated route guidance instructions, including those which may be dangerous or illegal
(2) a tendency for some drivers to have manually or vocally interacted with their IVNS while driving

9.2.3.1 Exploration

How have drivers experienced prevalent types of safety-negative behavioural adaptation to IVNS?

Although both surveys indicated widespread user satisfaction and system acceptance, the IVNS user survey showed that routing reliability was a particularly prevalent component of user dis-satisfaction. It illustrated the varied ways in which the majority of IVNS users have received poor routing performance, and in which some of these drivers have followed erroneous system-generated route guidance instructions. The survey also examined the frequency with which IVNS users update their system maps and some of their thoughts about map updates. Although most IVNS users who had received inaccurate route guidance had never updated their system maps, the results suggested that the currency of the underlying map data is also of particular importance as a significant proportion (42%) of those who had updated their system maps had still received poor guidance. In many of these scenarios (e.g. turn into a one-way street, perform prohibited manoeuvres, drive in bus lanes) drivers must have followed inaccurate system advice despite contradictory environmental information, such as road signs/markings. Discussions showed that without greater detail, it was impossible to speculate about whether drivers had followed this advice despite having perceived/attended to contradictory environmental information (i.e. trust) or due to attentional/ perceptual failures or some other reason. Therefore, although the IVNS user survey illustrated the varied contexts in which IVNS users have received and followed inaccurate route guidance instructions, it inadequately explored the specific contexts in which this occurred to have fully addressed this part of the second thesis aim.

The IVNS user survey also further explored the frequency with which some drivers enter destinations while driving. The results showed that nearly a fifth of respondents admitted to entering destinations while driving quite often or even more frequently and over half of them reported doing so at least occasionally. To further explore this form of behavioural adaptation to IVNS, respondents were also asked about destination entry tasks (i.e. destination entry by address, postcode, stored location and point of interest) and other forms of system interaction (e.g. change volume, manipulate map, browse points of interest) that they thought *should* be allowed while driving. Interestingly although only a quarter of respondents reported that they never entered destinations while driving, nearly a third indicated that no forms of destination entry should be allowed while driving, suggesting that some IVNS users enter destinations while driving despite being opposed to this behaviour. A much lower proportion of respondents also indicated that no other forms of system interaction should be allowed while driving, suggesting that IVNS users find it far more acceptable to perform these in-motion interactive tasks, presumably because they can typically be executed much quicker. For example, the interactive tasks that the highest numbers of respondents deemed acceptable were change volume, change view and manipulate map. Similarly a much higher proportion of respondents considered quickly executable destination entry methods (e.g. destination entry by stored location) to be acceptable while driving than longer duration methods (e.g. destination entry by address). This is also consistent with the diary study finding outlined above where system interactive tasks unrelated to destination entry were performed while driving much more frequently than destination entry tasks. Unfortunately no further information was collected about respondents' system interaction preferences, so it was inappropriate to speculate further about the reasons for the observed discrepancy between their attitudes (i.e. interactive tasks respondents feel *should* be allowed while driving) and their behaviour (i.e. interactive tasks respondents actually perform while driving).

Clearly although the IVNS user survey made a significant contribution, it did not completely address the exploration phase of the second thesis aim. Fortunately the diary study enabled detailed exploration of the specific contexts in which participants used their systems while driving and received/followed inaccurate route guidance instructions over a 2-week period of time.

Interestingly most of the scenarios described in the diary study, in which participants reported having received and/or followed inaccurate route guidance instructions could broadly be classified in the same categories identified in chapter 4 (e.g. perform prohibited manoeuvres, turn the wrong way into a one-way street etc.). In the IVNS user survey surprisingly few participants reported that they had received and/or followed inaccurate route guidance instructions guiding them into areas for which their vehicle dimensions were unsuitable. The discussion in chapter four noted that this may have been because HGV and LGV drivers were not specifically targeted in the sampling frame. In the diary study, worker drivers were specifically recruited due to the frequency with which they reported driving in unfamiliar areas. Several diary study participants drove heavy/light goods vehicles, and the diary study results showed that this is also a prevalent form of inaccurate route guidance received by these particular IVNS users. Indeed some of the diary extracts illustrated in section 5.3.5 show that development of systems that incorporate vehicle dimensions in route planning algorithms is a key design consideration that many of these drivers would like to see addressed in future systems.

Potential reasons for the high frequency with which most IVNS users have received inaccurate route guidance instructions (which is clearly a pre-requisite for following them) have already been discussed in this chapter. The above discussion has explained that the currency of the underlying map data is of particular concern since many IVNS users who have updated their system maps, have still received poor route guidance. The diary study further explored some of the reasons why participants received inaccurate guidance. In some cases participants' system maps were clearly out of date, but consistent with the IVNS user survey findings summarised above, map database errors also appeared to account for many of the problems reported by participants concerning the accuracy of route guidance instructions they had received. Other accounts indicated a poor correspondence between the database map and the visual map displayed on the IVNS screen. These qualitative accounts suggest that there is still much room for improvement in the design and/or construction of system maps. Therefore it will be particularly interesting over the next few years to track the progress of innovative developments in map design and construction such as the TOMTOM Mapshare program outlined in chapter 6.

From the detailed qualitative accounts of situations in which participants reported that they followed inaccurate route guidance instructions during the diary study, it was sometimes possible to extract potential explanations for this type of behavioural adaptation. The discussion in chapter 4 noted that in most cases, drivers must follow inaccurate or dangerous/illegal route guidance instructions despite contradictory road signs or other environmental information. In order to explain why some drivers behave this way, it is important to consider the extent to which they actually process road signs when presented with consistent and contradictory IVNS instructions. If road signs are not sufficiently processed, this would imply an attention or perception based explanation. However, if they are processed and drivers still follow inaccurate system instructions, the explanation may not be purely cognitive. It would indicate inappropriate reliance on the IVNS. The literature review outlined the relationship between trust in automation (i.e. the attitude) and reliance (i.e. the behaviour). The majority of qualitative accounts illustrated in table 5.6 tended to implicate trust based explanations for this type of behavioural adaptation. However, they also indicated a further reason why some drivers have followed inaccurate route guidance instructions that had been overlooked in the chapter four discussions. In some cases diary study participants appeared to have followed inaccurate or dangerous/illegal route guidance instructions despite seemingly being aware they were doing so. On some occasions this was because participants determined that it would have been more dangerous to deviate from the suggested path, but on others participants appeared to have proceeded simply because they failed to acknowledge any problems of behaving this way.

It was also particularly interesting to examine qualitative accounts from participants who had received inaccurate route guidance instructions but had not followed them during the diary study. In most cases participants appeared to have shown restraint when they received inaccurate system-generated route guidance because they had recognized contradictory road signs or other environmental information. Chapter two reviewed some of the trust in automation literature. Several studies, some of which have focused specifically on automated route planners (e.g. Kantowitz, Hanowski and Kantowitz, 1997) have demonstrated that trust in automation (and reliance) are closely related to system reliability. Typically these studies have shown that trust can deteriorate when system reliability is low, in these cases operators (i.e. drivers) prefer to perform tasks themselves rather than rely on automation, but trust can also increase again if system reliability improves. Consistent with this, some diary study participants indicated that they had not followed erroneous system-generated route guidance instructions because they had received poor guidance from their systems when driving through the same or similar areas in the past.

Compared to IVNS user survey respondents, a similar proportion of diary study participants thought that access to quickly executed destination entry features (i.e. by POI and stored location) and other IVNS functions (i.e. change volume and change view) should be allowed while driving, and a similar proportion thought no form of system interaction should be allowed while driving. The IVNS user survey did not collect enough extra information to speculate further about the reasons for the discrepancy between drivers' attitudes and their behaviour, but the detailed qualitative accounts of situations in which diary study participants had interacted with their systems during the 2 weeks provided some insight for this particular sample. For example, one participant who indicated that only quickly executable in-motion interactive tasks (e.g. change volume) should be allowed while driving and another who thought no forms of system interaction should be allowed while driving, manually interacted with their systems during the diary study, the former even entered a destination while driving. In each case there were mitigating circumstances (e.g. system malfunction, interactive task performed in heavy traffic), but nevertheless these diary entries show that there are sometimes unusual circumstances when even for these IVNS users, this behaviour appears justified (although the diary extract suggested that the participant who entered a destination while driving was not comfortable behaving this way but felt he had little choice in the prevailing circumstances). These findings suggest that the extent to which this sample manually interacted with their systems while driving may be somewhat situation specific, depending greatly on the prevailing circumstances at the time rather than a general propensity to interact with IVNS while driving.

At first glance, and in light of the findings of the driving simulator study reported in chapter 7 as well as previous studies reported in the literature which have shown that destination entry while driving can degrade driving performance/safety (e.g. Tijerina et al., 1998; 2000), the high proportions of IVNS user survey respondents and diary study participants who thought that every form of system interaction listed (including destination entry tasks), should be allowed while driving is great cause for concern. However, although differences between the IVNS user survey and the diary study preclude the ability to generalize between these samples with any confidence (e.g. the diary study specifically recruited worker drivers who mainly travel in unfamiliar areas), only a minority of drivers in the IVNS user survey indicated that they enter destinations while driving frequently (5%). Similarly the detailed qualitative accounts provided by diary study participants show that these attitudes in favour of allowing destination entry while driving, did not necessarily result in the degree of irresponsible driving behaviour that might have been expected. Table 5.3 shows that relative to other, more menial forms of system interaction performed while driving, participants rarely entered destinations. Also, although there were some notable exceptions (e.g. three participants took approximately two minutes to complete destination entry tasks, and one of these participants indicated that he found this task particularly distracting), table 5.3 shows that most participants favoured destination entry by stored location, point of interest or postcode, and as a result most instances of destination entry while driving entailed minimal keystrokes (<10) and some took only a short time (<=15 seconds) to complete.

A further important observation from the contextual information that diary study participants provided was that they rarely entered final destinations while driving and whole routes were rarely planned while driving. Most participants indicated that they performed these tasks in their vehicle before setting off or even before entering their vehicle or embarking upon their journeys. The majority of destination entry tasks illustrated in table 5.3 were performed while driving so that participants could obtain guidance to intermediary destinations along the way to satisfy prevailing moment to moment demands (e.g. hunger, fuel etc.) or because participants faced traffic congestion along their current route.

Finally, a particularly important diary study finding with regards to the remainder of this thesis was that participants rarely acknowledged that interactive tasks they performed while driving had caused **them** any distraction, degraded **their** driving performance or compromised **their** safety in any way, even though it was clear from many of the qualitative accounts that participants were aware that interactive tasks performed while driving can be detrimental in these ways. For example, several participants described attempts made to minimize the distraction caused by interactive tasks performed while driving and many were clearly aware of the differential impact of various interactive functions (e.g. scrolling, dragging etc.) on distraction, safety and performance. Yet participants rarely acknowledged that they had been distracted or that their driving performance or safety had been compromised in any way when they interacted with their systems while driving. The discussion in chapter five showed that it was impossible to confirm or deny participants' subjective perceptions because no additional objective measures were collected, but that this was also consistent with previous research concerning an optimism bias – a robust finding where drivers typically rate themselves as better, safer and more skilful than average drivers.

Clearly both the IVNS user survey and the diary study have addressed this phase of the second thesis aim. The large sample size obtained in the IVNS user survey, together with the rich qualitative accounts that emerged from the diary extracts have enabled detailed quantitative and qualitative exploration of many of the contexts in which these safety-negative behavioural adaptations to IVNS have occurred.

9.2.3.2 Individual differences

Are they any significant individual difference variates in drivers' experiences of safety-negative behavioural adaptation to IVNS?

To complete the second thesis aim the studies reported in chapters 4 and 5 also identified several individual difference variates significantly associated with participants' experiences of safety-negative behavioural adaptation to IVNS. Due to the large sample size achieved in the IVNS user survey, it was possible to identify stable demographic trends within a large and diverse IVNS user population. The primary focus of the diary study was to collect rich and detailed qualitative accounts concerning the varied contexts in which behavioural adaptation to IVNS occurs (see above). However, in an attempt to both replicate demographic trends identified in the IVNS user survey and to explore further individual difference variates in drivers' experiences of behavioural adaptation to IVNS beyond demographic data alone, the diary study also collected and analysed relevant participant demographic variables as well as other quantitative data from several relevant scales in the literature. As it was necessary to financially reimburse participants for recording diary entries over two weeks and because the project had a limited budget, the sample size was severely restricted. This represents a major limitation with these quantitative analyses as the low sample size severely restricted their statistical power. Therefore these quantitative findings were meant only as an initial starting point in understanding further individual differences in drivers' experiences of behavioural adaptation to IVNS upon which future research employing much large sample sizes could be based.

The driver survey reported in chapter 3 highlighted several interesting significant associations between responses to section 2 items and a range of driver and IVNS user characteristics, suggesting that in addition to IVNS usage, a whole range of other factors were also associated with the frequency with which IVNS users engaged in the various driving behaviours reported. Although these findings did illustrate a significant association between annual mileage and the frequency with which IVNS users reported driving with only half an eye on the road while looking at a map or navigation system display, they did not in general address the second aim of the thesis as this concerned identifying individual differences in drivers' experiences of safety-negative behavioural adaptation to IVNS only. Nevertheless due to the range of significant associations identified, the driver survey demonstrated the importance of also examining individual difference variates when considering behavioural adaptation to IVNS.

In addition to collecting much more data concerning safety-negative behavioural adaptation to IVNS, a further advantage of the IVNS user survey over the driver survey was that it mainly collected ratio level participant demographic data. This meant that powerful, parametric analyses could be used to identify the importance of several individual difference variables (e.g. driver age, driving experience, self-rated computing skill) in understanding drivers' experiences of behavioural adaptation to IVNS.

The IVNS user survey showed that those respondents who had entered destinations while driving were significantly younger, were significantly more experienced drivers[1] and rated themselves as significantly more skilled at using computers than those who had never previously entered destinations while driving. Furthermore, there were also significant positive correlations between each of these variables and the frequency with which drivers reported entering destinations while driving[2]. Interestingly, despite the small sample size the diary study replicated these age effects, but also showed that those participants who had entered destinations and/or manually interacted with their systems while driving during the diary study, had held their driving licenses for significantly less time than those who had not behaved in these ways. However, the diary study did not identify any differences between these groups of drivers in relation to self-rated computing skill.

As shown above, in exploring system interaction while driving, this thesis also considered drivers' thoughts about behaviours that *should* be allowed while driving. The IVNS user survey analyses showed that those respondents who thought that drivers should be allowed to enter destinations while driving and engage in other forms of system interaction while driving were also significantly younger, had held their driving licenses for significantly less time, were significantly more experienced drivers (following the Rothengatter et al., 1993 classification scheme shown in appendix AK) and rated themselves as significantly more experienced at using computers than those who thought drivers should not be allowed to interact with their systems in these ways while driving. Additionally, compared to those participants who thought no forms of destination entry should be allowed while driving, those who thought some should be allowed reported using their system actively even while driving in familiar areas significantly more frequently. In the previous section in this chapter the discussion showed that far more participants advocated allowing access to quickly executed destination entry functions and other forms

[1] Following the Rothengatter et al (1993) classification scheme which determines driving experience based on approximate mileage over the past 12 months and five years as well as the length of time drivers have held a full driving license (see appendix AK).

[2] Please note the significant correlation concerning self-rated computing skill was actually negative but this was because a reverse response format was used for computing skill which ranged from expert to no skills (see appendix F).

of system interaction while driving, than more complex forms of system interaction. Further analyses also showed that of those respondents who thought some form of destination entry should be allowed while driving, those who advocated access to quick and easily executed destination entry functions only had also driven significantly further in both the past 12 months and the past 5 years.

The discussions in chapters 4 and 5 showed that these findings, particularly those concerning both age and computing skill were consistent with findings from other studies reported elsewhere in the literature and later in this thesis. Concerning age, several previous studies have identified significant associations between [young] age and speeding as well as engagement in a range of other risky driving behaviours (e.g. Zhang et al., 1998; Aberg and Rimmo, 1998; Blockey and Hartley, 1995; Parker et al., 1995; Simon and Corbett, 1996). The discussion also showed how these age effects are consistent with the behavioural compensation literature, as several studies have indicated that older drivers compensate for deficiencies in perceptual, cognitive and motor skills (due to age-related declines in these abilities) by taking fewer driving risks such as less frequent engagement in distracted driving (Hakamies-Blomqvist, 1994; Holland and Rabbit, 1992; Simms, 1992, 1993; Rackoff, 1974).

The discussions in chapter 4 also explained how it was likely that skilled computer users have greater familiarity with data entry procedures (e.g. using QWERTY format keyboards) as well as in retrieving and interpreting information from visual displays (Ho et al., 2005). Svahn (2004) also reported a significant negative correlation between "*reduced awareness at system interaction*" and participants' self-rated computing skill. As these early thesis chapters demonstrated the relevance of computing skill to this form of behavioural adaptation to IVNS, participants in the later driving simulator studies were also asked to indicate how skilled they were at using computers and to estimate the number of years they have been using a computer for. Consistent with both Svahn (2004) and Ho et al. (2005) table 7.3 in chapter 7 shows that these variables were significantly associated with improved lateral driving performance measures when participants entered destinations while driving. The discussion in chapter 7 suggested the possibility that drivers skilled at using computers entered destinations while driving significantly more frequently than those less skilled because they are more likely to be able to perform this task safely. These findings also lend support to the design of computer-based training (i.e.

mitigation) intervention strategies like that used in the final simulator study reported in chapter 8, as a valid method of reducing the potential risks of entering destinations while driving.

The IVNS user survey also highlighted significant associations between demographic individual difference variables and the tendency for some drivers to have followed inaccurate and sometimes even dangerous or illegal system-generated route guidance instructions. In this case the analyses indicated that those who have followed such erroneous route guidance instructions were significantly older and had held their driving licenses for significantly longer than those who had received them but not followed them, indeed nearly three quarters of these participants were over the age of forty. Despite the smaller sample size, both these effects were also replicated in the diary study. This study also showed that those participants who had followed erroneous system-generated route guidance instructions either during the study or before the study began also considered themselves significantly less skilled at using computers than those who had received, but not followed these instructions at these times.

Furthermore, in the diary study, significant differences were also observed between these groups of participants in relation to their responses to the various scales that were employed. Specifically the analyses showed that those who had followed erroneous system-generated route guidance instructions either during the study or before the study began were significantly less confident drivers and had a significantly higher potential for complacency than those who had received but not followed them at these times. There were no significant differences between these groups in relation to their overall trust and distrust in automation scores, but individual item analyses for these scales showed that those who had followed erroneous system-generated route guidance instructions were significantly less wary of routing information they usually receive from their IVNS and considered their systems to be significantly less reliable than those who had received but not followed these route guidance instructions.

The previous section in this chapter explained how diary study participants' qualitative accounts of some of the contexts in which they had followed inaccurate route guidance instructions sometimes indicated that they had followed them despite being fully aware they were doing so. Clearly it is unlikely that these specific situations could be explained solely in terms of trust and complacency potential, but the above findings do suggest that in general, it would be useful for future research concerning this form of behavioural adaptation to IVNS to examine these issues more closely. The previous section explained how most of the qualitative accounts of situations in which diary study participants had followed inaccurate route guidance instructions implicated trust-based explanations for this behaviour much more frequently than attentional or perceptual explanations. Similarly, these quantitative analyses reported significant findings for trust and complacency scales only. The discussion in chapter 5 noted that although only subjective self-report measures of attention/perception were employed in the diary study, it would be useful for future studies to employ objective measures of attention and perception/visual acuity. Although the limited sample size and low statistical power of quantitative analyses in the diary study restrict the ability to draw any firm conclusions from these results in isolation, these findings did help to further address this phase of the second thesis aim by identifying individual difference variates in drivers' experiences of this form of behavioural adaptation beyond demographic data alone.

The discussions in chapters 4 and 5 showed how the age effects reported in both studies were consistent with both attentional/perceptual and trust/complacency based explanations for this phenomenon as increasing age has previously been linked to impaired performance on tasks of selective, sustained and divided attention as well as visual acuity. Associations between increasing age and over-trust in automation and complacency were also discussed in detail. Ho et al. (2005) suggested that age-related cognitive deficits in attention-allocation, working memory, mental workload, decision-making and interpreting stochastic information may reduce self-confidence in manual performance. Additionally some studies have indicated that older drivers are more likely to trust automated vehicle systems than their younger counterparts (Sanchez, Fisk and Rogers, 2004; Fox and Boehm-Davies, 1998).

Clearly detailed investigation of all these individual difference variates was necessary to have adequately explored driver behavioural adaptation to IVNS and therefore, to have addressed this phase of the second thesis aim. These findings have shown which drivers are most likely to experience these behavioural adaptations and they have also highlighted several potential areas of explanation for them that should be further addressed in future research. They could also contribute to the design of targeted remediation or mitigation intervention strategies. For example, in the later chapters of this thesis younger drivers were specifically targeted for intervention strategies as the research reported in this thesis has demonstrated that these drivers enter destinations while driving more frequently than their older counterparts. Similarly, based on other findings reported in this thesis, it would also be advisable for any future intervention strategies designed to prevent drivers from following inaccurate system-generated route guidance instructions to target older drivers specifically.

At the start of this chapter, the discussion summarised Michon`s (1985) hierarchical model of driving behaviour. It showed how Hatakka et al`s (1999) GADGET matrix provides a valuable extension to this model by including a further level above the strategic level concerning driver characteristics called *"goals for life and skills for living"*. As shown, Hatakka et al (1999) proposed that these driver characteristics can influence driving behaviour at lower levels, as they define how the driver functions as a person and this can affect how they solve tasks at the strategic level. Hatakka et al. (1999) suggested several driver characteristics that should be included in this level including demographic variables (e.g. age, gender, group identification) as well as other personality and motivational variables (e.g. sensation seeking, locus of control). While it is acknowledged that this model concerns driver behaviour not behavioural adaptation, it is noteworthy that by addressing the second aim, this thesis has identified a range of significant associations between several driver characteristics (e.g. age, driving experience and computing skill) and safety-negative behavioural adaptations to IVNS that occur at the strategic and tactical levels of driving behaviour. Clearly these findings are consistent with Hatakka et al`s (1999) extended model. The literature review explained that this thesis did not purport to evaluate, update, utilise nor propose any particular model of behavioural adaptation to IVNS. Nevertheless these findings suggest that Hatakka et al`s (1999) extended model might serve as a useful framework upon which to model behavioural adaptations to IVNS in future research.

