CRANFIELD UNIVERSITY

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THE IMPACT OF AIRPORT ROAD WAYFINDING DESIGN ON SENIOR DRIVER BEHAVIOUR

CENTRE FOR AIR TRANSPORT MANAGEMENT
SCHOOL OF AEROSPACE, TRANSPORT AND MANUFACTURING
PhD in Transport Systems

PhD
Academic Year: 2015 - 2016

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This thesis is submitted in partial fulfilment of the requirements for the degree of PhD in Transport Systems

ABSTRACT

Airport road access wayfinding refers to a process in which a driver makes a decision to navigate using information support systems in order to arrive to airport successfully. The purpose of this research is to evaluate senior drivers' behaviour of alternative airport road access designs. In order to evaluate the impact of wayfinding, the combination of simulated driving and completion of a questionnaire were performed. Quantitative data was acquired to give significant results justifying the research outcomes and allow non-biased interpretation of the research results. It represents the process within the development of the methodology and the concept of airport road access design and driving behaviour. Wayfinding complexity varied due to differing levels of road-side furniture. The simulated driving parameters measured were driving mistakes and performances of senior drivers. Three types of driving scenarios were designed consisting of 3.8 miles of airport road access. 40 senior drivers volunteered to undertake these tasks. The questionnaire was used as a supporting study to increase the reliability and validity of the research. Respondents who volunteered for the simulated driving test were encouraged to participate in the questionnaire sessions. The questionnaire was answered after each simulation test was completed. The Mean, Standard Deviation (SD) and Two-Way ANOVA test were used to analyse the results and discussed with reference to the use of the driving simulation. The results confirmed that age group has no significant effect of airport road access complexity design on driving behaviour. Although many studies have been conducted on wayfinding in general, a detailed evaluation on airport road access wayfinding network and driving behaviour in respect of senior drivers were still unexplored domains.

Keywords:
Wayfinding; Airport; Senior driver; Driving behaviour; Simulation

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

AA	Automobile Association
AASHTO	American Association of State Highway and Transportation Officials
ACI	Airports Council International
ACRP	Airport Cooperative Research Program
AEF	Aviation Environment Federation
ANOVA	Analysis of Variance
ASCII	American Standard Code for Information Interchange
CAA	Civil Aviation Authority
CCTV	Closed Circuit TV
CSS	Context Sensitive Solutions
DfT	Department for Transport
DKMA	Damien Kobel and Mark Adamson
DVLA	Driver and Vehicle Licensing Agency
F	Variance of the group means
FHWA	Federal Highway Administration
g’s	An acceleration equal to the acceleration of gravity
GIS	Geographic Information Systems
H_0	Null Hypothesis
H_1	Alternative Hypothesis
IAM	IAM RoadSmart
IPROW	Institute of Public Rights of Way and Access Management
LHR	London Heathrow Airport
M4	M4 Motorway
MDS	Minimum Data Set
NASA	National Aeronautics and Space Administration
NSW	New South Wales
NY	New York
Pax	Passenger
RAC	Royal Automobile Club
RoSPA	Royal Society for the Prevention of Accidents
S1	Simulation 1, ‘Less Complex’

S2	Simulation 2, ‘Complex’
S3	Simulation3, ‘More Complex’
SATM	School of Aerospace, Transport and Manufacturing
Sat Nav	Satellite Navigation
SD	Standard Deviation
SDL	Scenario Definition Language
Secs	Seconds
SEREC	Science and Engineering Research Ethics Committee
SOBJ	Static object
SPSS	Statistical Package for the Social Sciences
STISIM	System Technology, Inc. Simulator
TLX	Task Load Index
TNO	Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek
UK	United Kingdom
VTI	Swedish National Road and Transport Research Institute
WHO	World Health Organization

1 INTRODUCTION

Clear wayfinding assists drivers' navigation and represents the complete network of streets, a paradigm shift from traditional road design philosophy. Lynch (1960) explained that wayfinding is the progressive process by which people reach a destination successfully. Carpman and Grant (2002) stated that wayfinding helps people to identify their location, their next destination, and to choose the best route to the intended destination. Montello and Sas (2006) agreed that wayfinding occurs when people need to travel from one place to another on the intended route and direction without accident or delay to reach their destination successfully. Drivers, pedestrians, cyclists, motorists and bus passengers of all ages and abilities should be able to move safely (Harding et al., 2011).