9.2.4 Aim three

The final aim of the thesis comprised three phases: selection of a prevalent safety-negative form of behavioural adaptation for further study, understanding some of the reasons why some drivers behave this way and suggesting recommendations to inform the design of future potential remediation or mitigation intervention strategies.

9.2.4.1 Selection

Which type of safety-negative behavioural adaptation to IVNS should be selected for further study to address the final thesis aim?

Chapter 6 outlined the main reasons why system interaction while driving was selected for further study in the remainder of this thesis. This chapter stressed the importance of selecting a form of behavioural adaptation that would remain a salient issue for some time. It showed how several forms of behavioural adaptation to IVNS identified and explored in previous chapters were linked to limitations of contemporary systems and explained that due to recent and ongoing developments in the wider IVNS industry, some behavioural adaptation issues identified in this thesis may over time become much less serious.

This chapter has already mentioned that an obvious pre-requisite for drivers to follow inaccurate route guidance instructions is that they must first have received them. Chapter 6 noted that since the reliability of IVNS maps have been questioned in the media and elsewhere, the industry has taken several steps to improve the quality and reliability of system maps. Until very recently, IVNS users had to pay for map updates, but the IVNS user survey and the diary study indicated that some drivers considered these updates to be prohibitively expensive and many drivers reported that they had not updated their system maps. Chapter 6 also reported that recently several IVNS manufacturers have announced that they will no longer charge customers for map updates, so over time this may improve the quality of route guidance advice that IVNS users receive from their systems. However, the IVNS user survey and the diary study also showed that a significant proportion of respondents who had updated their system maps had still received poor route guidance information. The discussion noted that there was clearly still room for improvement in the quality of the underlying map data. Chapter 6 also outlined a recent development from TOMTOM (a popular IVNS manufacturer) called Mapshare, where subscribers can modify their own maps if they observe any discrepancies while driving. Innovatively, they can also share their corrections with other Mapshare subscribers and download any modifications proposed by other users using a personal computer connected to the internet. The discussion in chapter 6 showed that over time this should drastically improve the quality of these system maps, and therefore of IVNS route guidance instructions that are based on them. Several diary study participants with HGV and LGV driving licenses also reported that they had received and/or followed inaccurate system-generated route guidance instructions, guiding them along routes for which their vehicle dimensions (i.e. width, height, length and/or weight) were unsuitable or otherwise inappropriate. However, chapter 6 reported an increasing range of IVNS presently available to drivers which now use routing algorithms that are sensitive to the needs of HGV and LGV drivers. Chapter 6 concluded that due to these recent developments in system design, the frequency with which drivers receive inaccurate route guidance instructions will probably decrease over time, and in turn so will the frequency with which some drivers actually follow inaccurate route guidance instructions. These developments could even plausibly negate the need for future intervention strategies to prevent drivers from behaving this way or reduce the potential risks if they do.

Chapter 6 went on to explain that further developments in system design are also available or presently in development which designers and manufacturers hope might also one day prevent drivers from interacting with their IVNS while driving (e.g. integrating IVNS with other vehicle systems so they can determine when the vehicle is in motion, development of workload management and driver monitoring systems) or reduce the risks of behaving this way (e.g. development of novel user interfaces). However, the discussion showed that relative to integrated systems which have much more scope to limit system interaction while driving, nomadic systems and other portable after-market systems which typically do not restrict these functions while the vehicle is in motion are significantly more popular among drivers today. Although other factors such as [low] cost undoubtedly also play a role in the popularity of these systems, it is clear from their widespread adoption by most drivers that unrestricted access to these functions while the vehicle is in motion is by far the most popular option. Since system design is largely driven by consumer demand, it is likely that to survive in such a competitive market place, most IVNS manufacturers will be reluctant to completely restrict system interaction while driving completely in the most popular models, particularly since system interaction while driving is not yet banned outright in the UK and because IVNS users can also legitimately claim that passengers should be allowed unrestricted access to interactive functions while the vehicle is in motion. Chapter 6 also showed that it is a relatively simple matter for modern drivers with only basic experience at using the internet to discover methods for circumventing safety protocols should they be added to the design of contemporary or future IVNS models. Moreover, even if the present legal situation concerning system interaction while driving changes over the next few years in the UK, chapter 6 cited several studies which have documented the prevalence which many drivers today use hand-held mobile phones while driving, drive while intoxicated, disobey speed limits and do not adhere to other traffic laws, so it is unlikely that changes in the traffic law alone would completely eradicate this form of behavioural adaptation to IVNS. According to Llaneras (2000) a further difficulty with legislative solutions concerning engagement in distracted driving is that they are also notoriously difficult to enforce.

System interaction while driving was therefore selected as the most appropriate issue for further study to address the final aim of the thesis for the above reasons and also because of serious concerns about the validity of a pilot study designed to investigate the appropriateness of studying the tendency for some drivers to have followed inaccurate route guidance instructions in a driving simulator.

9.2.4.2 Understanding

How does system interaction while driving affect driving performance, and why might some drivers behave this way?

The literature review outlined several previous studies which demonstrated that manual destination entry can degrade driving performance. It also showed while vocal destination entry while driving can also degrade driving performance, though typically to a lesser extent. However, the previous sections showed that when diary study participants manually interacted with their systems while driving, they rarely acknowledged that this behaviour was associated with any declines in driving performance or safety, even though they were sometimes aware that driving safety/performance can be degraded when other drivers behave this way. Consistent with this evidence, some authors (e.g. Horrey, Lesch and Garabet, 2007; Wolgater and Mayhorn, 2005) have proposed that drivers may engage in distracted driving simply because they are unaware this behaviour can be dangerous. Chapter 7 cited several studies which have shown that younger drivers (i.e. those shown by this thesis to most frequently interact with their systems while driving) are also more likely to be miscalibrated about their own driving skills than their older counterparts. The penultimate study in this thesis was designed to determine the accuracy of young IVNS users' subjective ratings of the safety and performance effects of destination entry while driving. Consistent with previous research (e.g. Tijerina et al., 2000; 1998), this study showed that destination entry while driving was associated with degraded performance in longitudinal and lateral vehicle control measures. Furthermore, it demonstrated that young drivers' subjective ratings of the longitudinal and lateral performance effects of destination entry while driving were poorly aligned with objective measures of these parameters. Interestingly however, contrary to some previous research concerning younger drivers, the analyses also indicated that participants were not particularly over-confident in their lateral driving performance when they entered destinations while driving, relative to normal driving on the same stretch of road.

9.2.4.3 Intervention recommendations

What future strategies might prevent drivers from entering destinations while driving or reduce the potential risks of this behaviour?

The discussions in chapter 7 noted that the main findings concerning the misalignment of subjective performance ratings were consistent with Wolgater and Mayhorn`s (2005) hypothesis that some drivers might engage in distracted driving simply because they are unaware this behaviour can be dangerous. The discussion went on to illustrate potential incarnations of future intervention strategies to prevent drivers from entering destinations while driving (i.e. remediation) or reduce the risks of behaving this way (i.e. mitigation). Following on from the chapter 6 discussion in even more detail, it showed that system design considerations or legislative developments are unlikely to be anywhere near as effective in remediating or mitigating system interaction while driving as education and/or training based intervention strategies.

The potential effectiveness of insight training as a remediation intervention strategy was discussed in detail. Consistent with Wolgater and Mayhorn`s (2005) hypothesis outlined above, the principle behind insight training would be to show young drivers that destination entry while driving can degrade driving performance and safety, even if drivers are unaware of such negative performance effects of this behaviour.

The discussion in chapter 7 noted that although remediation oriented interventions would clearly be the preferred strategy there is mixed evidence concerning their potential effectiveness. It showed that in other domains outside of traffic psychology, in which researchers have attempted to address engagement in other high risk, driving unrelated individual behaviours such as drug taking and teenage pregnancies, mitigation strateiges (typically referred to in this context as harm-minimisation or harm-reduction strategies) have successfully been used in conjunction with remediation strategies to help reduce some of the problems or difficulties associated with individual engagement in risky behaviours. Citing Marlatt (2002) the discussion showed that similar strategies could also be usefully employed to address engagement in high risk driving behaviours, such as driving while distracted.

Previous studies in this thesis had already shown that drivers skilled at using computers enter destinations while driving significantly more frequently than those less skilled at using computers, and the driving simulator study reported in chapter 7 also showed that computing skill/experience was associated with increased control over lateral driving performance measures. Previous discussions in this thesis had already noted that this was probably because skilled computer users were more familiar with modern technological interface characteristics. These findings suggested that an intervention strategy in which young drivers receive training in computer/typing tasks may help to improve driving performance when/if they decide to enter destinations or engage in other forms of system interaction while driving. The potential for such a mitigation strategy to also teach young drivers techniques to minimize distraction and maximize driving performance/safety when performing such interactive tasks while driving was also discussed.

The discussions in chapter 7 showed how the design of such remediation and mitigation education/training based intervention strategies were also consistent with several key issues recommended by an NHTSA (2000) expert panel concerning the design of potential future education and training based intervention strategies to address distracted driving. Those recommendations consistent with using a form of insight training to remediate this form of behavioural adaptation were:

- There may be public confusion over safe behaviours in using devices
- It is important to find out the baseline level of knowledge the public has about risk, and find out what they believe they know. Knowledge gaps can be closed through education

- What you think drives what you do, unrelated to what you know. Focus in on what people think

Similarly, those NHTSA (2000) recommendations consistent with the design of potential mitigating intervention strategies as suggested in this thesis were:

- Programs that change unsafe behaviours need to be developed
- Promote the safe use of electronic devices as an alternative to bans

The final study in this thesis was reported in chapter 8. It was a driving simulator study designed to evaluate the effectiveness of the remediation (i.e. insight training) and mitigation (i.e. computer-based dual-task training) intervention strategies outlined briefly above and in much more detail in the chapter 7 discussion. Specifically it aimed to examine the effects of a remediation strategy on the frequency with which drivers subsequently enter destinations while driving, the effects of a mitigation strategy on subsequent destination entry time, driving performance measures when destinations are entered while driving and the use of any strategies employed by participants to minimize distraction and maximize driving performance/safety, as well as the effects of a combined remediation and mitigation intervention strategy on these driving behaviours. In a driving simulator study with a between-groups design, participants were observed and dependent measures were collected when participants tried to reach four unfamiliar destinations in simulated urban environments. They were given time limits within which to reach each destination, and in an attempt to replicate motivations drivers would usually experience when navigating to an unfamiliar destination, participants were told they would receive a small monetary reward each time they reached a destination within the specified time limit. In the diary study, although participants sometimes entered final destinations while driving, they rarely entered final destinations while driving, but much more frequently entered destinations while driving to satisfy intermediary demands (e.g. hunger, fuel) along their route based on prevailing circumstances. So in this final simulator study the effects of the intervention strategies on both scenarios were investigated (i.e. when drivers received destination information before setting off, and during their journey). Finally, for several reasons exactly the same sample of participants who took part in the previous study were recruited to participate in this final study. This was partly because all participants had received an equal amount of simulator and destination entry experience using this particular IVNS, and partly due to financial constraints, but the most important reason for using the same sample in this study was that the objective standardised scales that were developed in the previous study and which fundamentally affected the design of the intervention strategies employed in this study, were based on the performance statistics of this specific sample of young drivers. The discussion in chapter 7 explained that this could lead to problems in generalizing the results of the study reported in chapter 7 to the wider driving population, as the standardization was dependent upon the means and standard deviations of the specific population tested.

Overall the final driving simulator study reported few significant effects. The analyses revealed that the remediation intervention significantly affected the frequency with which participants subsequently entered destinations while driving in the first scenario (i.e. when participants were aware of destination information before setting off) and the mitigation intervention significantly affected subsequent destination entry duration in the first scenario. However, the mitigation strategy did not significantly affect subsequent longitudinal and lateral measures of driving performance when participants entered destinations while driving or engagement in strategies employed to minimize distraction and maximize driving performance/safety (e.g. chunking).

Overall the findings from the final simulator study reported in chapter 8 were consistent with Wolgater and Mayhorn`s (2005) hypothesis as simply informing and showing participants that entering destinations while driving can be dangerous did significantly affect the frequency with which they subsequently entered destinations while driving in the first scenario (i.e. when participants received destination information before setting off). The mitigation strategy however was less effective as it did not directly appear to directly affect the risks of behaving this way, although shorter duration destination entry tasks could reasonably be expected to improve driving performance due to reduced eyes off road time.

However, the discussion in chapter 8 described several limitations with this final simulator study that should be addressed in future studies evaluating the effectiveness of the proposed recommendations before they can definitively be either adopted or discarded. Regarding the remediation intervention strategy, the main limitations that were discussed concerned some of the difficulties associated with using driving simulators to examine the effects of a remediating intervention on the frequency with which drivers subsequently enter destinations while driving due to safety and legal concerns that can never be adequately replicated in a simulator, as well as the plausibility that participants' decisions to enter fewer destinations while driving were also caused by demand characteristics (i.e. it may have been quite obvious to participants they this study was designed to examine willingness to engage following the remediation intervention and they may therefore have behaved the way they thought the experimenter wanted them to behave in order to be "good participants" – see Orne, 1962).

Regarding the mitigation intervention strategy, the main limitations that were discussed included the efficacy of examining training effectiveness using only a single training session, the potential lack of transparency in the strategies that participants were taught to minimise distraction and maximise driving performance/safety and the lack of longitudinal and lateral driving performance measures employed that could have provided valuable insight about the degree of control that participants were able to exercise (i.e. this study only collected absolute driving performance measures such as number of lane deviations or speed exceedences, but neglected other more precise measures such as the standard deviations of lateral and longitudinal dependent measures).

The discussions indicated a need for further research to examine the effectiveness of these intervention recommendations using more naturalistic methodologies and possibly by conducting longitudinal studies in which participants receive multiple training sessions.

9.3 Future work

This thesis has identified a diverse range of behavioural adaptations to IVNS that could occur, and do occur, among a rapidly increasing proportion of drivers who are presently embracing IVNS. Consequently, it provides the basis for several relevant future studies to further and more widely investigate many of the issues raised. Some of these possibilities are described in more detail below.

Further research, extending studies already reported in the thesis could be also particularly beneficial. Although the surveys attracted adequate sample sizes, female IVNS users were repeatedly under-represented in the samples, despite several attempts to recruit them. Future studies should employ different sampling methodologies to better reach this demographic. For example, forming partnerships with large organisations such as OEM or vehicle manufacturers, insurance companies, as well as government and other traffic and road safety institutions (e.g. DVLA, DSA, ROSPA, TRL, NHTSA) could enable researchers to access databases of several thousand drivers and IVNS users. It is likely that this methodology would provide a more representative sample of IVNS users, without the possibility of biases introduced by self-selection and the internet sampling methodology in general. Such an approach may therefore attract a higher proportion of female IVNS users. Gender issues were largely neglected in the thesis, due to the small number of female respondents and participants, but there are several reasons to expect strong associations between gender and behavioural adaptation to IVNS. For example, research has consistently demonstrated a tendency for young males to take more driving risks, commit more driving violations and to be involved in more driving accidents than young female drivers. Gender should therefore be an important consideration for future work in this area.

Future studies, with greater available resources could also vastly increase the scope, reach and reliability of the diary study. A fundamental limitation was that it relied entirely on self-reported driving behaviour. Particularly in relation to system interaction while driving, it was impossible to objectively verify the accuracy of participants' assessments of the situations they encountered, as well as the driving performance and safety effects of interactive IVNS tasks, performed while driving. It would be beneficial for future research to employ a diary study methodology in conjunction with other more objective methods, such as in-vehicle recording equipment, to allow researchers to more accurately assess the driving situations encountered by participants, as well as the various manifestations of behavioural adaptation to IVNS that do occur. The methodology employed by a recent naturalistic study which collected a high volume of data concerning driving habits of a large sample of drivers, would be particularly suited to this kind of investigation. In the 100-car study, Dingus et al (2006) placed recording equipment, sensors and other data collection equipment in 100-vehicles for a one year period. They amassed an extensive database of driving behaviours, associated with crash/accident risk, such as willingness to engage in secondary tasks, risk taking, aggressive driving, traffic violations, impairment and error. They didn't specifically target IVNS users or behavioural adaptation, but did implicate use of wireless devices in crashes and near-misses. This methodology, in conjunction with a diary study, could provide extensive qualitative and quantitative data concerning behavioural adaptation to IVNS, and could accurately determine the degree of correspondence between subjective experiences and more objective measures of these parameters. An extensive study like this, could also amass a substantial database, to allow several future papers to report a variety of independent analyses of varied aspects of this data for many years to come.

Despite technological advances that should over time, drastically improve the accuracy and reliability of IVNS electronic maps, future studies should employ much larger sample sizes to identify further, stable individual differences in the frequency with which drivers follow inaccurate system-generated route guidance instructions. Further replication of complacency and trust-based findings, could potentially inform the design of future targeted remediating intervention or system design strategies to more appropriately calibrate system trust. Depending on a range of system-specific factors, many automated systems can also vary substantially in reliability. Some studies in the wider human factors and aviation literature, have demonstrated the utility of providing operators with feedback on varying levels of uncertainty about the support provided by automation (Amar et al, 1995; Selcon, 1990; Williamson and Williamson, 1995; Kirschenbaum and Arruda 1994, Banbury et al 1998). It may be possible to incorporate uncertainty information into system design, where, for example, feedback is provided to drivers about the potential unreliability of different map regions, based on the length of time since these regions were last recorded or revised by survey teams, traffic reports, accident/congestion hotspots etc.

As only those behavioural adaptations that could potentially, adversely affect driving safety were selected for greater consideration in this thesis, several other interesting aspects of behavioural adaptation, that didn't meet these criteria, were not further explored. The first two studies identified several behavioural adaptations that appeared to have positive effects on both driving safety and navigational efficiency. Although the importance of developing means to remediate or mitigate behavioural adaptation that could negatively affect driving safety is clear, it is undoubtedly also important, to support and encourage the diverse range of other manifestations of behavioural adaptation to IVNS also identified in the thesis.

The diary study highlighted a variety of other possible strategic and tactical level behavioural adaptations to system characteristics such as faults, unreliability, inefficiency, inaccuracy, and display modality, as well as several strategic attempts to minimise distraction, and novel applications of extra system functions (e.g. timing/distance information). The approach taken by this thesis has been to identify behavioural adaptation themes common to a diverse range of IVNS users, and further explore some of these using smaller more focused studies. However, clearly, there are also several individual behavioural adaptation nuances specific to smaller groups of IVNS users or even individual drivers. It would be worthwhile for future research to investigate these strategies using focused case study approaches, as it may be possible to identify further design improvements to eliminate or reduce the extent to which drivers must develop novel compensatory strategies. This line of research could also inform design by illustrating extra IVNS functions most useful to drivers. Those that are beneficial or most frequently used, could be developed further based on user preferences (e.g. IVNS that email time and mileage information directly to employers), and those less useful could be removed, or buried deeper within the hierarchy of menu options.

Both surveys reported in this thesis demonstrated high system acceptance and satisfaction, and illustrated the varied ways in which IVNS were used by drivers in familiar and unfamiliar areas. They showed that many users were more confident driving in unfamiliar areas since acquiring an IVNS, got lost less frequently and worried less about this; and made fewer navigational, tactical level, driving errors than ordinary drivers. A consistent proportion of IVNS users in both surveys also reported greater exploration of unfamiliar areas. Future work should examine the characteristics of these drivers in more detail. Demographic factors, such as occupation, age and gender, could potentially influence IVNS-mediated exploration of unfamiliar areas. However, several other individual difference variables which have been implicated in this, and previous behavioural adaptation research, such as locus of control, sensation seeking, trust/reliance, self confidence (in terms of both driving and navigational ability) could also play a role. This thesis already illustrated the potential role of trust in behavioural adaptation to IVNS, but has insufficiently considered interactions between trust and other attitudinal and behavioural variables.

Section 9.2.3.2 in this chapter described how the significant associations identified in this thesis between several individual difference variables and drivers' experiences of safety-negative behavioural adaptation to IVNS were consistent with Hatakka et al`s (1999) GADGET matrix which extended

Michon`s (1985) hierarchical model to illustrate the relevance of driver characteristics to engagement in strategic and tactical level driving behaviours. According to Keskinen (2007) the GADGET matrix has achieved the highest honour for any model of driving behaviour, as it is used as the basis for formal driver education and training in Norway, Sweden and Finland. In addition to more traditional formal training methods designed to improve control, tactical and strategic level driving skills, novice drivers are also informed that several driver characteristics can affect their driving behaviour and are taught strategies so that they can recognise these characteristics in themselves. Perhaps such training programmes could be modified so that novice IVNS users can be taught to recognise that behavioural adaptation to these systems can and does occur, so based on self identification and evaluation of driver characteristics they can learn to recognise behavioural adaptations most likely to affect themselves in particular.

In addition to the individual driver benefits of increased navigational efficiency, widespread implementation of IVNS technology has often been purported to offer significantly improved efficiency of overall traffic networks. From a wider societal perspective, it is particularly important to understand the factors that motivate drivers to fully utilise navigational features, and use them to inform frequent unfamiliar route choices, as it is likely that if high volumes of drivers were frequently prepared to deviate from familiar routes, this would optimise the efficiency of the overall traffic network. It would also be interesting for future research in other disciplines (e.g. sociology, town planning) to further examine the effects of IVNS on drivers' exploration of unfamiliar areas. It is likely that what appear to be positive indications of behavioural adaptation in terms of navigational efficiency, may actually be perceived negatively in other contexts (e.g. the small rural villages, which due to IVNS routing algorithms, have seen increasing volumes of traffic diverted through them).

Future research should also use the final two studies in the thesis, as informative pilots for further naturalistic research. Such studies would concern the development and evaluation, of potential remediating or mitigating interventions, for safety-negative behavioural adaptations to IVNS. Due to the potential size and detail of a behavioural adaptation database that could be amassed from a medium to large-scale longitudinal naturalistic study, it is likely that this much of this data could inform the design of additional targeted remediating and mitigating interventions unidentified in even in this thesis, for a range of safety-negative behavioural adaptations to IVNS including system interaction while driving and over-reliance. The final studies in the thesis described some recommendations for the design of potential interventions to provide drivers with insight about their objective driving performance during destination entry tasks, but it is likely that future, naturalistic approaches could further inform their design, beyond insight training alone. The final study in the thesis has also demonstrated that naturalistic intervention evaluations should probably be conducted in the long-term, and that training-based interventions designed to mitigate behavioural adaptations should probably take place over multiple sessions.

9.4 Final statement

All three aims of the thesis have been sufficiently addressed. This thesis represents the first attempt in the literature, to bring together research from diverse areas of human factors and traffic psychology to consider behavioural adaptation to in-vehicle navigation systems. By associating a range of these issues with behavioural adaptation to IVNS, it has indirectly increased the scope of several salient, previous research findings. Moreover, by investigating many of these issues in depth, using both quantitative and qualitative methodological approaches, it has set the several foundations for future work. Such work should aim to explore many of the issues raised, in order to inform the design and development of additional, effective remediating or mitigating intervention strategies for behavioural adaptations that could adversely affect driving safety.

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Appendix A – Driver survey pilot

Introduction

Prior to publishing the driver survey online and advertising the study, all items were piloted using a sample of 10 drivers. The pilot study was run to ensure that participants could understand the meaning and purpose of each item, to determine the average time that participants took to complete the survey and to verify the correct functioning of the online data collection methodology. General feedback was also collected about the survey as a whole in general discussions with participants once they had completed it. However due to the small sample size, questionnaire data was not analysed and comparisons between IVNS users and ordinary drivers were not drawn.

Method

10 drivers (6 male, 4 female, mean age=33 years, SD=6.6 years) took part in the pilot. Only 3 participants were IVNS users. All participants completed the survey online, using a Firefox web-browser. However, all participants completed the pilot from the same computer, to facilitate post-study discussions.

Results

All data saved correctly to a text file in a format immediately ready for analysis. As the web form refused to allow participants to submit incomplete forms, there was no missing data. All participants completed surveys without experimenter intervention, and there was universal agreement among participants that as a whole, the survey was clear enough to be completed remotely by participants. However, they also suggested some improvements concerning content and completion time.

Content

The main comments concerning questionnaire content were:

- *There are too many questions all at once. You should think about dividing it into sections.*
- *When you ask how many thousand miles I have driven in the past 12 months, you should include the word "thousand miles" after the response box, to further clarify the format you want to receive the response in.*
- *If this is an international survey, would you be better off asking how many kilometres we have driven over the past 12 months, as few places outside UK still think in miles.*

- *When you ask about the number of unfamiliar journeys made since using a navigation system or the number of times using the navigation system, you should add a follow up question to find out if this is typical. Because I for example, have made much more unfamiliar journeys this year than I normally do, because I have changed jobs and moved to a new city.*
- *When asking about navigation system manufacturer asking for manufacturer and model number sounds far too formal. You should ask them to provide the make and model instead of their navigation system instead.*
- *It won't let you submit the form unless you have completed information concerning navigation system manufacturer and model no. I know I use a GARMIN, but I'm not sure which model, as my husband bought it. It is possible that some people won't know the either of these details. You should force it to submit the form even if this information is not known, as you wouldn't want to lose data from these people due to a technicality like this*

Completion time

Participants took an average of just over 5 minutes to complete the survey (i.e. mean = 334 seconds, SD = 32.5 seconds). In the discussions following the questionnaire, participants were asked for any suggestions they could provide to reduce the completion time.

- Six participants suggested replacing as many questions requiring typed responses as possible with multiple choice selections.
- Although participants universally agreed the length was appropriate to attract drivers, three participants suggested shortening the survey by removing some of the DBQ items.

Discussion

All the questionnaire comments concerning item content were addressed and were implemented in the final survey, with the exception of asking participants to state annual mileage in kilometres. It was important both to minimise dropout, and to increase survey attractiveness to potential respondents, that the survey could be completed as quickly as possible. To further reduce task completion time, several variables that required ratio level data were converted to ordinal level multiple responses, and some DBQ items which had little relevance to the study, were omitted.

Appendix B – internet forums used to host advertisements for the driver survey

Website	Description
http://www.pocketpcmag.com/forum/forum.asp?FORUM_ID=42	GPS pocket pc, pda forum
http://www.mtekk.com.au/forums/viewforum.php?f=33&sid=21c9d9c72f0fc5be21aba9e93226a00f	Australian GPS devices and equipment forum
http://www.allaboutsymbian.com/forum/register.php?a=act&u=54827&i=31831084	Device shop and forum board
http://www.globalpositioningsystems.co.uk/forum/index.php	GPS forum
http://www.pdastreet.com/forums/forumdisplay.php?s=&forumid=108	PDA GPS message board
http://forums.gpscity.com/	General GPS forum
http://www.mp3car.com/vbulletin/forumdisplay.php?f=24	General GPS forum
http://www.gpspassion.com/forumsen/active.asp	General GPS forum
http://www.filesaveas.co.uk/cgi-bin/forum/YaBB.pl?board=navigation	Vehicle navigation message forum
http://www.smartdevicesdirect.com/forum/forumdisplay.php?f=9	Smart devices forum inc GPS/satellite nav
http://www.easydevices.co.uk/forum/default.asp	General GPS product support from a shop
http://www.totalpda.co.uk/forum/forumdisplay.php?f=12	PDA GPS message board
http://the-gps-forum.com/	General GPS forum
http://www.uktelematicsonline.co.uk/html/message_board.html	Telematics message board
http://forums.mercedesclub.org.uk/index.php?	Mercedes benz forum
http://www.fordforum.com/default.asp	Ford drivers forum
http://www.taxi-driver.co.uk/phpBB2/viewtopic.php?p=33057&	Taxi drivers forum
http://www.seatenthusiasts.co.uk/forum/index.php	Seat drivers forum
http://community.channel4.com/6/ubb.x?a=frm&s=162603557&f=1766037851	Channel 4 general drivers forum
http://www.renaultforums.co.uk/	Renault drivers fourm
http://bbs.scoobynet.co.uk/	Subaru drivers forum
http://www.gtouk.org.uk/returnforum.html	Mitsubishi drivers forum
http://www.volvoclub.org.uk/dc/dcboard.php	Volvo drivers forum
http://www.safespeed.org.uk/forum/index.php?sid=91d6ef45edfa309b5519516684459f3c	Forum on speeding
http://www.mgcars.org.uk/news/yournews.html	MG enthusiasts

Appendix C – Driver survey data

Item	Responses	No. of participants	Percentage of participants
Are you male or female?	male	328	72.9
	female	122	27.1
How old are you?	< 20 yrs	21	4.7
	21-30 yrs	168	37.3
	31-40 yrs	103	22.9
	41-50 yrs	80	17.8
	51-60 yrs	60	13.3
	> 60 yrs	18	4
How many years have you been driving for?	< 5 yrs	71	15.8
	5-10 yrs	81	18
	11-15 yrs	74	16.4
	16-20 yrs	60	13.3
	21-25 yrs	52	11.6
	> 25 yrs	112	24.9
Approximately how many miles (to the nearest thousand) have you driven in the past 12 months?	mean	17.1	n/a
	median	12	n/a
	SD	16.08	n/a
Do you commute regularly to work?	yes	313	69.6
	no	137	30.4
Do you have an in-car navigation system?	yes	157	34.9
	no	293	65.1
Is this your first navigation system?	yes	114	72.6
	no	43	27.3
Approximately how many times in the past month have you	mean	33	n/a
	median	10	n/a

used your navigation system?	SD	18.4	n/a
Would you consider the past month typical or atypical?	typical	135	86
	atypical	22	14
Approximately how long has the system been installed?	mean	16.5	n/a
	median	14.9	n/a
	SD	36.2	n/a
Was your navigation system fitted when you bought the car?	yes	12	7.7
	no	145	92.3
Are you satisfied with you navigation system	yes	138	88%
	no	12	7.6
	not sure	7	4.4
Do you feel that owning a navigation system has made you more confident at navigating?	yes	84	53.5
	no	64	40.8
	not sure	9	5.7
Do you trust your navigation system to provide accurate route guidance information?	yes	124	79.0
	no	28	17.8
	not sure	5	3.2
Approximately how many times the the past month have you made an unfamiliar journey?	mean	19.9	n/a
	median	5	n/a
	SD	52.2	n/a
Would you consider the past month typical or atypical?	typical	127	80.9
	atypical	30	19.1
Do you use any other advanced driver support systems?	collision warning system	5	3.2
	adaptive cruise control	18	11.5
	driver monitoring system	4	2.5
	vision enhancement system	3	1.9
	lane departure warning system	3	1.9
	other	21	13.4

Section 2

Please indicate the frequency with which you have engaged in the following behaviours over the past 6

	months		
Plan your route badly so you meet traffic congestion you could have avoided	never	51	11.3
	hardly ever	185	41.1
	occasionally	181	40.2
	quite often	21	4.7
	frequently	8	1.8
	nearly all the time	4	0.9
Miss give way signs and narrowly avoid colliding with traffic having the right of way	never	240	53.3
	hardly ever	182	40.4
	occasionally	24	5.3
	quite often	4	0.9
	frequently	0	0.0
	nearly all the time	0	0.0
Drive especially close to the car in front as a signal to the driver to go faster or get out of the way	never	150	33.3
	hardly ever	127	28.2
	occasionally	118	26.2
	quite often	29	6.4
	frequently	21	4.7
	nearly all the time	5	1.1
Misjudge your crossing interval when turning right and narrowly miss collision	never	243	54.0
	hardly ever	178	39.6
	occasionally	25	5.6
	quite often	2	0.4
	frequently	1	0.2
	nearly all the time	1	0.2
Worry about the consequences of getting lost	never	171	38.0
	hardly ever	142	31.6
	occasionally	94	20.9
	quite often	28	6.2

	frequently	13	2.9
	nearly all the time	2	0.4
Disregard red lights when driving late at night along empty roads	never	367	81.6
	hardly ever	49	10.9
	occasionally	24	5.3
	quite often	6	1.3
	frequently	3	0.7
	nearly all the time	1	0.2
Fail to notice that pedestrians are crossing when turning into a side street or main road	never	245	54.4
	hardly ever	171	38.0
	occasionally	30	6.7
	quite often	3	0.7
	frequently	1	0.2
	nearly all the time	0	0.0
Misread the signs and exit from a roundabout on the wrong road	never	110	24.4
	hardly ever	177	39.3
	occasionally	143	31.8
	quite often	16	3.6
	frequently	4	0.9
	nearly all the time	0	0.0
Lost in thought you forget that your lights are on full beam until flashed by other motorists	never	171	38.0
	hardly ever	188	41.8
	occasionally	81	18.0
	quite often	8	1.8
	frequently	1	0.2
	nearly all the time	1	0.2
Switch on one thing such as the headlights when you meant to switch on something else such as the wipers	never	199	44.2
	hardly ever	148	32.9
	occasionally	84	18.7
	quite often	11	2.4

	frequently	7	1.6
	nearly all the time	1	0.2
Stuck behind a slow moving vehicle on a two lane highway you are driven to frustration to try to overtake in risky circumstances	never	56	12.4
	hardly ever	144	32.0
	occasionally	166	36.9
	quite often	52	11.6
	frequently	29	6.4
	nearly all the time	3	0.7
Realise that you have no clear recollection of the road along which you have been travelling	never	233	51.8
	hardly ever	166	36.9
	occasionally	43	9.6
	quite often	5	1.1
	frequently	2	0.4
	nearly all the time	1	0.2
Fail to check your rear view mirror before pulling out changing lanes etc	never	7	1.6
	hardly ever	9	2.0
	occasionally	14	3.1
	quite often	45	10.0
	frequently	110	24.4
	nearly all the time	265	58.9
You are able to navigate regularly travelled routes entirely from memory	never	138	30.7
	hardly ever	153	34.0
	occasionally	122	27.1
	quite often	25	5.6
	frequently	9	2.0
	nearly all the time	3	0.7
Forget which gear you are currently in and have to check with your hand	never	141	31.3
	hardly ever	161	35.8
	occasionally	121	26.9
	quite often	22	4.9

	frequently	5	1.1
	nearly all the time	0	0.0
Drive with only half-an-eye on the road while looking at a map or navigation system display	never	58	12.9
	hardly ever	189	42.0
	occasionally	168	37.3
	quite often	25	5.6
	frequently	8	1.8
	nearly all the time	2	0.4
Get into the wrong lane approaching a roundabout or junction	never	116	25.8
	hardly ever	210	46.7
	occasionally	107	23.8
	quite often	12	2.7
	frequently	4	0.9
	nearly all the time	1	0.2
Lose your way and have to ask someone for directions	never	62	13.8
	hardly ever	89	19.8
	occasionally	130	28.9
	quite often	86	19.1
	frequently	47	10.4
	nearly all the time	36	8.0
Disregard the speed limits late at night or early in the morning	never	160	35.6
	hardly ever	231	51.3
	occasionally	52	11.6
	quite often	4	0.9
	frequently	3	0.7
	nearly all the time	0	0.0
Underestimate the speed of an oncoming vehicle when overtaking	never	30	6.7
	hardly ever	96	21.3
	occasionally	204	45.3
	quite often	77	17.1

	frequently	35	7.8
	nearly all the time	8	1.8
Use unfamiliar routes to avoid congested ones	never	243	54.0
	hardly ever	181	40.2
	occasionally	24	5.3
	quite often	0	0.0
	frequently	2	0.4
	nearly all the time	0	0.0
Fail to notice someone stepping out from behind a bus or parked vehicle until it is nearly too late	never	304	67.6
	hardly ever	130	28.9
	occasionally	16	3.6
	quite often	0	0.0
	frequently	0	0.0
	nearly all the time	0	0.0
Try to overtake without first checking your mirror and then get hooted at by the car behind which has already begun its overtaking manoeuvre	never	132	29.3
	hardly ever	167	37.1
	occasionally	127	28.2
	quite often	12	2.7
	frequently	11	2.4
	nearly all the time	1	0.2
Cross a junction knowing that the traffic lights have already turned against you	never	175	38.9
	hardly ever	171	38.0
	occasionally	88	19.6
	quite often	9	2.0
	frequently	7	1.6
	nearly all the time	0	0.0

IVNS manufacturers represented in the driver survey

Manufacturer	No. Participants	Percentage
Tomtom	41	25.7
Garmin	31	19.5
Car company installed	13	8.2
HP	11	6.9
Home made	8	5.7
Navman	9	5.7
Microsoft	2	1.3
Mitek	6	3.8
Inav corporation	16	3.1
Destinator	5	3.1
Compaq	2	1.3
Co-pilot	2	1.3
Xda	2	1.3
Other	21	13.3

Appendix D : Instructions for participants in driver survey and IVNS user survey

Instructions

Thank you for agreeing to take part in this research. We would like you to complete a short survey, about your driving behaviour, and use of in-vehicle equipment. You will be completing this survey completely anonymously, so please answer all questions truthfully. The survey should take no more than 5-10 minutes to complete. Once you have completed the questionnaire, please press the "submit" button at the bottom of the page, to save your responses. If you wish to receive a summary of the results, please email nottnikf@gmail.com, and a copy will be sent to you when available. If you have any questions about this research, or are unclear in any way about the nature of this research, please email me at the above address, and I will respond as soon as possible. Please click next to continue to the survey.

Appendix E : IVNS user survey pilot

Introduction

Prior to publishing and advertising the IVNS user survey it was piloted using a sample of 8 IVNS users. As before, the pilot was run primarily to ensure that participants understood each item, that the web form was functioning correctly and to examine the average completion time. In discussions with participants, after they had completed the survey, they were also asked to provide general feedback. Participant data was not analysed due to the small sample size.

Method

8 participants (7 male, 1 female, mean age = 28 years, SD=6.9 years) took part in the pilot. They completed the survey in a web-browser, but all participants completed the survey using the same computer, to facilitate post-study discussions.

Results

The web form functioned correctly as all the data was saved in a text file in a format immediately ready for analysis. Participants completed the survey in approximately 5 minutes (mean = 311 seconds, SD = 28.2 seconds). They universally agreed that the questionnaire was short enough to attractive to most IVNS using web surfers, but stressed that even know there aren't many items per section, the number of sections, makes it appear longer than it is, so it is important that no more further questions are added. All participants completed the questionnaire without need for experimenter intervention. However, not all participants agreed that in it would be understandable to a wide audience in its current form. While participants understood the reason for all these items, they suggested several amendments to the wording of items to make them clearer.

Content

The structure of several items was altered based on pilot participants' feedback. Each item that participants found particularly difficult to understand is listed below, along with participants' comments of suggestions for potential improvements.

Item 30

Do you use your navigation system for route guidance purposes as frequently as you used to use traditional navigation methods?

- *The wording doesn't make sense. Need to re-read it a couple of times to understand*
- *Try rewording to 'did you drive in unfamiliar areas as frequently before you started using a navigation system as you did afterwards'*
- *Change to 'Do you drive as frequently in unfamiliar areas since you started using a navigation system as you did before you used one'*
- *What are traditional navigation methods. I assume you mean normal maps, but people out there could think your referring to a compass or something! You should ass an example of traditional navigation methods. Also you should consider replacing the word traditional with conventional.*
- *Try ' Do you drive in unfamiliar areas as frequently since you started using a navigation system as you did before you used one'*

Item 31

Do you think using a navigation system has affected the amount of time it takes for you to learn routes that over time you have travelled more regularly?

- *Change wording it's a bit convoluted*
- *Doesn't make sense*
- *Change to 'Consider the length of time it takes you to learn a route to the point that you no longer require any navigation assistance…*

Item 16

How do you feel about the cost of updating maps?

- *Unbalanced responses need equal cheap options*

Item 38

Have you ever been delivered to the wrong final destination?

- *Add "not-sure" response option*

Items 34-35

Has your navigation system ever generated route instructions that you would consider to be inefficient or wrong ?

Has your navigation system ever generated potentially dangerous/illegal route instructions?

- *In both these questions change “generate” to “suggest”.*

Discussion

Several of these comments were addressed in the final survey. The content of items 30-31 wasn’t changed as participants suggested, but instead was grouped with items 29 and 32. The instructions for each of these items were altered to ensure their meaning was clear.

Appendix F : Table showing results for each question in the IVNS user survey

Item	N	Categories	Frequency/descriptive stats	Percentage
Are you male or female?	`N=872	Male	844	96.8
		Female	28	3.2
How old are you?	N=710	Mean	44.7	n/a
		Median	45	n/a
		Mode	35	n/a
		SD	12.7	n/a
How many years held full driving license	N=710	Mean	26	n/a
		Median	25	n/a
		Mode	20	n/a
		SD	13.2	n/a
Thousand miles driven per year	N=710	Mean	18	n/a
		Median	15	n/a
		Mode	12	n/a
		SD	15.9	n/a
Thousand km driven per year	N=710	Mean	29	n/a
		Median	24	n/a
		Mode	19	n/a
		SD	25.5	n/a
Thousand miles driven past 5 years	N=710	Mean	88.3	n/a
		Median	70	n/a
		Mode	100	n/a
		SD	70.9	n/a
Thousand km driven past 5 years	N=710	Mean	142	n/a
		Median	112	n/a
		Mode	160	n/a
		SD	114	n/a

		Inexperienced novice	1	0.1
		Experienced novice	4	0.6
Driving experience level	N=710	Inexperienced driver	65	9.1
		Experienced driver	250	35
		Very experienced driver	395	55.2
		Self-employed	140	16.1
		Employed (manager)	207	23.7
		Employed	370	42.4
Employment	`N=872	Retired	120	13.8
		Student	16	1.8
		Other	19	2.2
		Expert	307	35.2
		Considerable skills	378	43.3
Computer Skill	`N=872	Moderate skills	158	18.1
		Some skills	22	2.5
		Insignificant skills	6	0.7
		No skills	1	0.1
		Integrated	123	14.1
		Separate	453	51.9
Navigation system type	`N=872	PDA	260	29.8
		Mobile phone	16	1.8
		Handmade	11	1.3
		Other	9	1
Is this your first navigation system?	`N=872	Yes	504	57.8
		No	368	42.2

Months using navigation system ?	N=710	Mean		20	n/a	
		Median		12	n/a	
		Mode		24	n/a	
		SD		38.6	n/a	
Months using current map	N=710	Mean		11.3	n/a	
		Median		6	n/a	
		Mode		12	n/a	
		SD		35.3	n/a	
Have you ever purchased map update?	`N=872	Yes		374		42.9
		No		498		57.1
	N=467	More than once a year		73		15.6
		Once a year		212		45.4
		Once every 2 years		116		24.8
		Once every 3 years or more		66		14.1
Why did you update the map ?	N=441	Due to holiday or trip/change of address		82		18.6
		Due to manufacturer advice		85		19.3
		Due to advice from other sources		46		10.4
		Due to awareness of roadworks road changes		115		26.1
		System previously gave inaccurate instructions		91		20.6
		It was a gift		9		2
		Other		44		10
		It was free/warranty/part of software or hardware updgrade		39		8.9
		Good sense to update a map/like to keep up to date when available		36		8.2
		Extra features with new maps (e.g. TMC)		9		2
		Beta test/produce maps		11		2.5
How do you feel about the cost of updating?	N=487	Reasonable	142			29.2
		Expensive		237		48.7
		Very expensive		108		22.2

How do you feel about the cost of updating?	N=487	Reasonable	142	29.2
		Expensive	237	48.7
		Very expensive	108	22.2
Is it important to update map ?	N=510	Yes	400	45.9
		No	70	8
		Not sure	40	4.6
Why didn’t you update the map ?	N=550	Its too expensive	145	26.4
		I bought system too recently/bought new system	218	39.6
		Wasn’t aware they needed updating	16	2.9
		Don’t use my system often enough	50	9
		Don’t need to/Don’t need to yet	78	14.2
		Don’t know how to/Don’t know how often updates available	8	1.5
		Other	56	10.2
		Awaiting maps/waiting for offer	2	0.4
		No map updates available	33	6
		Don’t know if my area is covered by update	1	0.2
		Area I travel in not been updated/not enough changes to justify	5	0.9
		Loss of current software features	4	0.8
		Forget to update	2	0.4
Would you update map in future ?	N=679	Yes	569	83.8
		No	32	4.7
		Not sure	78	11.5
Frequency of passive usage infamiliar areas	N=872	Never	132	15.1
		Hardly ever	163	18.7
		Occasionally	232	26.6
		Quite often	127	14.6
		Frequently	117	13.4
		Nearly all the time	101	11.6
Frequency of passive usage in unfamiliar areas	N=872	Never	121	13.9
		Hardly ever	157	18
		Occasionally	163	18.7
		Quite often	125	14.3
		Frequently	122	14