A complete plan of airport road access wayfinding reflects a new way of thinking about how streets are designed and may be put together in a number of different ways as alternative routes to access the airport; however, it must be intentionally designed to serve all potential users. Transport planners and transportation agencies have a responsibility to design, operate, and maintain the entire right of way to enable safe access for drivers, transit users and vehicles, pedestrians and cyclists, as well as for the elderly, children and people with disabilities. A right of way is a legal right allowing the public to pass along a linear or specific route over land or private property (with permission) at all times (IPROW, 2016; UK Government, 2016).

Airport ground access travel, in the UK, continues to be dominated by private vehicle trips (e.g. private car). For instance, private vehicles contribute to 58.6 per cent and 58.3 per cent of transport mode share to London Heathrow International Airport (73.1 million annual passengers) and Gatwick Airport (37.9 million annual passengers), respectively (Budd, 2016; CAA 2015a). Airport travellers preferred the private car when travelling to the airport (ACI and DKMA, 2012; Chang, 2013; Humphreys and Ison, 2005). Birmingham Airport (2006) reported that the private car is the most important means of access to Birmingham Airport, accounting for 88 per cent of passenger trips and 73 per cent of employee trips, which generated nearly 11 million vehicle trips in 2005. Senior travellers (e.g. senior drivers) preferred to drive to the airport and spent more time in the vehicle (Ashford, Mumayiz and Wright, 2011; Chang, 2013). Chang (2013) stated that senior travellers likely to travel by car to the airport due to influence of both physical and psychology factors (i.e. decreasing in eyesight, mobility, strength and cognition).

The airport environment such as airport roadway design can be very complex (Harding et al., 2011). Shapiro (1997) stated that when the airport access area becomes more difficult and time consuming, inadequate access limits the growth potential of airport facilities. In order to deal with airport road complexity, sign systems should be standardised with regards to terminology, lettering style, location and colour (Harding, 2012). Hence, when senior drivers are confronted by a complex environment, they are more easily able to locate sign information if it is presented in a consistent format. ACRP Report 52 highlighted that drivers entering an airport environment bring with them all of their experience and expectations about roadway design and traffic control (Harding et al., 2011). This experience is gained by driving on conventional roads and motorways. Therefore, the more an airport roadway can be made to look and function like a regular road, the more it will conform to driver expectations, which will lead to a safer and less frustrating driving experience. Roadway signs should be considered fundamentally different than airport terminal signs (Harding, 2012; Harding et al., 2011) as users of roadway signs (e.g. car drivers) are moving and their attention should primarily be directed toward the safe operation of their vehicle. Drivers will more easily and safely navigate when they can rely on their previous experience with roadway signs. By making airport roadway signs look and feel like other roadway signs, the needs of the driver are better served.

Airport road access wayfinding is important for this movement and its significance is gathering momentum (Fewings, 2001). Communities find the overall view a valuable approach for providing alternatives to traffic congestion, making places safer and more liveable. Clear wayfinding, navigation and signage play an important role in ensuring that airport roads are sensitive to the needs of all users in the context of the facility that is being designed. For instance, the Federal Highway Administration (2015) has introduced a Context Sensitive Solutions (CSS) programme which complements interdisciplinary network teams working with public and agency stakeholders to tailor solutions to the setting (e.g. preserving scenic, aesthetic, historic and environmental resources) and maintain mobility. Therefore, the following basic wayfinding elements should be considered in designing and developing a complete airport road access wayfinding design:

1. Signage should complement a legible environment and not clutter the streetscape – eliminate the excessive use of posts and columns by mounting signage on existing posts, structures and buildings;
2. Public art should enhance the experiences of those passing without interfering with pedestrian circulation; it should be context-sensitive reflecting the aesthetic, cultural and environmental values of the local area;
3. Seating and benches should be designed and placed appropriately without obstructing movement on the footpath;
4. Tree surrounds should be planted to allow for tree growth without causing a hazard to pedestrians. When installing tree grates, the developers should consider to providing electrical outlets for future feature lighting of the trees; and
5. Rubbish bins should be located for convenient pedestrian use and service access.

These elements in developing a complete street apply not only to road planning at urban or rural levels but also to commercial buildings and road access (e.g. airport road access). All of these elements require airport roadway sign practitioners to plan and design the safest and efficient information signing system for airport roadway users. Therefore, in order to increase safe driving behaviour in airport areas, airport planners are required to be aware of unintentional hazards created by the inappropriate choice or placement of signage and wayfinding in intended airport areas.