		Nearly all the time	184	21.1
Frequency of active usage in familiar areas	N=872	Never	130	14.9
		Hardly ever	238	27.3
		Occasionally	312	35.8
		Quite often	103	11.8
		Frequently	53	6.1
		Nearly all the time	36	4.1
Frequency of active usage in unfamiliar areas	N=872	Never	3	0.3
		Hardly ever	6	0.7
		Occasionally	33	3.8
		Quite often	84	9.6
		Frequently	251	28.8
		Nearly all the time	495	56.8
Preferred source of RG information	N=872	Display only	53	6.1
		Mainly display	130	14.9
		Both of equal importance	616	70.6
		Mainly voice	71	8.1
		Voice only	2	0.2
Correspondence between system and own RG	N=872	Very low correspondence	34	3.9
		Low correspondence	91	10.4
		Moderate correspondence	468	53.7
		High correspondence	261	29.9
		Very high correspondence	18	2.1
Do you ever enter destinations while driving ?	N=872	Never	224	25.7
		Hardly ever	230	26.4
		Occasionally	260	29.9
		Quite often	113	13
		Frequently	45	5.2

Which dest_entry features should be allowed while driving?	N=872	Enter destination by address	231	26.5
		Enter destination by postcode	239	27.4
		Enter destination by POI	301	34.5
		Enter destination by previously stored destination	526	60.3
		None of these	290	33.3
Which nav_functions should be allowed while driving ?	N=872	Change volume	658	75.5
		Manipulate map	311	35.7
		Change preferences	200	22.9
		Browse POIs	176	20.2
		Change view	518	59.4
		None of these	146	16.7
How often do you now travel in unfamiliar areas ?	N=872	Much less frequently than before	14	1.6
		Less frequently than before	36	4.1
		About as frequently than before	586	67.2
		More frequently than before	167	19.2
		Much more frequently than before	169	7.9
Has NS affected attention to traffic and roadsigns ?	N=872	Decreased	29	3.3
		Slightly decreased	126	14.4
		No effect	282	32.3
		Slightly increased	189	21.7
		Increased	246	28.2
Has time to learn routes increased or decreased ?	N=872	Decreased	93	10.7
		Slightly decreased	181	20.8
		No effect	438	50.2
		Slightly increased	116	13.3
		Increased	44	5
Do you think RG is always completely reliable ?	N=872	Yes	128	14.7
		No	744	85.3
Has system every given inefficient/wrong RG instructions ?	N=780	Yes	715	91.7
		No	38	4.9
		Not sure	27	3.5

Has system ever given dangerous/illegal RG instructions ?	N=778	Yes	326	41.9
		No	452	58.1
What dangerous/illegal instructions were given ?	N=348	Turn into a street signposted as no-entry/no permitted turning	191	54.9
		Perform prohibited manoeuvres	149	42.8
		Drive the wrong way down a one-way street	138	39.7
		Driver is bus lanes/streets vehicle is not allowed or unsuitable/train tracks	42	12.1
		Drive through fjords, woodland/rural areas cars not allowed	70	20.1
		Drive through pedestrianised zones/city areas cars not allowed	59	17
		Other	39	11.2
		Drive onto cycle tracks	1	0.3
		No road or turn exists/map is wrong	7	2
Have you ever followed this advice ?	N=411	Yes	74	18
		No	337	82
Have you ever been delivered to the wrong final destination ?	N=872	Yes	250	28.7
		No	622	71.3
Has it happened more than once ?	N=363	Yes	151	41.6
		No	212	58.4
Whose fault was it ?	N=280	My fault	53	18.9
		System fault	161	57.5
		Both	66	23.6

Appendix G – IVNS –related web forums, on which the IVNS user survey was advertised

Websites

http://www.expansys.com/forum.asp?man=TOMTO&code=TOMTOMGO
http://www.yournav.com/forum/
http://www.pocketgpsworld.com/modules.php?name=Forums&file=viewforum&f=6&sid=
http://www.datastormusers.com/cgi-bin/ultimatebb.cgi?/ubb/forum/f/2.html
http://forums.motionbased.com/smf/index.php?PHPSESSID=350242c1dafec8a6ef0fc6c1a6e81f2e&board=3.0
http://www.gps-shop.co.za/gocforum/
http://forums.groundspeak.com/GC/index.php?s=de4ee189567aa149c956192a5c13ce10&showforum=48
http://forum.delorme.com/index.php?sid=be4081c7962b46bb1f34dd28f550ba4c
http://forums.automotive.com/community/69/1023/aftermarket-accessories/navigation-gps-systems/index.html
http://www.pdalive.com/forums/forumdisplay.php?s=38deb02e0c5d26dd714fa50eadf88048&forumid=4
http://www.palmzone.net/viewforum.php?f=24
http://www.avforums.com/forums/forumdisplay.php?s=cc39597354745c63637ca31b3ffdcdfb&f=234
http://forum.digitalspy.co.uk/board/forumdisplay.php?f=164
http://discussion.brighthand.com/forumdisplay.php?f=53
http://www.mtekk.com.au/Forums/tabid/56/view/topics/forumid/29/Default.aspx
http://www.daveburrowsforums.com/
http://www.geekzone.co.nz/forums.asp?forumid=14
http://www.vitotechnology.com/en/forum/list.php?FID=8
http://www.carnavigationforum.com/index.php
http://www.navplate.com/forum/
http://www.navigate3d.de/mbbs22en/category-view.asp?action=collapse&cat=13
http://www.mobiletechreview.com/ubbthreads/ubbthreads.php?Cat=&C=1
http://www.digi-darkroom.com/forumdisplay.php?s=06a44fbaddcaf28209a35f5628f743df&f=71
http://navmanunlocked.forumwise.com/navmanunlocked-forum-15.html
http://www.eten-users.net/forum20
http://www.pocketgpsworld.com/modules.php?name=Forums&file=viewforum&f=9
http://www.twig.com.au/forum/index.php?sid=bbc7f9551b507b6b5c8cab8ac05e0ae4
http://www.aximusers.com/forum/forumdisplay.php?f=29
http://www.fourpages.co.uk/mioA701/viewforum.php?f=12&sid=2eab96727edeb395228ecba13d5fe20e
http://www.freedrive.co.uk/forums/
http://www.firstloox.org/forums/forumdisplay.php?f=71
http://mobilitytoday.com/forum/forumdisplay.php?f=83
http://support.fujitsu-siemens.com/forum/viewforum.php?f=23
http://www.boards.ie/vbulletin/forumdisplay.php?s=0147d0eafffdcc16797ababdb024bb4c&f=497
http://forums.vnunet.com/forum.jspa?forumID=2
http://www.kia-forums.com/uk/
http://www.satnavforensics.com/forums/viewforum.php?f=1&sid=dd19b50c0aff69985d8e9ece5258815f
http://forum.rac.co.uk/index.php?s=767beeb40452a78a221d7dcde8be5af1
http://www.mobilegazette.com/forum/viewforum.php?f=16
http://www.pda-essentials.co.uk/forum/viewforum.php?f=13
http://www.motorcaravanning.co.uk/forum/
http://cerocscotland.com/forum/forumdisplay.php?s=5b3df22f47133248cd13048ff7aa7a36&f=37
http://www.janisian.com/forum/showthread.php?t=152
http://forums.gpsireland.ie/
http://www.drive-smart.co.uk/forum/viewforum.php?f=3&sid=e1820a66097f4409e7bbb781d444b88e
http://www.fiatforum.com/

http://forums.mg-rover.org/forumdisplay.php?f=57
http://forums.handbag.com/forumdisplay.php?s=44b49d8bba699ed3bb606972a5d6bfbe&forumid=74
http://gpsinformation.info/forum/
http://www.gpsmoldova.com/forum/
http://www.aximsite.com/boards/forumdisplay.php?f=34
http://www.smartdevicesdirect.com/forum/forumdisplay.php?f=9
http://forum.telenav.com/index.php?sid=d56ef5c5363001d7e75fe170bf041943
http://forums.gps.org.nz/index.php?sid=70c4ec1904ce4209a701d1253e7649c1
http://forum.packardbell.com/en/profile.php?mode=activate&u=46415&act_key=5cc5d3078d4
http://forums.thecarfanatics.com/
http://www.definitivedriving.com
http://www.forums.automotivedesignline.com/jive3/thread.jspa?threadID=300423314
http://www.car-forums.com/talk/
http://www.brisbaneperformance.com/forumdisplay.php?f=3
http://www.motorcars-ltd.com/ubbthreads/addpost.php
http://www.honda-acura.net/forums/index.php
http://www.rx7club.com/forumdisplay.php?f=22
http://www.cars-directory.net/forums/
http://www.forums.performancecar.co.nz
http://www.carforums.net/index.php?
http://www.britishcarforum.com/ubbthreads/ubbthreads.php
http://www.classicsandcustoms.com/classic_car_forum/default.aspx
http://forums.theautochannel.com/posting.php
http://www.aussiecarforum.com
http://forums.beyond.ca
http://www.talkaudio.co.uk
http://www.ten-tenths.com/forum/index.php?
http://www.zerotohundred.com/newforums/showthread.php?p=1749195#post1749195
http://www.benzworld.org/forums/
http://www.car-seat.org/showthread.php?p=52393#post52393
http://www.carforums.com/forums/
http://www.usedcarmart.co.uk/forum/
http://www.carforum.net/
http://greenhybrid.com
http://forums.780tuners.com/index.php
http://pub6.bravenet.com/forum/437920974/
http://pub18.bravenet.com/forum/1497413551/
http://pub9.bravenet.com/forum/770328088/
http://www.hawaiithreads.com/

http://mercury.mweb.co.za/cgi-bin/forum/GPS/postlist.pl?Cat=&Board=GPS_forum&page=1&view=expanded&sb=6

Appendix H: The cognitive failures questionnaire – Broadbent, Cooper, Fitzgerald and Parkes (1982)

The following questions are about minor mistakes which everyone makes from time to time, but some of which happen more often than others. We want to know how often these things have happened to you in the past 6 months. Please mark an "X" in the appropriate column.

	1	**2**	**3**	**4**	**5**
	Very often	Quite often	Occasionally	Very rarely	Never
Do you read something and find you haven't been thinking about it and must read it again?					
Do you find you forget why you went from one part of the house to the other?					
Do you fail to notice signposts on the road?					
Do you find you confuse right and left when giving directions?					
Do you bump into people?					

Do you find you forget whether you've turned off a light or a fire or locked the door?					
Do you fail to listen to people's names when you are meeting them?					
Do you say something and realise afterwards that it might be taken as insulting?					
Do you fail to hear people speaking to you when you are doing something else?					
Do you lose your temper and regret it?					
Do you leave important letters unanswered for days?					
Do you find you forget which way to turn on a road you know well but rarely use?					

Do you fail to see what you want in a supermarket (although it's there)?					
Do you find yourself suddenly wondering whether you've used a word correctly?					
Do you have trouble making up your mind?					
Do you find you forget appointments?					
Do you forget where you put something like a newspaper or a book?					
Do you find you accidentally throw away something you meant to keep?					
Do you daydream when you ought to be listening to something?					
Do you find you forget people's names?					

Do you start doing one thing at home and get distracted into doing something else (unintentionally)?					
Do you find you can't quite remember something although it's "on the tip of your tongue"?					
Do you find you forget what you came to the shops to buy?					
Do you drop things?					
Do you find you can't think of anything to say?					

Appendix I: Mindful attention awareness scale – Brown and Ryan (2003)

Below is a collection of statements about your everyday experience.

Using the 1-6 scale, please indicate how frequently or infrequently you currently have each experience.

Please answer according to what really reflects your experience rather than what you think your experience should be, by selecting the appropriate response.

*1. What is your email address?

*2. I break or spill things because of carelessness, not paying attention or thinking of something else

1	2	3	4	5	6
almost always	very frequently	somewhat frequently	somewhat infrequently	very infrequently	almost never

*3. I find it difficult to stay focused on what's happening in the present

1	2	3	4	5	6
almost always	very frequently	somewhat frequently	somewhat infrequently	very infrequently	almost never

*4. I tend to walk quickly to get where I'm going without paying attention to what I experience along the way

1	2	3	4	5	6
almost always	very frequently	somewhat frequently	somewhat infrequently	very infrequently	almost never

*5. I forget a person's name almost as soon as I've been told it for the first time

1	2	3	4	5	6
almost always	very frequently	somewhat frequently	somewhat infrequently	very infrequently	almost never

*6. It seems I am running on automatic without much awareness of what I'm doing

1	2	3	4	5	6
almost	very	somewhat	somewhat	very	almost
always	frequently	frequently	infrequently	infrequently	never

*7. I rush through activities without being really attentive to them

1	2	3	4	5	6
almost	very	somewhat	somewhat	very	almost
always	frequently	frequently	infrequently	infrequently	never

*8. I get so focused on the goal I want to achieve that I lose touch with what I am doing right now to get there

1	2	3	4	5	6
almost	very	somewhat	somewhat	very	almost
always	frequently	frequently	infrequently	infrequently	never

*9. I do jobs or tasks automatically, without being aware of what I'm doing

1	2	3	4	5	6
almost	very	somewhat	somewhat	very	almost
always	frequently	frequently	infrequently	infrequently	never

*10. I find myself listening to someone with one ear, doing something else at the same time

1	2	3	4	5	6
almost	very	somewhat	somewhat	very	almost
always	frequently	frequently	infrequently	infrequently	never

*11. I drive places on “automatic pilot” and then wonder why I went there

1	2	3	4	5	6
almost always	very frequently	somewhat frequently	somewhat infrequently	very infrequently	almost never

*12. I find myself preoccupied with the future or the past

1	2	3	4	5	6
almost always	very frequently	somewhat frequently	somewhat infrequently	very infrequently	almost never

*13. I find myself doing things without paying attention

1	2	3	4	5	6
almost always	very frequently	somewhat frequently	somewhat infrequently	very infrequently	almost never

Please press the "submit data" button below.

Thank you for taking the time to complete this questionnaire.

Appendix J : driving ability scales – Parker, Macdonald, Sutcliffe and Rabbitt (2001)

During normal driving, how would you rate your ability:

(1) To read road signs

1	2	3	4	5
very poor	poor	adequate	good	very good

(2) To notice vehicles, pedestrians etc out of the corner of your eye

1	2	3	4	5
very poor	poor	adequate	good	very good

(3) To recognise when your attentions has wandered

1	2	3	4	5
very poor	poor	adequate	good	very good

(4) To divide your attention between two tasks

1	2	3	4	5
very poor	poor	adequate	good	very good

Appendix K : driving confidence scales – Parker, Macdonald, Sutcliffe and Rabbitt (2001)

How nervous do you feel:

(1) When overtaking

1	2	3	4	5
not at all	a little	moderately	very	extremely

(2) When turning right

1	2	3	4	5
not at all	a little	moderately	very	extremely

(3) When joining a motorway

1	2	3	4	5
not at all	a little	moderately	very	extremely

(4) When changing lanes on a motorway

1	2	3	4	5
not at all	a little	moderately	very	extremely

(5) When driving in heavy traffic

1	2	3	4	5
not at all	a little	moderately	very	extremely

When driving:

(6) How relaxed do you usually feel?

1	2	3	4	5
not at all	a little	moderately	very	extremely

(7) How stressed do you usually feel?

1	2	3	4	5
not at all	a little	moderately	very	extremely

(8) How confident do you usually feel?

1	2	3	4	5
not at all	a little	moderately	very	extremely

(9) When you are driving and you are suddenly faced with a potentially dangerous situation, how flustered do you become?

1	2	3	4	5
not at all	a little	moderately	very	extremely

(10) When you are driving and things happen quickly, giving you little time to think, how calm do you remain?

1	2	3	4	5
not at all	a little	moderately	very	extremely

Appendix L: Trust in automation scale – Jian et al (2000)

Below is a list of statements for evaluating trust between people and automation.

Please mark the number which best describes your feeling or your impression towards the navigation system you have been using during this diary study.

Please note: 1 = not at all, 7 = extremely

1. The system is deceptive

|_____|_____|_____|_____|_____|_____|_____|
1 2 3 4 5 6 7

2. The system behaves in an underhanded manner

|_____|_____|_____|_____|_____|_____|_____|
1 2 3 4 5 6 7

3. I am suspicious of the system's intent, action, or outputs

|_____|_____|_____|_____|_____|_____|_____|
1 2 3 4 5 6 7

4. I am wary of the system

|_____|_____|_____|_____|_____|_____|_____|
1 2 3 4 5 6 7

5. The system's actions will have a harmful or injurious outcome

|_____|_____|_____|_____|_____|_____|_____|
1 2 3 4 5 6 7

6. I am confident in the system

|_____|_____|_____|_____|_____|_____|_____|
1 2 3 4 5 6 7

7. The system provides security

|___|___|___|___|___|___|___|
1 2 3 4 5 6 7

8. The system has integrity

|___|___|___|___|___|___|___|
1 2 3 4 5 6 7

9. The system is dependable

|___|___|___|___|___|___|___|
1 2 3 4 5 6 7

10. The system is reliable

|___|___|___|___|___|___|___|
1 2 3 4 5 6 7

11. I can trust the system

|___|___|___|___|___|___|___|
1 2 3 4 5 6 7

12. I am familiar with the system

|___|___|___|___|___|___|___|
1 2 3 4 5 6 7

Appendix M : The complacency potential rating scale (CPRS) – Singh, Molloy and Parasuraman (1993)

Due to its' length, questionnaire 1 is split over 2 pages. When you reach question 13, please click the "**submit data**" button to submit your results, then click "**questionnaire 1b**" in the navigation bar on the top of your screen, to go to the second part of the questionnaire. When you reach the end of questionnaire 1b, please click the "**submit data**" button to submit your responses.

Please make sure you **enter your email address for both parts of this questionnaire** so that we may correctly identify your responses.

Please read each of the statements below carefully and select the response that you feel accurately reflects your views or experiences. The responses vary on a scale of agreement/disagreement, from "**strongly agree**" to "**strongly disagree**".

Remember, this is an opinion survey and not a test of intelligence or ability. There are **no right or wrong answers**, only answers that fit your views accurately. Please do not spend too long thinking about each item, and do not skip any question.

1. What is your email address…………………………………………………….

2. Manually sorting through card catalogues is more reliable than computer-aided searches for finding items in a library.

☐	☐	☐	☐	☐
Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree

3. If I need to have a tumor in my body removed, I would choose to undergo computer-aided surgery using laser technology because computerized surgery is more reliable and safer than manual surgery.

☐ ☐ ☐ ☐ ☐

Strongly Agree | Agree | Undecided | Disagree | Strongly Disagree

4. People save time by using automatic teller machines (ATMs) rather than a bank teller in making transactions.

☐ ☐ ☐ ☐ ☐

Strongly Agree | Agree | Undecided | Disagree | Strongly Disagree

5. I do not trust automated devices such as ATMs and computerized airline reservation systems.

☐ ☐ ☐ ☐ ☐

Strongly Agree | Agree | Undecided | Disagree | Strongly Disagree

6. People who work frequently with automated devices have lower job satisfaction

☐ ☐ ☐ ☐ ☐

Strongly Agree | Agree | Undecided | Disagree | Strongly Disagree

7. I feel safer depositing my money at an ATM than with a human teller.

☐ ☐ ☐ ☐ ☐

Strongly Agree | Agree | Undecided | Disagree | Strongly Disagree

8. I have to tape an important TV program. To ensure that the correct program is recorded, I would use the automatic programming facility on my VCR/DVD rather than manual recording..

☐ ☐ ☐ ☐ ☐

Strongly Agree | Agree | Undecided | Disagree | Strongly Disagree

9. People whose jobs require them to work with automated systems are lonelier than people who do not work with such devices.

Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree
☐	☐	☐	☐	☐

10. Automated systems used in modern aircraft, such as the automatic landing system, have made air journeys safer.

Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree
☐	☐	☐	☐	☐

11. ATMs provide a safeguard against the inappropriate use of an individual's bank account by dishonest people.

☐ ☐ ☐ ☐ ☐

Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree

12. Automated devices used in aviation and banking have made work easier for both employees and customers.

☐ ☐ ☐ ☐ ☐

Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree

13. I often use automated devices.

☐ ☐ ☐ ☐ ☐

Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree

14.What is your email address…………………………………………………….

15. People who work with automated devices have greater job satisfaction because they feel more involved than those who work manually.

Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree
☐	☐	☐	☐	☐

16. Automated devices in medicine save time and money in the diagnosis and treatment of disease.

Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree
☐	☐	☐	☐	☐

17. Bank transactions have become safer with the introduction of computer technology for the transfer of funds.

Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree
☐	☐	☐	☐	☐

18. I would rather purchase an item using a computer than have to deal with a sales representative on the phone because my order is more likely to be correct using the computer.

Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree
☐	☐	☐	☐	☐

19. Work has become more difficult with the increase of automation in aviation and banking.

Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree
☐	☐	☐	☐	☐

20. I do not like to use ATMs because I feel that they are sometimes unreliable

Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree
☐	☐	☐	☐	☐

21. I think that automated devices used in medicine, such as CAT-scans and ultrasound, provide very reliable medical diagnosis.

Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree
☐	☐	☐	☐	☐

Appendix N: Sample diary entry form

Part 1

The context of your user experience

1. Approximate date and time of experience:

2. City/town/village/area name :

3. Number of passengers in car :

4. Were you making a familiar, unfamiliar or only partially familiar journey? :

Part 2

Diary entry

Appendix O: Original advertisement for diary study

We would like you to take part in a paid, Sat-Nav user diary study. We would like you to complete diary entries, outlining user-experiences. Diary entries need not be too long or detailed so long as they adequately convey your user-experience.

The study will be run over the course of 2 weeks. Once you are recruited to participate, you will receive a participant information pack outlining the research in more detail, and a personalised calendar showing when to submit your diary entries.

Week 1

You should submit diary entries for week 1 at the end of week 1.

When we receive completed diary entries for week 1, you will receive payment of **£10** (approx $20).

Week 2

You should submit diary entries for week 2 at the end of week 2.

When we receive completed diary entries for week 2 you will receive a further payment of **£10.**

You will also receive a bonus payment of **£5** (approx $10) at the end of week 2 if you also complete the 5 short online questionnaires associated with this research at your convenience.

Total = **£25** for participation in this study.

(Please note that approximate dollar equivalent is for US dollars only. Payment will be made using either Paypal or a personal cheque)

In order to participate in this research you must:

1. Be over 17 years old
2. Be able to read and write English
3. Have at least 6 months driving experience
4. Use an in-vehicle satellite navigation system

So that we may verify your age and driving experience, please complete the short initial questionnaire. Once we are satisfied that you meet the eligibility requirements, you will be sent a participant information pack and personalised calendar so that you may begin the study as soon as possible.

Appendix P : Initial eligibility questionnaire for the diary study

*1. What is your email address? (please provide the email address you check most often as we will contact you and provide payment using this address)

*2. Are you male or female?

1	2
male	female

*3. How old are you? (in years)

*4. How many years have you held a full driving license?

5. What is the make and model of your navigation system? (if known)

*6. Is this your first in-vehicle navigation system?

1	2
Yes	No

*7. Approximately how many years and/or months have you been using an in-vehicle navigation system?

*8. How frequently do you make the following types of journey in your vehicle? *

Holiday/trip

Familiar

Unfamiliar

9. Which of the following functions do you think navigation system users should be allowed to access while driving?

Enter destination by address

Enter destination by post code

Enter destination by point of interest

Enter destination by previously stored location

Change view

Manipulate map

Change volume

Browse points of interest

Change preferences

None of these

You have reached the end of this questionnaire. Please click the "submit data" button below.

Appendix Q : Participant information pack for the diary study

Nick Forbes (principal researcher)

Driving Research Group (DRG)

University of Nottingham

Dept. of Computer Science & IT

Jubilee Campus

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Nottingham

NG7 2RD

Tel: 01159 514226

07878 444973

Email: nlf@cs.nott.ac.uk

Participant Information pack

Introduction

Thank you for your agreeing to take part in this research. In this booklet the study will be outlined and some further information for participants will be explained.

Background

We are interested in the behaviour of drivers who use an in-vehicle navigation system like you. Unlike less complex in-vehicle equipment such as stereos; navigation systems have the potential to significantly affect driving behaviour in many different ways.

Simply surveying navigation system users on a single occasion can, and has, revealed some interesting findings; but it is difficult to gain sufficient insight into the ways in which these systems are used from day to day, using surveys alone. However, in previous studies, users of a wide range of different systems (e.g. computer software, automatic pilots) have been asked to keep a short diary of particular user-experiences. Combining this diary information with other survey data has proved to be a very successful method in past research.

Study outline

We would like you to take part in a diary and questionnaire based navigation system user study. You will be paid £25 (approx $50) for participating. In your role as a participant you will be required to complete a short diary detailing your experiences in using your navigation system over the course of 2 weeks, and to complete 5 short online questionnaires at your convenience during the study.

For each diary entry, you will be required to answer a set of 4 simple questions to highlight the context of your experience, and to write a short diary entry illustrating your experience in more detail.

On pages 4-9 we explain the particular areas of investigation. Please read though these pages carefully. If, while you use your navigation system over the next 2 weeks, you think any of your user- experiences fall within this remit, we would like you to record a diary entry.

In addition to your diary entries, we would also like you to complete 5 short online- questionnaires, by visiting the following website at your convenience during the study:

www.freewebs.com/user-study-questionnaires

Data collection and payment

Week 1

We would like you to send us completed diary entries for week 1, at the end of week 1 (seven days after you begin the study). Once we receive these completed diary entries, you will be paid **£10** using Paypal.

Week 2

We would like you to send us completed diary entries for week 2, at the end of week 2. Once we receive these completed diary entries, you will be paid a further **£10** using Paypal.

Questionnaires

You will also receive a bonus payment of **£5** at the end of week 2, provided you have completed each of the 5 online-questionnaires. *Please make sure you include your email address when you complete each questionnaire so that we may correctly identify **your** responses*.

Total = **£25** for participation.

*Please note if you do not have a Paypal account or you are unable to get one, we can send you a personal cheque for payment provided that **you email us with a correspondence postal address.***

Please turn to the next page

Personal information

To participate in this research, we will need you to provide us with a correspondence email address, so you can be paid.

During the questionnaires and the diary study, you may also reveal various forms of information concerning your attitudes and driving behaviour.

We would like to take this opportunity to assure you:

1. Once all the data has been collected and is ready for analysis, all personal information will be completely destroyed, and wiped from any computer records. We would be happy to provide you with confirmation of this if you require it.
2. Your personal information will not be given to any other parties.

Participation in this study is essentially anonymous, so please complete questionnaires and diary entries truthfully, to enable us to receive good, reliable data.

The questionnaires

Each questionnaire is very short and should only take about 2-3 minutes to complete.

Questionnaires 1 and 2 are designed to examine your feelings and attitudes towards both your own navigation system and other automated/computerised systems that you may encounter.

Questionnaires 3 and 4 are designed to investigate the frequency with which you experience a range of everyday lapses of attention and memory (e.g. entering a room to look for one thing and coming out with something else).

The final questionnaire is designed to find out little bit more about your attitudes, your driving behaviour and your navigation system.

The diary

In the diary section of this study we would particularly like to find out about the types of user experiences outlined over the next few pages. Please read these pages carefully. Over the next 2 weeks, whenever you encounter any of the issues presented below while using your navigation system, simply record these experiences as diary entries.

1. *Occasions where you interact with the navigation system while you are driving*

If at any time you enter a destination or address **while you are driving** please record this experience as a diary entry. Please also briefly describe any additional relevant information. This may include:

- The method of destination entry (e.g. typing address, vocal recognition, postcode entry, entry using stored location).
- The approximate length, number of characters and/or number of key-presses for the destination information you entered.
- The approximate amount of time you think it took for you to successfully enter the destination information.
- Whether you feel that entering this particular destination diverted your attention from the driving task or any other tasks you were performing, and if so the extent to which you think it did.
- Whether any other factors caused you to enter this particular destination while driving (e.g. time constraints, traffic, stress).
- Whether you entered the destination all in one go, or over a series of stages.
- Any further additional relevant information that you think might help to put this user-experience in context.

If at any time you interact with the navigation system in any other way **while you are driving**, please also record this experience as a diary entry. It doesn't matter how long the interaction lasts. Interactions may include:

- Browsing points of interest
- Changing volume
- Changing preferences/settings
- Changing view/manipulate the map
- Any other forms of system interaction

For each diary entry please also describe any additional information. This may include:

- The approximate length of time it took for you to complete your interaction.
- Whether you feel that this particular form of system interaction diverted your attention from the driving task, and if so the extent to which you think it did.
- Whether you performed this particular form of system interaction in one step or over a series of stages.

- Whether any other factors caused you to interact with the system in this way while driving on this particular occasion (e.g. browsing points of interest because you needed to find toilet facilities).
- Any further additional relevant information that you think might help to put this user-experience in context.

2. *Occasions where you receive inaccurate or unreliable route guidance information*

If at any time you receive route guidance information or instructions that you believe are **wrong**, **inaccurate**, **unreliable** or **unusual**, please record this experience as a diary entry. For example, your navigation system may:

- Instruct you to drive in bus lanes
- Instruct you to drive the wrong way down a one-way street, or turn into some other street signposted as no-entry
- Instruct you to drive on private roads, roads for emergency vehicles only or other roads with restricted access
- Instruct you to perform prohibited manoeuvres (e.g. U-turn where it is not permitted)
- Instruct you to drive through pedestrianised zones
- Instruct you to drive into potentially dangerous areas (e.g. non-roads, farm tracks, fjords/rivers, cycle tracks, footpaths).
- Instruct you to drive into areas with inappropriate width/weight/height restrictions.
- Inform you of roundabouts, turnings and other road objects that do no exist.
- Fail to inform you of roundabouts, turnings and other road objects that you encounter on your journey.
- Provide any other form of wrong, inaccurate, unreliable or unusual route guidance instructions.

For each diary entry, please describe any additional information. This may include:

1. An explanation of how you realised the information you received was inaccurate/unreliable. For example, you may have discovered this because:

    - You encountered a turn that was not shown on your system map
    - You observed road-signs that contradicted system instructions
    - You observed the behaviour of other drivers and road users

- You intuitively knew that the system was mistaken
- You have an excellent knowledge of local routes which surpasses guidance you received from your navigation system
- Any other reason

Please turn to the next page

2. The approximate length of time (e.g. seconds/minutes/hours/days) that it took before you realised you had received inaccurate/unreliable route guidance instructions from your navigation system. Please also indicate any possible reasons why you think may not have realised immediately. For example you may have:

    - Been distracted by other vehicles, pedestrians etc.
    - Put too much trust/faith/confidence in the navigation system
    - Been thinking about something else
    - Some other explanation

3. What you did when you received inaccurate/unreliable route guidance instructions from your navigation system. For example, you may have:

    - Immediately realised the navigation system was mistaken, and recalculated an alternative route using your navigation system, environmental information (e.g. road signs, traffic behaviour), common sense or some other information.
    - Begun following inaccurate guidance instruction(s), only to realise while following the instruction(s) that the system was mistaken.
    - Completely followed inaccurate guidance instruction(s), only to realise later in your journey or several hours/days later that the system had been mistaken.
    - Followed inaccurate guidance instruction(s), even though you were aware they may have been incorrect.
    - Some other explanation.

4. The presence, availability and/or visibility of road signs or other environmental information (e.g. landmarks, the behaviour of surrounding traffic) that may have informed you that the navigation system was mistaken.

5. Any further additional relevant information that you think might help to put this user-experience in context.

Please turn to the next page

3. *Occasions where you get distracted while using your navigation system in any way*

Depending on various internal (e.g. fatigue, stress) and external (e.g. weather, traffic demands) factors, driving even without in-vehicle equipment can place significant demands on a drivers' attention. Navigation system users must learn to attend to both the driving scene and auditory and/or visual route guidance instructions.

However, as drivers become more experienced, so many driving tasks quickly become automatic requiring much less focused attention. Similarly as navigation system users become more experienced, so the combined task of driving and using a navigation system may demand less focused attention.

Any time you find that you have become distracted while using your navigation system in any way, even if for just a few seconds, please record this experience as a diary entry.

For each diary entry please describe any additional information. This may include:

- The type of distraction
- The approximate duration of distracted driving
- Any factors that made you realise you were distracted
- The extent to which you think the distraction affected your attention to the tasks of driving and/or navigating.
- Your surroundings while you experienced distraction (e.g. were you on a long straight section of road, coming up to a junction, or in light traffic ?)
- Any further additional relevant information that you think might help to put this user-experience in context.

4. *Occasions where you make navigational errors or have other problems, in which **you**, not your navigation system are to blame:*

Occasionally everybody makes mistakes. If at anytime over the next 2 weeks, while using your navigation system you get lost or make some other form of navigational error; **and you are to blame,** please record this as a diary entry. For example, navigational errors may include:

- Missing an important turning suggested by the navigation system
- Incorrectly following instructions from your navigation system (e.g. using the wrong lane on a roundabout).
- Ignoring system advice only to later realise you should have followed it
- Arriving at an incorrect destination because you inputted it wrongly
- Mis-understanding or mis-interpreting a particular auditory or visual instruction.
- Any other navigational error for which you are to blame

For each diary entry please describe any additional information. This may include:

- The type/severity of the navigational error
- The length of time it took for you to notice you had made a navigational error
- Any other factors that may have caused you to make a navigational error (e.g. driving workload, stress, mood).
- Any safety implications of your navigational error
- Any further additional relevant information that you think might help to put this user-experience in context.

5. *Any user-experiences that you feel are worth noting.*

The primary purpose of this diary study is to examine the behaviour of navigation system users and in particular to find identify behavioural changes over time (in terms of system use and driving performance/safety). We are particularly interested in hearing about:

- How you think your driving behaviour has changed since you started using a navigation system
- How your behaviour has changed with experience of using the navigation system.
- Any differences in your driving behaviour when you use your navigation system, relative to traditional navigational methods such as paper maps or asking directions.

Please also feel free to illustrate these points with specific examples that may arise during the diary study.

This section is a completely open ended section. If you have any further experiences over the next 2 weeks, that also fall within this remit, please feel free to note them in your diary entries.

Also in this section, please note instances of any of the following:

- The navigation system displays quirky, strange or unusual behaviour, not addressed in the types of user-experiences outlined over the last few pages.
- The navigation system causes a distraction from the primary driving task that is unrelated to system interaction.
- Something goes wrong because you have a poor understanding of exactly how your navigation system should work (e.g. unaware that it doesn't take vehicle height/width/weight into account when planning routes)
- Your level of faith/trust/confidence in your navigation system changes for some reason.
- Your navigation system exceeds your expectations (e.g. provides accurate information on a brand new housing estate, provides much more detail or is much more informative than you expected).
- Any other user-experience that you feel is worth noting.

Completing diary entries

Based on usage patterns highlighted in previous survey research, it is anticipated that most participants will use their navigation systems in some way, between 1 and 8 times per week. We would like you to complete a diary entry for each time you use your navigation system, *provided that your user experience falls within the remit outlined over the previous 5 pages*. Please submit all entries for a week, at the end of each week.

Ideally you should record your experiences on the day that you encounter them so that your experience and any thoughts you had during your experience are still fairly fresh in your mind. However, we realise of course that due to a number of factors, this may not always be possible. You may even choose to complete your entries at the end of each week. The frequency with which you record experiences is entirely up to you, we simply ask that you try to be as accurate as possible in completing your diary entries.

Please use a separate diary entry form for each user-experience, and begin each diary entry by answering the four standard questions. These questions are explained in the sample diary entry form on page 11 of this information pack. Please simply type your responses to these questions (see pages 12-13 for example diary entries).

Please be as detailed as you see fit when reporting your user-experiences. State and refer to any factors that you think may be relevant to your diary entry, no matter how insignificant they may seem. These may include, but will by no means be limited to:

1. *Environmental factors* – such as the weather, driving conditions, congestion, visibility, surrounding traffic, other drivers, traffic jams/delays, road issues, children/passengers in the car, road noise, radio noise, other noise, other potential distractions etc.
2. *Driver factors* – such as mood, tiredness/alertness, stress, boredom, irritability, mental workload, attention to surrounding traffic, road signs, potential hazards, attention to the vehicle, the navigation system, other in-vehicle equipment or other accessories (e.g. mobile phones etc.).
3. *Vehicle factors* – such as any problems/faults with the vehicle, any improvements or modifications to the vehicle, vehicle control factors (e.g. acceleration, braking, steering) other notable vehicle issues (e.g. feeling sluggish, low petrol/diesel) etc.
4. *Navigation system and routing factors* – such as unusual/strange system behaviour, system accessibility, traffic information (where available), route difficulty/complications (e.g. due to lots of roundabouts, traffic lights), route accessibility, route advantages, unusual route choices etc.

Sample diary entry form

Part 1

The context of your user experience

1. Approximate date and time of experience:

   Please include the date and time of each separate user experience

2. City/town/village/area name :
   We would just like to get a general idea of where you were geographically during your user-experience.

3. Number of passengers in car :
   Please enter number of passengers if applicable. If you were alone type 0 here.

4. Were you making a familiar, unfamiliar or only partially familiar journey? :

   Drivers tend to have good mental representations of ***familiar areas****. They can easily find their way to the majority of destinations. In contrast drivers tend to have poor mental representations of* ***unfamiliar areas****. They will find it very difficult to find their destinations without some form of navigational support. Drivers have some knowledge of* ***partially familiar areas****. They may be able to find some destinations, but in many cases will require at least some navigational support.*

Part 2

Diary entry

In this section, please be as detailed as you think you need to be in order to adequately convey your user-experience, taking note of information given on pages 4-9 of this information pack. Your diary entry may be as long as you wish.

Example diary entry (1)

Part 1

The context of your user experience

1. Approximate date and time of experience: 5th July 2007, *8 pm*

2. City/town/village/area name : *Nottingham*

3. Number of passengers in car : 0

4. Were you making a familiar, unfamiliar or only partially familiar journey? : Familiar

Part 2

Diary entry

I entered an address while I was driving. I was in a hurry to get to an appointment. I was lost and behind time already, because I thought I knew the way but did not, so I began entering the destination while I tried to get back onto a familiar road.

I entered the destination using the keypad. It was approx. 8 characters long, and required 8 key presses. I made a mistake entering it the first time, so made 2 attempts, I think both attempts took about 4/5 seconds in total, and do not think it significantly diverted my attention from the driving task, particularly since I was on an empty, quiet road, and my full attention returned to driving as soon as the destination was entered and the navigation system began its job.

On this occasion I am glad I entered the destination while driving as I had to reach my appointment on time, and I did. I don't think safety was compromised in any way at any time during this short interaction.

Example diary entry (2)

Part 1

The context of your user experience

1. Approximate date and time of experience: *8/7/07,* 9.30 am

5. City/town/village/area name : London (M25)

6. Number of passengers in car : 1

7. Were you making a familiar, unfamiliar or only partially familiar journey? : Partially familiar

Part 2

Diary entry

I received inaccurate route instructions from my navigation system. I was driving along the motorway, and it instructed me to take a slip road that was for police and emergency vehicles only. I realised that it was wrong when I saw signs showing this, almost immediately after I turned onto the slip road. The only problem was that I was already taking the slip road when I noticed the signs so I had no choice but to continue along that route.

I didn't notice any road signs before entering the slip road, and am not sure whether there were any. However, I was fairly distracted in talking to other passengers at the time, and since my navigation system has never made a mistake before I had no real reason to doubt its instructions on this occasion.

It was also quite wet and there was lots of rain, which may to some extent have obscured my view. Also other drivers appeared to be turning onto the same road as me, so I didn't see a problem at the time that I turned.

Appendix R: Example personalised calendar that was given to a diary study participant

Below is a personalised calendar detailing the dates on which you should email your diary entries to us. Please also complete the 5 online questionnaires at your convenience during the study, by visiting the following website:

www.freewebs.com/user-study-questionnaire

September 2007

<table>
<tr><th>Sunday</th><th>Monday</th><th>Tuesday</th><th>Wednesday</th><th>Thursday</th><th>Friday</th><th>Saturday</th></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td>1</td></tr>
<tr><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td></tr>
<tr><td>9</td><td>10</td><td colspan="3">11 12 13
Begin study</td><td>14</td><td>15</td></tr>
</table>

16	17	18	19 **Submit week 1 diary entries**	20	21	22
23	24	25	26 **Submit week 2 diary entries**	27	28	29
30						

Appendix S : Diary study participants' responses to the various scales

item	response	frequency
Confidence scale		
overtaking	1	8
	2	6
	3	6
	4	0
	5	0
turning right	1	15
	2	5
	3	0
	4	0
	5	0
joining motorway	1	15
	2	2
	3	1
	4	2
	5	0
change lanes	1	13
	2	4
	3	3
	4	0
	5	0
heavy_traffic	1	11
	2	4
	3	3
	4	2
	5	0
relaxed	1	1
	2	2
	3	2
	4	13
	5	2
stressed	1	11
	2	6
	3	3
	4	0
	5	0

confident	1	0
	2	1
	3	3
	4	11
	5	5
flustered	1	6
	2	9
	3	4
	4	1
	5	0
calm	1	0
	2	0
	3	7
	4	12
	5	1
Ability scale		
road_signs	1	0
	2	0
	3	0
	4	11
	5	9
wandered	1	0
	2	2
	3	6
	4	8
	5	5
corner	1	0
	2	0
	3	0
	4	11
	5	9
divide	1	0
	2	2
	3	7
	4	10
	5	1
CPRS		
1	1	0
	2	1
	3	1
	4	8
	5	10

2	1	0
	2	5
	3	10
	4	5
	5	0
3	1	10
	2	9
	3	0
	4	1
	5	0
4	1	7
	2	11
	3	0
	4	0
	5	2
5	1	0
	2	7
	3	6
	4	6
	5	1
6	1	0
	2	0
	3	3
	4	15
	5	2
7	1	5
	2	10
	3	0
	4	5
	5	0
8	1	0
	2	5
	3	6
	4	8
	5	1
9	1	7
	2	9
	3	4
	4	0
	5	0
10	1	1
	2	6

	3	3
	4	9
	5	1
	1	7
	2	11
11	3	1
	4	1
	5	0
	1	10
	2	9
12	3	1
	4	0
	5	0
	1	2
	2	11
13	3	6
	4	1
	5	0
	1	5
	2	9
14	3	2
	4	4
	5	0
	1	5
	2	9
15	3	2
	4	4
	5	0
	1	0
	2	3
16	3	0
	4	13
	5	4
	1	3
	2	15
17	3	2
	4	0
	5	0
	1	7
18	2	7
	3	6
	4	0

	5	0
19	1	0
	2	2
	3	9
	4	9
	5	0

Trust scale

1	1	11
	2	6
	3	2
	4	0
	5	1
	6	0
	7	0
2	1	14
	2	4
	3	1
	4	0
	5	1
	6	0
	7	0
3	1	11
	2	4
	3	3
	4	1
	5	0
	6	1
	7	0
4	1	9
	2	5
	3	4
	4	0
	5	1
	6	1
	7	0
5	1	15
	2	4
	3	0
	4	0
	5	1
	6	0

	7	0
6	1	0
	2	1
	3	1
	4	0
	5	9
	6	6
	7	3
7	1	2
	2	0
	3	0
	4	5
	5	8
	6	3
	7	2
8	1	2
	2	1
	3	1
	4	4
	5	7
	6	3
	7	2
9	1	0
	2	1
	3	2
	4	0
	5	10
	6	4
	7	3
10	1	0
	2	1
	3	1
	4	1
	5	9
	6	5
	7	3
11	1	0
	2	2
	3	0
	4	3
	5	8
	6	3

	7	4
	1	0
	2	0
	3	1
12	4	0
	5	2
	6	6
	7	11

	CFQ	
Item	frequency	
	1	6
	2	8
1	3	6
	4	0
	5	0
	1	3
	2	8
2	3	8
	4	1
	5	0
	1	0
	2	4
3	3	16
	4	0
	5	0
	1	1
	2	1
4	3	4
	4	14
	5	0
	1	1
	2	2
5	3	10
	4	7
	5	0
	1	1
	2	1
6	3	9
	4	7
	5	2
7	1	2

	2	6
	3	10
	4	2
	5	0
	1	0
	2	1
8	3	8
	4	11
	5	0
	1	1
	2	4
9	3	6
	4	8
	5	1
	1	0
	2	3
10	3	4
	4	9
	5	4
	1	1
	2	4
11	3	5
	4	8
	5	2
	1	0
	2	0
12	3	3
	4	12
	5	5
	1	1
	2	1
13	3	11
	4	7
	5	0
	1	0
	2	1
14	3	4
	4	6
	5	9
	1	1
15	2	9
	3	7

	4	3
	5	0
	1	1
	2	1
16	3	2
	4	11
	5	5
	1	1
	2	2
17	3	6
	4	10
	5	1
	1	0
	2	2
18	3	2
	4	11
	5	5
	1	2
	2	2
19	3	9
	4	7
	5	0
	1	3
	2	7
20	3	9
	4	1
	5	0
	1	3
	2	6
21	3	7
	4	4
	5	0
	1	1
	2	7
22	3	9
	4	3
	5	0
	1	1
	2	0
23	3	4
	4	13
	5	2

24	1	0
	2	0
	3	5
	4	11
	5	4
25	1	1
	2	3
	3	7
	4	8
	5	1

Maas

Item	response	
1	1	0
	2	1
	3	0
	4	4
	5	7
	6	8
2	1	0
	2	1
	3	3
	4	4
	5	9
	6	3
3	1	1
	2	2
	3	9
	4	2
	5	3
	6	3
4	1	0
	2	5
	3	7

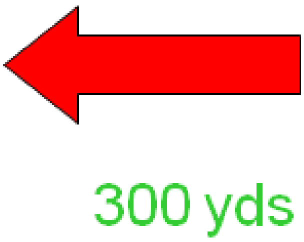
	4	0
	5	7
	6	1
5	1	0
	2	2
	3	6
	4	4
	5	7
	6	1
6	1	0
	2	2
	3	6
	4	4
	5	8
	6	0
7	1	0
	2	2
	3	3
	4	9
	5	6
	6	0
8	1	0
	2	2
	3	6
	4	7
	5	4
	6	1
9	1	0
	2	3
	3	5
	4	8
	5	3
	6	1
10	1	0
	2	0
	3	1
	4	2
	5	9
	6	8
11	1	1
	2	1
	3	5

	4	7
	5	3
	6	3
12	1	0
	2	3
	3	3
	4	5
	5	7
	6	2

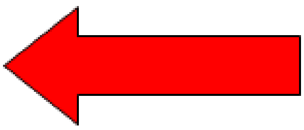
Appendix T : Photograph of the STISIM driving simulator

Appendix U: screenshots of the pseudo navigation system used in the pilot

In 300 yards turn right

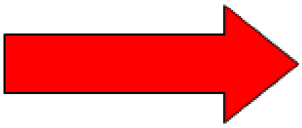


Turn right now

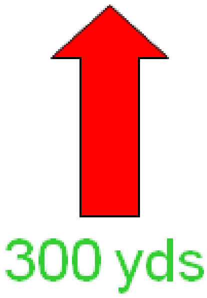


In 300 yards turn right

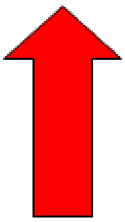
Turn right now



In 300 yards continue straight ahead



Continue straight ahead now



Appendix V – Simulator study 1 pilot

Introduction

The first simulator study was piloted to ensure that all destinations entailed similar difficulty to enter while driving and to ensure that the subjective scales had adequate face validity for use in the main study.