1.1 Senior Drivers and Airport Road Access

There are challenges in defining when an individual becomes an elderly or senior citizen. Most developed countries set the age of senior citizens at 65 years old, but in other regions such as Africa, the “senior” threshold is much lower at 50 years (WHO, 2016). Orimo et al. (2006) stated that with recent technology in the medical and health science industry, the average lifespan has increased rapidly, thus, such a definition of elderly to simply include all persons over 65 years might be no longer appropriate for this era with a life expectancy of 80 years. WHO (2016) agreed that a definition of senior is arbitrary and introduces additional problems of data comparability across nations. For example, the MDS Project[1] collaborators agreed at the 200 Harare MDS Workshop to use the chronological age of 60 years as a guide for the working definition of “old”; however, this definition was revisited (i.e. “older” was set at the age of 50 years) due to it not taking into account the real situation of older persons in developing countries.

Therefore, this airport road access wayfinding research set the minimum age of 50 years as a “senior”, and selected 40 senior drivers aged 50 years and above as a sample of the population. The definition of “senior” being aged 50 years and above was set to allow an accepted minimum “older”[2] age (i.e. based on the MDS Workshop case) globally (Kowal, Rao and Mathers, 2003). This research, hopefully, could be extended to be applied to other countries for airport road access wayfinding improvements.

[1] The workshop was convened on behalf of the World Health Organization’s Minimum Data Set (MDS) Project on Ageing and Older Adults in sub-Saharan Africa, by South African MDS Project collaborators Monica Ferreira (Institute of Ageing in Africa, University of Cape Town) and Craig Schwabe (Geographic Information Systems Centre (GIS), Human Sciences Research Council).

[2] WHO (2016).

WHO (2011) reported that the number of people aged 65 and over is projected to grow from an estimated 524 million in 2010 to nearly 1.5 billion in 2050, with most of the increase in developing countries (Figure 1-1).

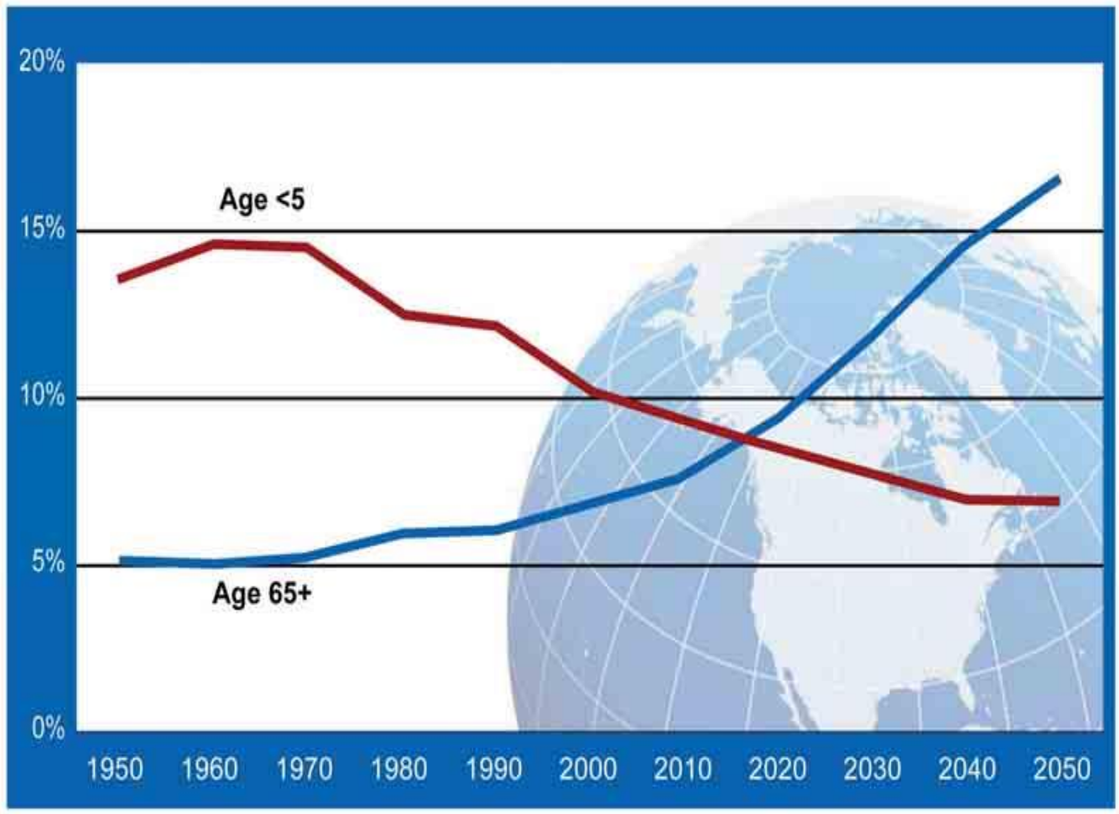


Figure 1-1 Forecasted young children and older people population: 1950-2050 (Source: WHO, 2011)