Method and results

4 participants (4 male, 0 female, mean age = 31 years, SD = 6.3 years) took part in the pilot. All participants had full UK driving licences. 2 participants had previously used an IVNS and 2 participants had never previously used one. The pilot was carried out using the STISIM driving simulator and the TOMTOM GO IVNS described in chapter 7. Participants followed the procedure outlined in chapter 7, with some additions (see below).

Destination entry

Before completing the simulator tasks, participants were asked to enter 12 destinations while stationary in the vehicle. They were asked to complete each destination entry task, but to highlight any destination, that they thought was more or less difficult than the others. This meant that 3 destinations were excluded. All those remaining were allocated to destination entry tasks in the two simulator studies.

Subjective scales

Once they had completed the simulator tasks, participants were asked to provide subjective performance ratings. These were not compared with actual ratings due to the small sample size. Once participants had completed the pilot, they were asked in an informal discussion about the clarity of the scales. All participants clearly understood what the scales were asking and all participants could see the benefit of including each scale, given the nature of the experiment. No scales were suggested for potential deletion.

Appendix W: subjective performance rating scales used in the first simulator study

Please answer the following eight questions based on your experience in the driving simulator, by circling the appropriate number. There are no right or wrong answers. Please ensure your response accurately reflects your own experience.

1. Compared to normal driving, how would you rate your ability to remain within lane boundaries when entering destinations while driving?

1 2 3 4 5 6 7 8 9

(much worse) (much better)

2. Compared to normal driving, how would you rate your ability to maintain an appropriate speed when entering destinations while driving?

1 2 3 4 5 6 7 8 9

(much worse) (much better)

3. Compared to normal driving, how would you rate your overall driving performance when entering destinations while driving?

1 2 3 4 5 6 7 8 9

(much worse) (much better)

4. Compared to normal driving, how **safe** would you rate driving while entering destinations to be?

1 2 3 4 5 6 7 8 9

(not at all safe) (extremely safe)

5. Compared to normal driving, how **risky** would you rate driving while entering destinations to be?

1 2 3 4 5 6 7 8 9

(not at all risky) (extremely risky)

6. Compared to normal driving, how **confident** were you about your driving ability when entering destinations while driving?

1 2 3 4 5 6 7 8 9

(not at all confident) (extremely confident)

Appendix X: Simulator study questionnaire

Participant number………		Date of trial……/……/………	
Navigation system user simulator study			
SECTION A PERSONAL PROFILE			
Please note: • All information on this form will be treated in the strictest confidence • No individuals will be identified			
A1 How old were you on your last birthday?			
…………..years			
A2 Are you male or female? (*Please tick the appropriate box)*			
Male		*Female*	
SECTION B DRIVER PROFILE			
B1 How many years have you held a full driving licence?			
…………..years			
B2 Approximately how many thousand miles/kilometres have you driven in the past 12 months?			

……………………………….thousand miles/km (*please delete as appropriate*)	
B3 Is this mileage typical? (*please tick the appropriate response)*	
Yes	
No	
B4 On how many days do you drive in a typical week? (*Please circle the appropriate number)*	
Never *Everyday* 0 1 2 3 4 5 6 7	
B5 What type of vehicle do you drive? (*Please tick all those that apply)*	
Motorcycle	
Car	
Light goods vehicle	
Heavy goods vehicle	

B6 How confident do you feel when driving?	
Very unsure *Very confident* 1 2 3 4 5 6 7	
B7 Are you left or right handed?	
Left handed	
Right handed	
SECTION C EXPERIENCE WITH TECHNOLOGY	
C1 How would you rate your level of skill at using computers? (*Please tick the appropriate response)*	
No skills	
Insignificant skills	
Some skills	

Moderate skills	
Considerable skills	
Expert	
C2 Approx how many years have you been using a computer for?	
………………*years*	
C3 Have you ever used an electronic in-vehicle navigation system?	
Yes	
No	
What is the make and model (if known)?	
Make: *Model*:	

Have you ever used a previous in-vehicle navigation system while driving? (? (*Please tick the appropriate box)*	
Yes	
No	
Do you presently own an electronic in-vehicle navigation system? (*Please tick the appropriate box)(if you answer no, please skip the next question)*	
Yes	
No	
If yes, how frequently do you use a navigation system while driving ? (*Please tick the appropriate box)*	
Never	
Very infrequently	
Occasionally	
Frequently	
Very frequently	
How frequently do you use your stereo while driving? (*Please tick the appropriate box*	

Never	
Very infrequently	
Occasionally	
Frequently	
Very frequently	
End of questionnaire	

Appendix Y: First simulator study participant consent Form

The purpose of this study is to investigate driving behaviour while using an in-vehicle navigation system. As a participant, you will be asked to drive normally in the driving simulator, and to use the in-vehicle navigation system to find your way to destinations.

In order to take part in this study you must hold a valid driving licence for a manual car.

Most of the study will take place in the driving simulator. You will sit in the front seat of the test car with a view of the road ahead of you and to either side. Although examining driving in this way is much safer than it would be on the road, risks for participating in this experiment, do include possible simulator sickness (generally less than 10% of participants ever experience symptoms) and possible headaches and/or eyestrain. To minimize any harm, each simulator session will be limited to 20 minutes. In the event that you should experience symptoms, we will remove you from the experiment and provide a place for you to rest.

If you regularly suffer from/experience any of the following conditions it is advisable that you do not take part in the trial:

- **Migraine**
- **Blurred vision**
- **Motion sickness**

The experimenter will explain equipment being used and make any necessary adjustments to ensure your comfort. You will then have a practice drive to familiarise yourself with the navigation system and the driving simulator controls before the study commences.

As a participant you will be guaranteed complete confidentiality and anonymity, with all recorded data from your participation identified by number only. The study will be recorded by video in order to monitor your interactions with the controls of the car and the driving scene. All videos will be deleted once analysis is complete.

If you have any questions please do not hesitate to ask.

You may withdraw from this experiment at anytime.

I HAVE READ AND FULLY UNDERSTOOD THE ABOVE. MY PARTICIPATION IN THIS STUDY IS ENTIRELY VOLUNTARY.

Signature : ……………………………

Print name: ………………………………

Date:………………

Appendix Z: Brief instructions and overview for participants in both simulator studies

What are navigation systems?

Drawing on the US governments' global positioning satellite technology (GPS), in-vehicle navigation systems support drivers by providing real-time route guidance information in the form of a visual 2D/3D map as well as turn-by-turn audio guidance. Many systems also provide real time traffic monitoring to inform drivers of congestion, road works etc… Initially, vehicle navigation systems were very expensive. Up market vehicle manufacturers built them into some of their vehicles at the design stage. Some manufacturers disabled access to certain system functions while the vehicle was moving.

However, in the past 10 years this technology has dramatically decreased in price leading to the release of much cheaper after-market units. These are much more affordable, and have allowed a much wider range of drivers to install GPS technology in their own vehicles in much the same way as they may previously have installed a new CD player. Millions of drivers have already adopted this technology, and industry forecasts suggest that as more drivers make the transition from paper-based to electronic route guidance, sales of vehicle navigation systems increase exponentially over the 10 years.

Most after-market navigation systems do not limit system functionality, because navigation systems are no longer physically connected to the rest of the vehicle, as they once were.

Overview of the study

This study is split into 3 phases. Phases 1 and 3 will be completed in the simulator.

Phase 1

Shortly you will enter the driving simulator to begin phase 1. We want you to drive along a straight road with some bends. In phase 1 we are looking at your ability to enter destinations, both while driving and while stationary. Your destination information will be displayed on the destination card.

Sometimes drivers using navigation systems know their destination before starting their journey, and other times they learn their destination during their journey. We would like you to experience both scenarios.

(a) You will be asked to read destination 1 before you set off. Once you start driving, as soon as you feel comfortable doing so, we would like you to enter this destination into the navigation system while you are driving. Once you have entered the destination, the navigation system will instruct you to “continue straight ahead”. Please follow this advice and continue driving. Shortly after this, the navigation system will inform you that you have arrived at your destination. When you hear this, please continue driving and after a few minutes, you will be asked verbally to enter destination 2. Please repeat this procedure for destination 2. When you reach destination 2, please pull up outside the destination and wait for the next phase.

(b)You will be asked to read destination 1 and enter it into the navigation system before you set off. Once you have entered the destination, the navigation system will instruct you to “continue straight ahead”. Please follow this advice and start driving. Shortly after this, the navigation system will inform you that you have arrived at your destination. When you hear this, please continue driving and after a few minutes you will be asked verbally to enter destination 2. This time, please find a suitable place to pull over on the side of the road, and enter the destination while stationary. Once you have entered the destination, the navigation system will instruct you to “continue straight ahead”. Please follow this advice and continue driving, and shortly after this the system will inform you that you have arrived at your destination. Please pull up outside the destination and wait for the next phase.

Phase 2

In phase 2 of this study, you will leave the simulator to answer a short questionnaire and then either watch a short presentation or complete a short task outside of the simulator.

Phase 3

In phase 3 of this study, you will be required to successfully navigate to 4 destinations in an urban environment. **However, this time it is completely up to you how you use the navigation system to reach the destinations.** You will receive 2 destinations before you set off, and 2 destinations during your journey.

Phase 3 will be timed. In addition to destination information, the destination card will also show the distance to the next destination, the average speed limit on the roads you will need to use and the time at which you should aim to reach each destination. The time is shown on the top right hand side of the navigation system screen at all times. Each time you reach a destination legally and within the time limit, you will receive a 50 pence bonus for participating in this study.

Appendix AA: Destination entry cards used in the first simulator study

Phase 1a

Destination 1 : ROATH   53 THE PARADE

Destination 2 : REDCAR   5 COAST ROAD

Phase 1a

Destination 1 : WIGAN 25 DAISY ROAD

Destination 2 : GLASGOW 3 LUSS ROAD

Appendix AB: Characteristics of both simulator study samples

Item	Response	Frequency
Age	mean	25.2
	median	24
	SD	5.88
Gender	male	19
	female	5
Years with full driving license	mean	5.9
	median	4
	SD	4.69
Mileage past 12 months (thousand miles)	mean	7.8
	median	5
	SD	8.3
Mileage typical?	yes	18
	no	6
Days drive	0	2
	1	1
	2	2
	3	1
	4	3
	5	5
	6	4
	7	6
Vehicle	motorcycle	0
	car	24
	LGV	2
	HGV	1
Confident	1 (very unsure)	1
	2	0
	3	0
	4	0
	5	8
	6	8
	7(very confident)	7
Left or right handed	left	2
	right	22
Computing skill	no skills	1
	insignificant skills	2
	some skills	5
	moderate skills	8
	considerable skills	7

	expert	1
No. yrs using computer	mean	8.3
	median	9
	SD	4.9
Every used IVNS?	yes	24
	no	0
IVNS make and model	make	TOMTOM
	model	various
Ever used IVNS while driving	yes	24
	no	0
Presently own IVNS	yes	13
	no	11
If yes, how frequently do you enter destinations while driving	never	0
	very infrequently	4
	occasionally	6
	frequently	2
	very infrequently	12
How frequently do you use stereo controls while driving	never	0
	very infrequently	1
	occasionally	2
	frequently	4
	very infrequently	17

Appendix AC : Summary of performance data in the first simulator study

				lane position	speed (mph)	long accel due to throttle (ft/secsqu)	lat. acc(ft/secsqu)	long. vel (ft/sec)	lat. vel (ft/sec)
p1	WD	MEAN	DEST1	-7.321731602	36.51051948	1.68965368	-0.512597403	53.55025974	0.071601732
		SD		0.963006405	1.044215823	0.64116732	1.48053463	1.531702356	0.757946618
		MEAN	DEST2	-6.611304348	34.08474308	1.104822134	-0.841185771	49.99193676	-0.053003953
		SD		0.752255523	1.816349151	0.694363123	1.258275849	2.664083087	0.54880504
	NWD	MEAN	DEST1	-7.150874317	58.6952459	2.226721311	-1.169398907	86.08901639	0.162240437
		SD		0.934850461	3.336981728	2.130314728	2.567178545	4.894652174	0.629450229
		MEAN	DEST2	-7.365228216	38.62630705	3.087551867	-1.581120332	56.65373444	-0.14780083
		SD		3.296975263	9.901581695	2.341980871	1.822273989	14.52252679	0.992418205
p2	WD	MEAN	DEST1	8.426866359	37.55313364	0.719631336	-1.050875576	55.07995392	-0.114930876
		SD		1.52728649	4.045099613	0.555140833	1.443933243	5.932888911	1.055962839
		MEAN	DEST2	-9.259829868	40.59758034	0.811568998	-1.111398866	59.54489603	-0.021833648
		SD		1.174579135	9.619184558	0.646451265	1.546827744	14.10857455	0.57331063
	NWD	MEAN	DEST1	-9.436342593	46.78217593	2.301435185	-1.77162037	68.61532407	0.049583333
		SD		0.38409792	2.389171772	0.385066923	2.105581434	3.504179682	0.362050122
		MEAN	DEST2	-7.913163265	43.97318367	2.057469388	-1.280142857	64.49559184	-0.080163265
		SD		1.07267149	7.183852695	2.167126235	1.949056764	10.53711039	0.574274659
p3	WD	MEAN	DEST1	-6.465883495	39.02258252	1.773708738	-0.142330097	57.23467961	0.054582524
		SD		0.994289799	5.055564308	1.297210278	1.864137591	7.414917741	0.727753573
		MEAN	DEST2	-8.060740741	51.64483539	1.603847737	-1.623909465	75.74788066	-0.018333333
		SD		0.787210308	7.465616986	1.779961719	2.581364608	10.94972264	0.541575308
	NWD	MEAN	DEST1	-7.781374322	49.65786618	2.067450271	-0.093309222	72.83359855	0.026311031
		SD		0.870498312	2.096159827	0.524332745	2.93797933	3.074685544	0.466388908
		MEAN	DEST2	-7.964910891	53.46861386	1.55150495	-1.848217822	78.42271287	-0.01239604
		SD		1.00191525	8.306004382	1.095869098	2.474177271	12.18231696	0.673001157
p4	WD	MEAN	DEST1	-6.515361842	45.22225329	1.560493421	0.165707237	66.32753289	0.042664474
		SD		1.66968075	3.968699116	0.774057807	3.851567963	5.820975323	1.443598197
		MEAN	DEST2	-7.667779579	39.81690438	1.117536467	-0.028800648	58.39961102	-0.00184765
		SD		3.72131995	4.703750574	0.662935541	2.740587111	6.899317219	1.565492793
	NWD	MEAN	DEST1	-6.29320298	76.85391061	4.207150838	1.636741155	112.7223091	0.006089385
		SD		1.764947195	10.75171515	2.214418129	8.408442741	15.76970877	1.633121718
		MEAN	DEST2	-4.82605	79.35655	4.105733333	-2.62685	116.3927167	-1.155716667
		SD		8.388840761	20.49514172	4.415645366	11.75738746	30.06043702	5.676733567
p5	WD	MEAN	DEST1	-6.815549451	36.59428571	1.405164835	-0.643351648	53.67357143	0.008901099
		SD		1.173794656	0.380458121	0.201329079	1.093801358	0.557748922	0.755702374
		MEAN	DEST2	-8.408931298	44.27572519	1.681933842	1.126437659	64.93903308	0.137531807
		SD		5.001989184	5.348134573	1.899167198	2.637050964	7.843923788	2.078647707
	NWD	MEAN	DEST1	-7.143670473	47.36973899	1.867455139	0.661353997	69.47747145	0.001337684
		SD		1.224089926	4.313651638	1.479794539	3.255487568	6.326946726	0.589193399
		MEAN	DEST2	-10.23066489	37.06300532	0.528617021	1.034840426	54.36047872	0.01143617
		SD		4.720266019	8.354847935	1.129861916	1.544230372	12.25379614	1.193475177
p6	WD	MEAN	DEST1	-9.174528689	32.29120902	1.062848361	0.017192623	47.36147541	-0.078729508
		SD		3.0732405	5.098291977	1.570882213	2.053596762	7.477802186	1.228557201
		MEAN	DEST2	-9.637351598	36.82408676	0.124452055	1.335273973	54.01018265	-0.079908676
		SD		4.781947634	15.0420291	0.548992875	1.725598306	22.06257757	1.1915513
	NWD	MEAN	DEST1	-7.266105991	46.40619816	3.176774194	-0.041221198	68.06412442	0.02718894
		SD		2.260283311	13.59638699	3.279294932	3.011549996	19.94174835	1.123233918
		MEAN	DEST2	-9.455201465	46.47637363	0.192783883	2.200110294	68.14208791	0.273992674
		SD		5.358188557	7.554751405	0.536360572	1.659306191	11.20750722	1.052737936
p7	WD	MEAN	DEST1	-7.097593583	50.11657754	0.972192513	-2.211871658	73.50609626	0.057807487

		SD		0.769430096	3.076635687	0.33289542	2.743540845	4.513178225	0.816604566
		MEAN	DEST2	-7.569617225	51.91177033	0.67492823	-3.086889952	76.13889952	0.143636364
		SD		0.842678221	3.885647682	0.526824777	1.998212276	5.699319142	0.790761671
	NWD	MEAN	DEST1	-7.522227273	48.26290909	3.680818182	-1.480954545	70.78690909	0.104727273
		SD		1.262440213	14.98131633	4.84819387	2.512825276	21.97301623	1.151369016
		MEAN	DEST2	-7.715833333	61.22046296	2.333101852	-4.327638889	89.7925463	0.01412037
		SD		0.855004556	5.214405161	1.359924112	3.872285243	7.648670868	1.060694448
p8	WD	MEAN	DEST1	-6.187989865	54.41118243	1.523918919	-0.437212838	79.8054223	-0.050591216
		SD		0.985686657	5.304132567	0.939478118	4.038215648	7.778986934	0.924629796
		MEAN	DEST2	-11.74204225	30.85123239	0.689577465	1.135739437	45.24985915	0.155140845
		SD		5.832334935	8.168371189	1.318055304	1.477667134	11.98061101	1.378923499
	NWD	MEAN	DEST1	-5.671508475	50.42622034	1.607372881	-0.218813559	73.96077966	-0.005457627
		SD		0.752561621	3.7524304	1.063142048	3.09781038	5.503883957	0.38759812
		MEAN	DEST2	-10.93868966	30.56037931	0.879068966	1.048586207	44.82317241	0.03562069
		SD		5.576241278	5.842563622	1.284305648	1.176791898	8.569059269	1.159079903
p9	WD	MEAN	DEST1	-6.578121212	48.59018182	1.190242424	-0.687393939	71.26793939	-0.052060606
		SD		2.159391453	2.491456493	1.156043479	3.596943638	3.654514498	1.97081681
		MEAN	DEST2	-6.965833333	30.8525	0.33289542	-0.049	45.25	0.031833333
		SD		1.135676147	2.359691609	0.67492823	0.987027209	3.462038686	0.947679578
	NWD	MEAN	DEST1	-7.12260274	76.83	7.645616438	-1.787671233	112.6878767	0.237671233
		SD		0.73119935	10.3191933	1.226791707	2.428925132	15.13507906	1.130812367
		MEAN	DEST2	-8.140967742	41.46903226	1.304677419	-0.067258065	60.82241935	-0.070483871
		SD		0.217155302	0.868148038	1.475808995	0.182605634	1.272565094	0.15707811
p10	WD	MEAN	DEST1	-8.753908297	55.71207424	0.43220524	-0.803777293	81.71323144	0.262882096
		SD		3.874854442	17.69938559	1.150232659	6.412381105	25.9600807	3.100107288
		MEAN	DEST2	-13.03935484	32.27136201	2.149677419	-0.782616487	47.33283154	0.162473118
		SD		5.686614817	3.974272877	1.740313243	2.244685001	5.829433275	1.784094387
	NWD	MEAN	DEST1	-8.629678161	54.54050575	1.872068966	0.087632184	79.9948046	-0.004551724
		SD		1.898065444	7.040207483	2.449142208	4.192581132	10.32615752	0.857970475
		MEAN	DEST2	-6.287358491	26.73622642	1.283396226	-0.596415094	39.21396226	0.649245283
		SD		2.04142781	8.137844457	2.21743003	0.708221213	11.93665208	0.94489692
p11	WD	MEAN	DEST1	-6.593462783	37.48676375	0.95184466	-0.716828479	54.98187702	0.072880259
		SD		1.111419466	4.274974582	0.703167344	1.85161503	6.269731169	0.74507242
		MEAN	DEST2	-11.95397554	21.35932722	1.103914373	-0.09030581	31.3282263	0.163272171
		SD		6.98560936	3.652036852	1.558450534	0.97558315	5.356483879	1.342737793
	NWD	MEAN	DEST1	-7.658842444	46.20987138	1.536334405	-1.094726688	67.77614148	-0.042990354
		SD		0.663111394	2.754267185	1.422159445	2.157636664	4.03982488	0.413746529
		MEAN	DEST2	-9.095555556	31.37388889	0.980185185	0.973333333	46.01685185	0.743703704
		SD		1.564029227	0.67185021	1.097383665	0.447222033	0.984872033	1.027154517
p12	WD	MEAN	DEST1	-7.007398649	47.89040541	1.216182432	-1.757871622	70.24101351	0.042804054
		SD		1.568655148	4.276570046	0.941250135	3.27897212	6.272478194	1.762764174
		MEAN	DEST2	-11.35275037	30.36237668	1.381838565	0.105829596	44.53307922	0.109147982
		SD		5.742520147	3.260235224	0.657422428	2.329270935	4.781416505	1.882311857
	NWD	MEAN	DEST1	-8.09097561	47.62602787	2.181289199	-1.737595819	69.85317073	0.020801394
		SD		0.810234203	2.166270095	0.641493076	2.061103345	3.177230517	0.459382056
		MEAN	DEST2	-13.03935484	32.27136201	2.149677419	-0.782616487	47.33283154	0.162473118
		SD		5.686614817	3.974272877	1.740313243	2.244685001	5.829433275	1.784094387
p13	WD	MEAN	DEST1	-7.410017986	38.79149281	1.857895683	0.03557554	56.89552158	-0.045395683
		SD		1.905315419	8.14564809	1.418405549	1.872020403	11.9474179	0.599419258
		MEAN	DEST2	-10.9322381	23.68090476	1.659238095	0.303714286	34.73280952	0.101428571
		SD		3.385554062	6.931583954	2.244587832	0.680007398	10.16645861	1.128090166
	NWD	MEAN	DEST1	-8.088807018	42.89278947	1.494789474	-0.166614035	62.91119298	0.014035088
		SD		2.020413132	3.652051513	1.199783976	1.963581322	5.356328319	0.608540158
		MEAN	DEST2	-7.150874317	58.6952459	2.226721311	-1.169398907	86.08901639	0.162240437
		SD		0.934850461	3.336981728	2.130314728	2.567178545	4.894652174	0.629450229
p14	WD	MEAN	DEST1	-7.191835206	41.79580524	2.41670412	-1.6482397	61.3017603	0.196554307
		SD		1.804748541	5.746291613	0.520087831	2.510203443	8.428085493	1.027933598
		MEAN	DEST2	-12.81588832	25.62172589	1.025431472	0.725177665	37.57979695	0.122081218
		SD		4.133063899	5.423506948	2.651636084	1.052399394	7.955291523	0.92012989

	NWD	MEAN	DEST1	-7.987509579	32.15206897	1.337356322	-0.83394636	47.15770115	0.103984674
		SD		0.863665893	1.333687893	0.989046697	0.917836577	1.95601579	0.242677817
		MEAN	DEST2	-7.266105991	46.40619816	3.176774194	-0.041221198	68.06412442	0.02718894
		SD		2.260283311	13.59638699	3.279294932	3.011549996	19.94174835	1.123233918
p15	WD	MEAN	DEST1	-8.589785933	40.54033639	1.267155963	-0.712110092	59.46079511	-0.09351682
		SD		1.224292565	2.658422697	0.720345552	2.103272242	3.899459689	0.86085429
		MEAN	DEST2	-6.313989637	24.72435233	1.665233161	-0.784611399	36.26388601	-0.198290155
		SD		1.773906394	3.341824558	1.755667926	1.442807224	4.901410291	1.112139304
	NWD	MEAN	DEST1	-9.722253086	52.43756173	1.751203704	-1.229166667	76.91009259	-0.084783951
		SD		1.40516942	5.015311532	1.794859387	3.429571941	7.355862155	0.767160913
		MEAN	DEST2	-7.913163265	43.97318367	2.057469388	-1.280142857	64.49559184	-0.080163265
		SD		1.07267149	7.183852695	2.167126235	1.949056764	10.53711039	0.574274659
p16	WD	MEAN	DEST1	-8.904371257	30.43257485	0.010958084	-0.264191617	44.63538922	0.082934132
		SD		0.592774307	5.077041754	0.188945181	0.653074591	7.447024614	0.472614251
		MEAN	DEST2	-12.64142857	21.31857143	2.438639456	-0.052517007	31.26768707	-0.27170068
		SD		5.838273577	7.96623362	2.874674881	0.811876605	11.68399866	0.935980457
	NWD	MEAN	DEST1	-8.011801242	45.94881988	2.021801242	-0.637639752	67.39347826	-0.003913043
		SD		0.64055629	1.230914994	1.061244487	1.047903571	1.805177021	0.533011695
		MEAN	DEST2	-7.541488095	40.64029762	0.71125	-1.855535714	59.60755952	-0.238928571
		SD		1.324067694	5.33668026	0.469316215	1.721837119	7.827555923	0.317578857
p17	WD	MEAN	DEST1	-7.98161435	57.72022422	2.350941704	-0.1982287	84.65858744	0.045134529
		SD		1.19263304	2.726041859	1.264021409	4.477782382	3.998554124	0.973199221
		MEAN	DEST2	-10.37606061	41.40575758	1.755353535	1.285690236	60.72949495	0.068249158
		SD		4.496288293	7.017379259	2.200157847	1.988922433	10.29297307	1.450258003
	NWD	MEAN	DEST1	-7.570045977	86.44266667	3.738850575	-1.587172414	126.7856552	-0.038988506
		SD		1.615380282	8.396512375	3.724902258	10.65512309	12.31554129	2.028280329
		MEAN	DEST2	-7.347365854	56.42063415	2.098390244	-2.750829268	82.75278049	-0.111414634
		SD		0.541079067	3.930842359	2.312104941	2.995604262	5.765224395	0.497810351
p18	WD	MEAN	DEST1	-7.192532751	31.9590393	0.629432314	-0.346113537	46.87510917	0.044847162
		SD		0.791571641	3.014672008	0.537077154	0.726417673	4.422246949	0.453398085
		MEAN	DEST2	-9.61180758	21.8593586	0.960087464	0.25728863	32.06090379	0.070728863
		SD		5.305851476	4.589698629	1.105837379	0.802307306	6.731567039	0.905126268
	NWD	MEAN	DEST1	-5.95827907	46.47702326	2.036976744	-0.933069767	68.16837209	0.131302326
		SD		0.741742906	3.435752169	1.31032017	1.553051825	5.039239823	0.544863163
		MEAN	DEST2	-7.764600939	38.67173709	3.145868545	0.641126761	56.72004695	-0.128450704
		SD		2.166160732	13.7738814	3.552319973	1.671495672	20.20247443	0.76548908
p19	WD	MEAN	DEST1	-8.322128852	35.95959384	1.001862745	-0.53232493	52.74201681	0.00754902
		SD		1.864482513	10.07894098	0.669115535	1.949262507	14.78276966	1.012765098
		MEAN	DEST2	-13.45140952	24.84971429	0.995904762	-0.028514286	36.44697143	0.051219048
		SD		5.783518198	3.980072801	1.031160222	1.59718457	5.83726772	1.568140959
	NWD	MEAN	DEST1	-8.418115502	46.93729483	1.796337386	-0.574224924	68.84346505	0.031550152
		SD		0.949196619	4.769423283	0.743074031	3.19079547	6.995356331	0.649588582
		MEAN	DEST2	-8.952291407	45.0050934	1.44143213	-0.359912827	66.00938979	0.083486924
		SD		1.418398338	6.486554103	0.784626484	2.995010792	9.514005951	0.718696032
p20	WD	MEAN	DEST1	-7.37971223	40.36363309	0.698093525	-1.023561151	59.20190647	-0.025107914
		SD		1.737553549	6.779899585	1.162758903	1.427448526	9.943758758	0.861301481
		MEAN	DEST2	-8.710787037	22.47013889	0.860972222	0.547638889	32.95657407	0.054861111
		SD		5.147078271	5.268386848	1.94740841	0.865893532	7.727327004	1.165448303
	NWD	MEAN	DEST1	-7.725888889	45.62388889	2.082481481	-1.548185185	66.91666667	0.035296296
		SD		0.687755189	2.533561357	1.045273016	1.811780749	3.715745358	0.533503975
		MEAN	DEST2	-6.696347032	46.42894977	2.056666667	-0.375936073	68.09812785	-0.093835616
		SD		0.88810043	4.124763134	2.405567383	2.488218001	6.049801776	0.306444377
p21	WD	MEAN	DEST1	-6.474698795	42.55503614	1.752457831	-0.056987952	62.41542169	-0.062843373
		SD		1.047675754	3.250004227	1.441963145	2.424400984	4.766621846	0.89437864
		MEAN	DEST2	-8.55937397	29.43093904	1.868204283	0.020280066	43.16622735	-0.259884679
		SD		5.948459817	11.89258157	2.670409155	0.921864817	17.44320148	0.91982949
	NWD	MEAN	DEST1	-6.758030635	47.28940919	1.738161926	-0.180196937	69.35986871	-0.016695842
		SD		1.27140638	0.708888957	0.486606257	2.746730945	1.039397591	0.441361805
		MEAN	DEST2	-7.970164609	34.7191358	0.517037037	1.36744856	50.92238683	0.293374486

		SD		3.643595986	5.18044883	0.466837729	0.719327102	7.598505675	0.55899494
				-					
p22	WD	MEAN	DEST1	6.965833333	30.8525	0.33289542	-0.049	45.25	0.031833333
		SD		1.135676147	2.359691609	0.67492823	0.987027209	3.462038686	0.947679578
				-					-
		MEAN	DEST2	9.174528689	32.29120902	1.062848361	0.017192623	47.36147541	0.078729508
		SD		3.0732405	5.098291977	1.570882213	2.053596762	7.477802186	1.228557201
	NWD	MEAN	DEST1	-7.12260274	76.83	7.645616438	-1.787671233	112.6878767	0.237671233
		SD		0.73119935	10.3191933	1.226791707	2.428925132	15.13507906	1.130812367
				-					
		MEAN	DEST2	8.418115502	46.93729483	1.796337386	-0.574224924	68.84346505	0.031550152
		SD		0.949196619	4.769423283	0.743074031	3.19079547	6.995356331	0.649588582
				-					
P23	WD	MEAN	DEST1	7.569617225	51.91177033	0.67492823	-3.086889952	76.13889952	0.143636364
		SD		0.842678221	3.885647682	0.526824777	1.998212276	5.699319142	0.790761671
				-					
		MEAN	DEST2	6.465883495	39.02258252	1.773708738	-0.142330097	57.23467961	0.054582524
		SD		0.994289799	5.055564308	1.297210278	1.864137591	7.414917741	0.727753573
				-					-
	NWD	MEAN	DEST1	7.913163265	43.97318367	2.057469388	-1.280142857	64.49559184	0.080163265
		SD		1.07267149	7.183852695	2.167126235	1.949056764	10.53711039	0.574274659
		MEAN	DEST2	-6.29320298	76.85391061	4.207150838	1.636741155	112.7223091	0.006089385
		SD		1.764947195	10.75171515	2.214418129	8.408442741	15.76970877	1.633121718
				-					-
P24	WD	MEAN	DEST1	9.174528689	32.29120902	1.062848361	0.017192623	47.36147541	0.078729508
		SD		3.0732405	5.098291977	1.570882213	2.053596762	7.477802186	1.228557201
				-					
		MEAN	DEST2	7.191835206	41.79580524	2.41670412	-1.6482397	61.3017603	0.196554307
		SD		1.804748541	5.746291613	0.520087831	2.510203443	8.428085493	1.027933598
				-					
	NWD	MEAN	DEST1	8.088807018	42.89278947	1.494789474	-0.166614035	62.91119298	0.014035088
		SD		2.020413132	3.652051513	1.199783976	1.963581322	5.356328319	0.608540158
				-					
		MEAN	DEST2	8.418115502	46.93729483	1.796337386	-0.574224924	68.84346505	0.031550152
		SD		0.949196619	4.769423283	0.743074031	3.19079547	6.995356331	0.649588582

Appendix AD: procedure for creating z-scores, and the extra 3 point scale used to verify findings in the first simulator study

lane position WD	lane positionNWD	original 3point recode	Difference WD/NWD	ZSCORE_LANPOS_D2
0.8	3.3	3.0	-2.5	-1.5
1.2	1.1	1.0	0.1	-0.5
0.8	1.0	3.0	-0.2	-0.6
3.7	8.4	3.0	-4.7	-2.4
5.0	4.7	1.0	0.3	-0.4
4.8	5.4	3.0	-0.6	-0.8
0.8	0.9	3.0	-0.1	-0.6
5.8	5.6	1.0	0.2	-0.5
1.1	0.2	1.0	0.9	-0.2
5.7	2.0	1.0	3.7	0.9
7.0	1.6	1.0	6.4	2.0
5.7	5.7	2.0	0.0	-0.5
3.4	0.9	1.0	2.5	0.5
4.1	2.3	1.0	1.8	0.2
1.8	1.1	1.0	0.7	-0.3
5.8	1.3	1.0	4.5	1.3
4.5	0.5	1.0	4.0	1.1
5.3	2.2	1.0	2.9	0.6
5.8	1.4	1.0	4.4	1.2
5.1	0.9	1.0	4.2	1.1
5.9	3.6	1.0	2.3	0.4
3.1	0.9	1.0	2.2	0.3
1.0	1.8	3.0	-0.8	-0.9
1.8	0.9	3.0	-0.1	-0.6

speed (mph) WD	speed (mph) NWD	original 3point recode	Difference WD/NWD	ZSCORE_SPEED_D2
1.8	9.9	3.0	-8.1	-1.3
9.6	7.2	1.0	2.4	0.7
7.5	8.3	3.0	-0.8	0.1
4.7	20.5	3.0	-15.8	-2.7
5.3	8.4	3.0	-3.1	-0.4
15.0	7.6	1.0	7.4	1.6
3.9	5.2	3.0	-1.3	0.0
8.2	5.8	1.0	2.4	0.7
2.4	0.9	1.0	1.5	0.5
4.0	8.1	3.0	-4.1	-0.5
3.7	0.7	1.0	3.0	0.8
3.3	4.0	3.0	-0.7	0.1
6.9	3.3	1.0	3.3	0.8
5.4	13.6	3.0	-8.2	-1.3
3.3	7.2	3.0	-3.9	-0.5
8.0	5.3	1.0	2.7	0.7
7.0	3.9	1.0	3.1	0.8
4.6	13.8	3.0	-9.2	-1.5
4.0	6.5	3.0	-2.5	-0.2
5.3	4.1	1.0	1.2	0.4
11.9	5.2	1.0	6.7	1.5
5.1	4.8	1.0	0.3	0.3
5.1	10.8	3.0	-5.7	-0.8
5.7	4.8	1.0	0.9	0.4

Appendix AE: Piloting the final simulator study

Introduction

The intervention study was also piloted on the same sample as the previous pilot. The purpose of the pilot was to ensure the face validity of the interventions, ensure there were no problems guiding participants to destinations and to calculate reasonable and less reasonable task completion times for each destination in the intervention study.

Method

4 participants (4 male, 0 female, mean age = 31 years, SD = 6.3 years) took part in the pilot. All participants had full UK driving licences. 2 participants had previously used an IVNS and 2 participants had never previously used one. The pilot was carried out using the STISIM driving simulator and the TOMTOM GO IVNS described in chapter 7. Each participant underwent one of the four conditions used in the intervention (i.e. no intervention, safety-based intervention, training-based interventions and safety-training based intervention). 2 participants were asked to enter destinations while driving to each of the four destinations, and then to enter the same destinations while stationary before driving to each of the four destinations again. The other 2 participants completed these tasks in the reverse order. The time taken to reach each destination when participants entered destinations while driving and while stationary, were recorded.

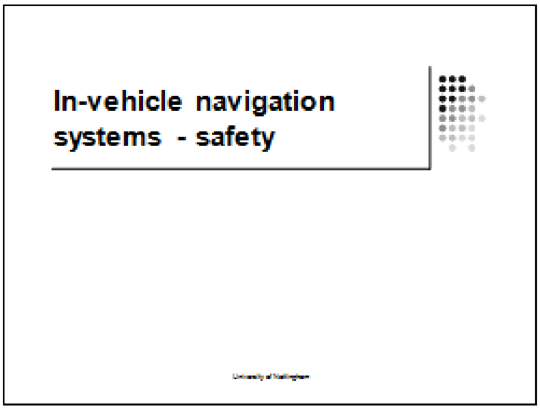
Results

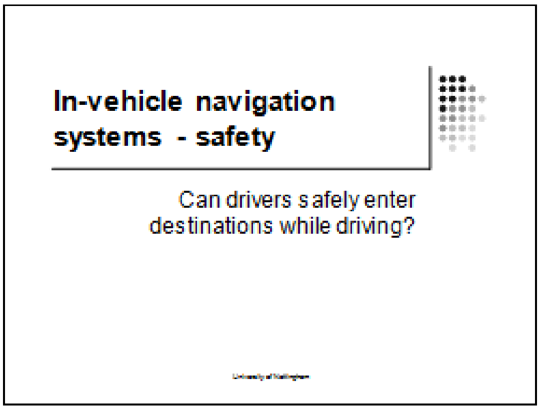
Participants had no problem following route guidance instructions to the correct destinations and they also clearly understood the messages in the interventions, but the participant assigned to the safety and training condition objected that the tasks and presentations together took too long. Table 1 below, shows average task completion times for each of the four destinations, when participants completed destination entry tasks while driving and while stationary. The table also shows reasonable and less reasonable time limits, that were calculated based on this data for use in the intervention study.

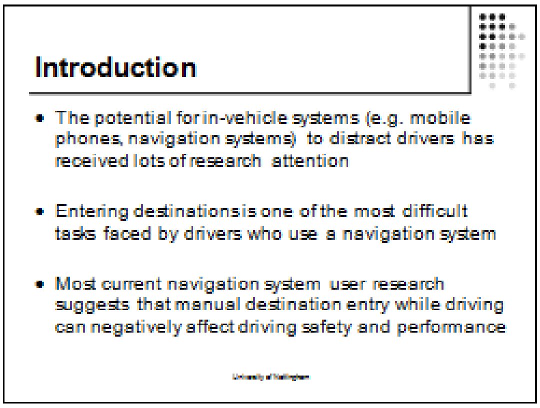
Table 1: task completion times in the pilot and resulting calculated time constraints for each destination in the intervention study

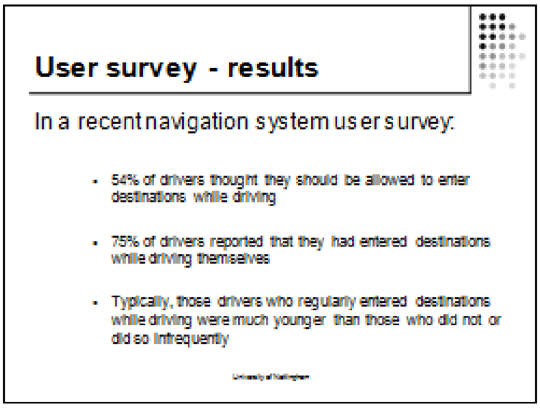
		Average task completion time	Time limit in intervention study
Reasonable	Destination 1 (while driving)	2 mins	2 mins 30 secs
	Destination 1 (while stationary)	1 mins 53 secs	
Less reasonable	Destination 2 (while driving)	2 mins 47 secs	3 mins
	Destination 2 (while stationary)	2 mins	
Reasonable	Destination 3 (while driving)	1 min 47 sec	2 mins 40 secs
	Destination 3 (while stationary)	1 min 59 sec	
Less reasonable	Destination 4 (while driving)	3 mins 33 sec	3 mins 45 secs
	Destination 4 (while stationary)	3 mins 28 sec	

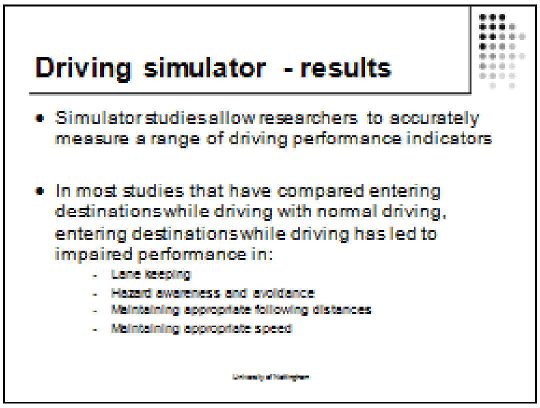
Appendix AF: Screenshots from the safety intervention (i.e. remediation) used in the final simulator study











Driving simulator - results

- Simulator studies allow researchers to accurately measure a range of driving performance indicators
- In most studies that have compared entering destinations while driving with normal driving, entering destinations while driving has led to impaired performance in:
  - Lane keeping
  - Hazard awareness and avoidance
  - Maintaining appropriate following distances
  - Maintaining appropriate speed

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Driving simulator - videos

- Over the next few pages you will be shown 2 videos of drivers using a navigation system while driving in a past study

University of Nottingham

Driving simulator - videos

- Over the next few pages you will be shown 2 videos of drivers using a navigation system while driving in a past study

In particular, concentrate on:

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Driving simulator - videos

- Over the next few pages you will be shown 2 videos of drivers using a navigation system while driving in a past study

In particular, concentrate on:

- The top right video *showing drivers using the navigation system while driving*

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Driving simulator - videos

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In particular, concentrate on:

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&

- The bottom left video *showing drivers' ability to stay within lane boundaries*

University of Nottingham

Summary

- Performance usually suffers when drivers enter destinations while driving
- Divided attention research shows that this is because most people find it difficult to complete more than one task at the same time
- Especially when they are unfamiliar with either task

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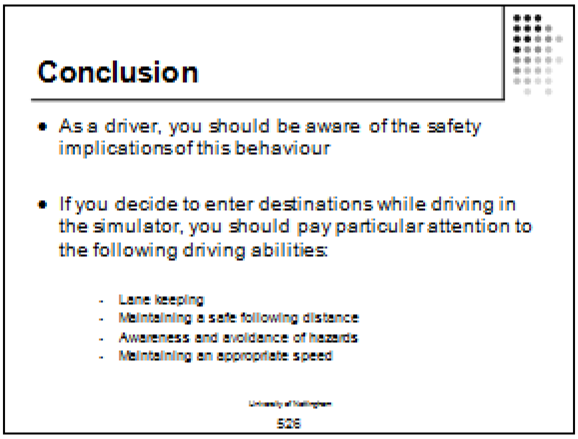
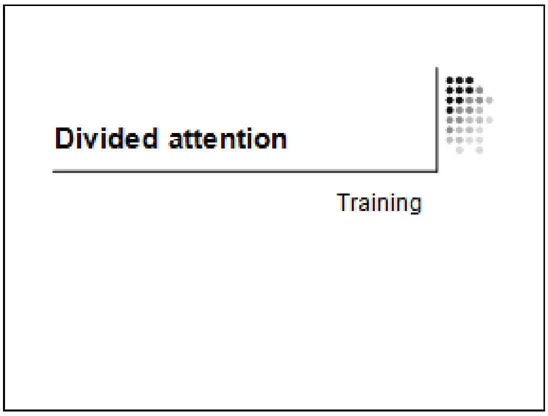
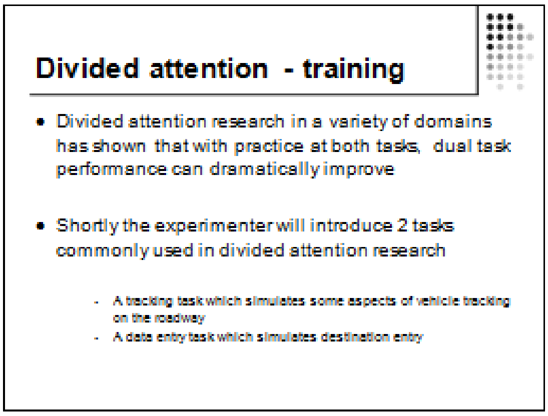
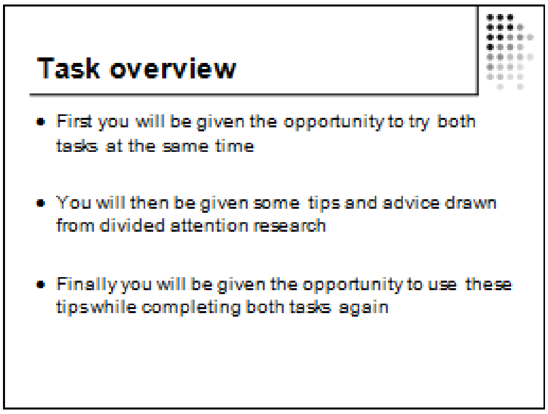
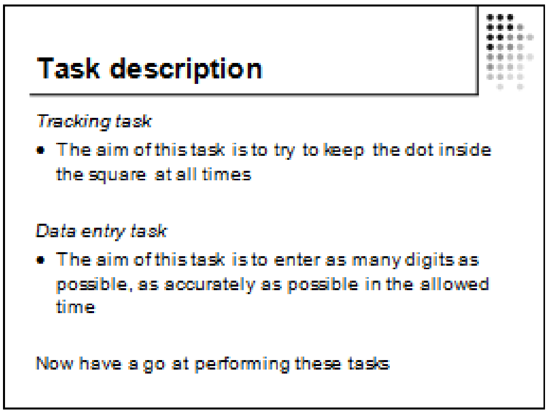

Conclusion
As a driver, you should be aware of the safety implications of this behaviour
If you decide to enter destinations while driving in the simulator, you should pay particular attention to the following driving abilities:
- Lane keeping
- Maintaining a safe following distance
- Awareness and avoidance of hazards
- Maintaining an appropriate speed
526

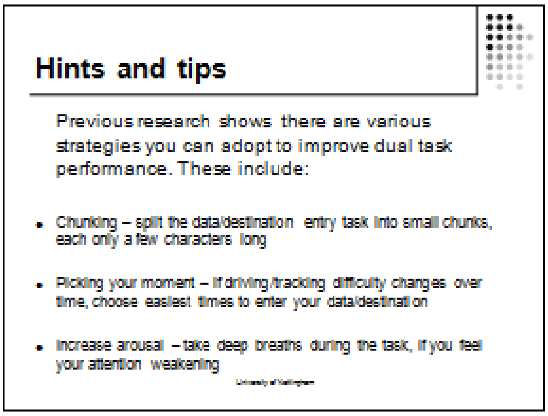
Appendix AG: Screenshots from the training intervention (i.e. mitigation) used in the final simulator study

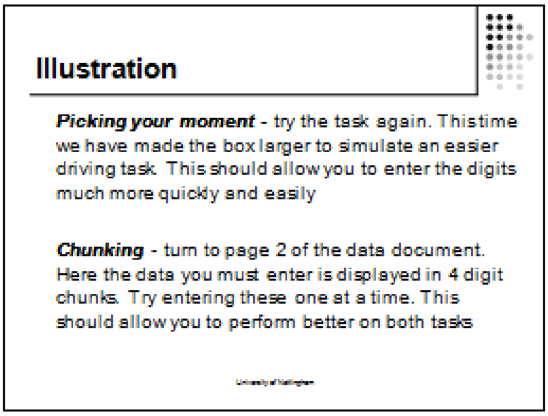




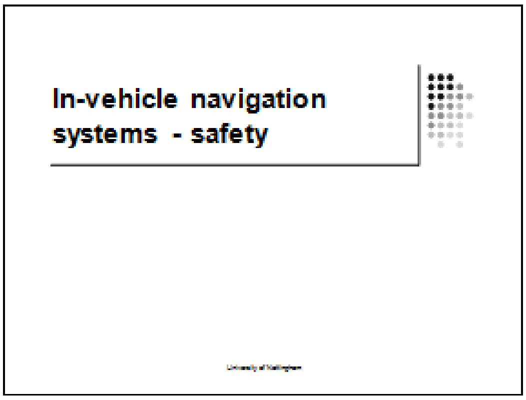


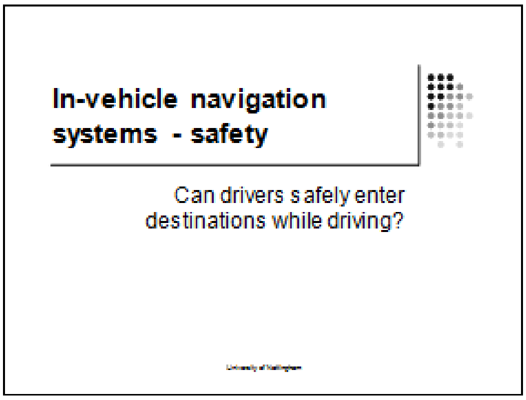


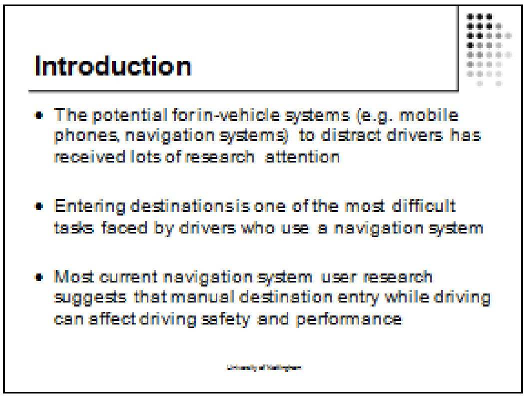


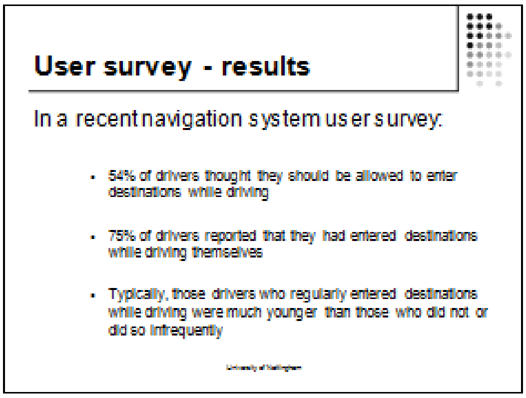


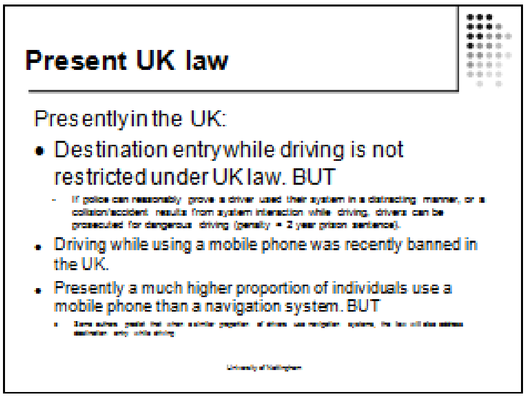
Appendix AH: Screenshots from the combined safety and training intervention used in the final simulator study

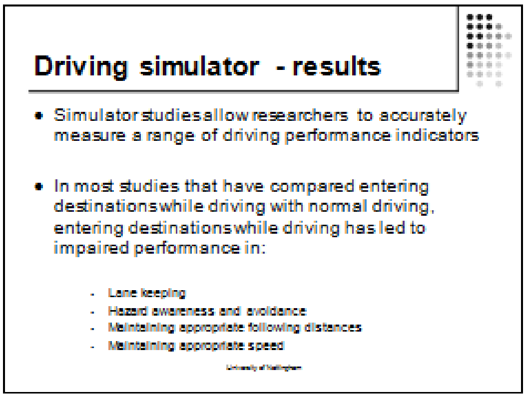












Driving simulator - results

- Simulator studies allow researchers to accurately measure a range of driving performance indicators
- In most studies that have compared entering destinations while driving with normal driving, entering destinations while driving has led to impaired performance in:
  - Lane keeping
  - Hazard awareness and avoidance
  - Maintaining appropriate following distances
  - Maintaining appropriate speed

Driving simulator - videos

- Over the next few pages you will be shown 2 videos of drivers using a navigation system while driving in a past study

Driving simulator - videos

- Over the next few pages you will be shown 2 videos of drivers using a navigation system while driving in a past study

In particular, concentrate on:

Driving simulator - videos

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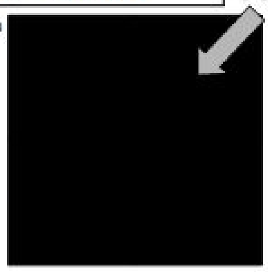
- The top right video *showing drivers using the navigation system while driving*



Driving simulator - videos

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In particular, concentrate on:

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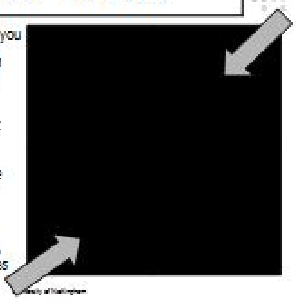
  &

- The bottom left video *showing drivers' ability to stay within lane boundaries*



Summary

- Performance usually suffers when drivers enter destinations while driving
- Divided attention research shows that this is because most people find it difficult to complete more than one task at the same time
- Especially when they are unfamiliar with either task

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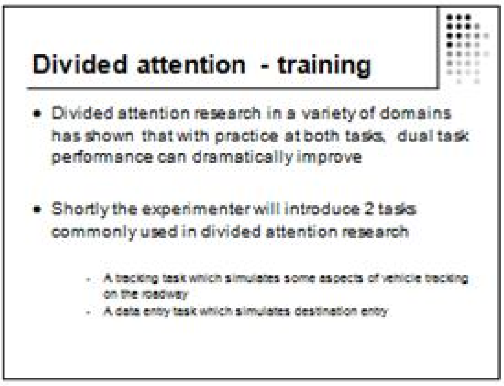
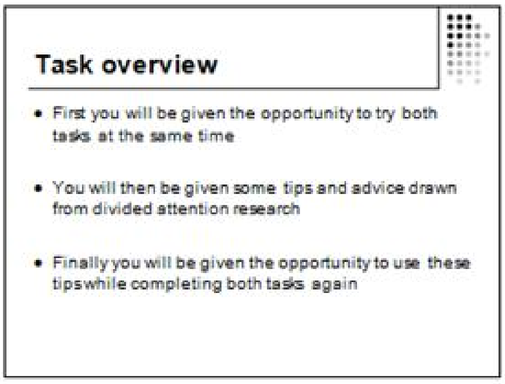
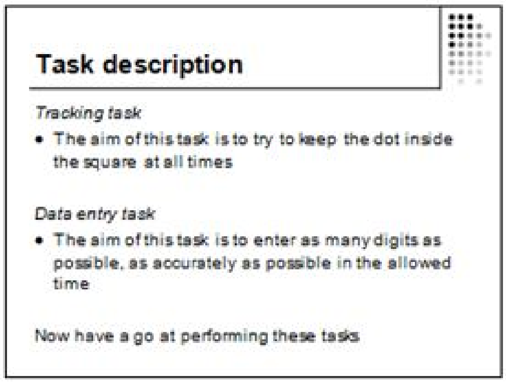
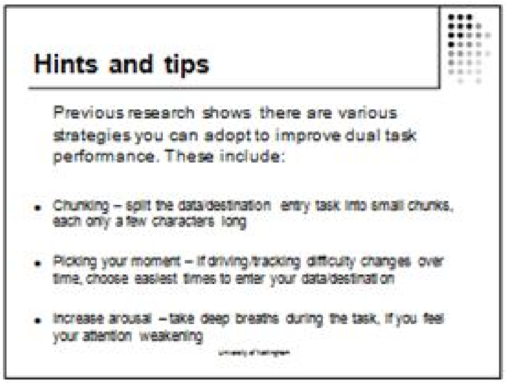

Divided attention - training
Divided attention research in a variety of domains has shown that with practice at both tasks, dual task performance can dramatically improve
Shortly the experimenter will introduce 2 tasks commonly used in divided attention research
A tracking task which simulates some aspects of vehicle tracking on the roadway
A data entry task which simulates destination entry


Task overview
First you will be given the opportunity to try both tasks at the same time
You will then be given some tips and advice drawn from divided attention research
Finally you will be given the opportunity to use these tips while completing both tasks again


Task description
Tracking task
The aim of this task is to try to keep the dot inside the square at all times
Data entry task
The aim of this task is to enter as many digits as possible, as accurately as possible in the allowed time
Now have a go at performing these tasks


Hints and tips
Previous research shows there are various strategies you can adopt to improve dual task performance. These include:
Chunking – split the data/destination entry task into small chunks, each only a few characters long
Picking your moment – if driving/tracking difficulty changes over time, choose easiest times to enter your data/destination
Increase arousal – take deep breaths during the task, if you feel your attention weakening

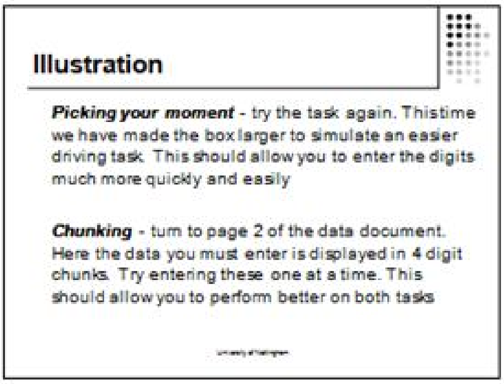


Illustration
Picking your moment - try the task again. This time we have made the box larger to simulate an easier driving task. This should allow you to enter the digits much more quickly and easily
Chunking - turn to page 2 of the data document. Here the data you must enter is displayed in 4 digit chunks. Try entering these one at a time. This should allow you to perform better on both tasks

Appendix AI: Destination entry cards used in the final simulator study

Phase 3

Destination : YEOVIL 5 STARS LANE

Speed limit : 30-40 mph

Distance : 1.2 miles

Time : 2 minutes 30 seconds
(To receive £1 bonus)

Phase 3

Destination : SKETTY 19 THE PARK

Speed limit : 30-40 mph

Distance : 1.5 miles

Time : 3 minutes
(To receive £1 bonus)

Phase 3

Destination : EXETER 4 HARDY ROAD

Speed limit : 30-40 mph

Distance : 1.4 miles

Time : 2 minutes 40 seconds
(To receive £1 bonus)

Phase 3

Destination : NEATH 4 DALTON ROAD

Speed limit : 30-40 mph

Distance : 1.5 miles

Time : 3 minutes 45 seconds
(To receive £1 bonus)

Appendix AJ: Final consent form completed by participants before leaving

It is not unusual to feel disoriented after leaving the simulator. This can manifest itself a variety of ways (including dizziness, headaches, nausea, blurred vision, tiredness etc).

If you suffer any of the above symptoms or feel a need to rest for any reason whatsoever, please alert the experimenter who will provide you with a rest area and refreshment drink.

Once you are feeling comfortable enough to leave here and resume your normal activities (e.g. walking , driving), please sign below to acknowledge you are leaving this session unaffected.

Signature:……………………… Date:…………………….

Please also be aware that you just drove in a simulated environment. **In no way should you attempt to replicate your behaviour in the driving simulator, in any other vehicle.** Please sign below to acknowledge you are aware of this.

Signature:……………………… Date:………………….

Finally, please sign below to confirm that you have received payment of £10 for participating in this study.

Signature:……………………… Date:………………….

Appendix AK: Rothengatter et al`s (1993) driving experience classification scheme

Driving experience level	Indicators
Inexperienced novice	License < 1 year Driven < 1000 km
Experienced novice	License < 1 year Driven >1000km
Inexperienced driver	License 1-5 years Driven <100,000 km in the past 5 years OR License > 5 years Driven < 10,000 km in the past year
Experienced driver	License < 5 years Driven >100,000 km in the past 5 years OR License > 5 years Driven <100,000 km in the past 5 years and driven more than 10,000 km in the past year
Very experienced driver	License > Driven >100,000 km in the past 5 years

Source: Rothengatter, Alm, Kuiken, Michon and Verwey (1993)

Appendix AL

A-priori power analyses for each study in the thesis

T-test: difference between two independent means for small, medium and large effect sizes[1]

(applicable to studies reported in chapters 3, 4, 5 and 7)

	Small effect size (d=0.2)	Medium effect size (d=0.5)	Large effect size (d=0.8)
Tails	2	2	2
Alpha error probability	0.05	0.05	0.05
Required power (input)	0.95	0.95	0.95
Sample size group 1	651	105	42
Sample size group 2	651	105	42
Total sample size	1302	210	84
Actual power (output)	0.95	0.95	0.95

A series of post-hoc power analyses were run after the analysis to determine the actual effect sizes. All post-hoc effect sizes are reported to one decimal place to aid comparisons.

In the studies reported in chapter 3-5, effect sizes for the different analyses ranged from 0.3 to 0.5

In the study reported in chapter 7, effect sizes for the different analyses ranged from 0.6 to 0.8

Correlations for small, medium and large effect sizes

(applicable to the study reported in chapter 7)

	Small effect size (r=0.1)	Medium effect size (r=0.3)	Large effect size (r=0.5)
Tails	2	2	2
Required power (input)	0.95	0.95	0.95
Total sample size	1289	134	42
Degrees of feedom	1287	132	2
Actual power (output)	0.95	0.95	0.95

In the study reported in chapter 7, post-hoc effect sizes for correlation analyses ranged from 0.5 to 0.8

[1] Based on effect size conventions in Cohen (1988).

Mixed model ANOVA for small, medium and large effect sizes

(applicable to the study reported in chapter 8)

	Small effect size (f=0.1)	Medium effect size (f=0.25)	Large effect size (f=0.4)
Alpha error probability	0.05	0.05	0.05
Required power (input)	0.95	0.95	0.95
Number of groups	4	4	4
Total sample size	300	52	24
Actual power (output)	0.95	0.96	0.95

In the study reported in chapter 8, post-hoc effect sizes for ANOVA analyses ranged from 0.2 to 0.4

Appendix AM

Table showing IVNS manufacturers used by respondents in the driver survey reported in chapter 3

Manufacturer	Model	Number of participants	Percentage of participants
Tomtom	Navigator	3	**1.8**
	Navigator 3	1	**0.6**
	Navigator 4	1	**0.6**
	Navigator 5	13	**7.7**
	Go 300	8	**4.7**
	Go 700	3	**1.8**
	Unspecified	12	**7.1**
Total		**41**	24.3
Garmin	Iq 3200	1	**0.6**
	Iq 3600	17	**10.1**
	Iq M4	1	**0.6**
	GPS	3	**1.8**
	Streetpilot	2	**1.2**
	Streetpilot 3	2	**1.2**
	Unspecified	5	**3.0**
Total		**31**	18.3
HP	Ipaq	9	**5.3**
	Ipad	1	**0.6**
	550	1	**0.6**
Total		**11**	6.5
Navman	Pin	2	**1.2**
	Icn320	3	**1.8**
	Icn520	1	**0.6**
	Icn550	3	**1.8**
Total		**9**	5.3
Microsoft	Street and trips 05	1	**0.6**
	Map point	1	**0.6**
Total		2	1.2
Co-pilot	Pocket	1	**0.6**
	Unspecified	1	**0.6**
Total		2	1.2
Destinator technologies	PN	2	**1.2**
	Destinator 3	3	**1.8**
Total		5	3.0
Xda	Xda	1	**0.6**
	Xda11	1	**0.6**
Total		**2**	1.2
Mitek	Mio	6	3.6
I-Nav corporation	Iguidance	16	9.5
Compaq	Unspecified	2	1.2
Car company installed	n/a	**13**	7.7
Homemade	n/a	**8**	4.7
Other	**Numerous**	21	12.4