Driving represents the most significant mode of transportation for senior drivers in terms of mode share and distance travelled (O'Hern and Oxley, 2015). With an increasing ageing population throughout much of the developed world combined with increasing life expectancies, it is necessary to understand travel behaviour, mobility and safety implications of active transport used (i.e. the private car) on airport road access (Budd, Ison and Ryley, 2011; Chang, 2013; Tam, Lam and Lo, 2008) by senior drivers. Understanding senior drivers' mobility and accessibility needs was crucial to ensure that a specific requirement of road access systems is fully provided (Alsnih and Hensher, 2003). The output of this research could be significantly beneficial to airport management, road sign design professionals and airport users, including senior drivers, in the future.

Senior drivers are a large and increasing proportion of the population (National Institute on Aging, National Institutes of Health and U.S. Department of Health and Human Service, 2011; RoSPA, 2010). In 2014, 21,490 casualties were reported as being senior drivers in the UK (Department for Transport, 2015a, 2015b). Senior drivers are commonly involved in road accidents often because of misjudged speed or distance of other vehicles or failing to see a hazard (Department for Transport, 2015c; RoSPA, 2010).

Senior drivers are likely to drive to the airport due to carrying extra luggage and prefer more time spent in the vehicle (Ashford, Mumayiz and Wright, 2011; Chang, 2013). With a current ageing population throughout much of the developed world, there is an imminent need to understand the current transportation requirements (Alsnih and Hensher, 2003; O'Hern and Oxley, 2015) of senior drivers, and to ensure sustained safe mobility and comfort on airport road access (Chang, 2013; Chebli and Mahmassani, 2002; O'Hern and Oxley, 2015). The results confirmed that the wayfinding has importance for the promotion of safe driving behaviour.

Hence, an improvement on airport road access wayfinding design for senior drivers and airport users should be considered by airport management, road sign design professionals and road authorities.

1.2 Problem Statements

Poor wayfinding provision discourages drivers (Burns, 1998; Darken and Sibert, 1996; Montello and Sas, 2006) in airport areas. For instance, people fail to navigate or to find a place the first time because they are unable to understand the complete topological structure of the space (Darken and Sibert, 1996). They cannot perceive the space from a single viewpoint in large-scale spaces

(Passini, 1981; Raubal and Winter, 2002), and have to navigate through extensive areas to locate specific ‘things’ in space (Leversen, Hopkins and Sigmundsson, 2013). Examples of large-scale spaces are buildings, the architectural environment and cities. The space as urban elements (e.g. paths, landmarks and districts) is useful in dividing the environment into smaller and clearly connected parts (Lynch, 1960) from the departure point to the destination in order to navigate to the airport. Taking landmarks as one of the recognised indicators visible to any traveller implies the importance of signage in road design (Weisman, 1979, 1981, cited in Baskaya, Wilson and Özcan, 2004).

Previous literature (Beijer, Smiley and Eizenman, 2004; Burns, 1998; Charles and Haddad, 2007; Darken and Sibert, 1996; Findlay and Southwell, 2004a; Fuller, 2002; Harding, 2012; Harding et al., 2011; Raubal, 2001; Raubal and Egenhofer, 1998; Raubal and Worboys, 1999; Smiley, Houghton and Philp, 2004) discussed wayfinding and signage as having a supporting role in the urban landscape and architecture. The design of signage, wayfinding, roads and the facilities provided for airport building is very important to all travellers, as airports contribute to high growth economies, affect the environment and quality of life. Meanwhile, the government aims to ensure all transportation networks, including airport signage, are protected by effective systems and adequate policies for safe driving behaviour.

The debate concerning visual effects caused by the proliferation of signs and wayfinding along roads has led to considerable discussion by transport planners. This is a major problem which threatens to become greater as more elements are added to roadside landscapes; much of the road furniture is not there to help with road design and it is understandable that transport authorities consider this one of their main priorities (Transport Scotland, 2006). Ineffective signage (Leversen, Hopkins and Sigmundsson, 2013) around airport areas distracts from wayfinding. Harding (2012) stated that many airports have not established the concept of ‘simple, functional and less is more’ for airport signage systems. He suggests a simple wayfinding and sign message could help reduce the overall cost of poor signage systems which make them less attractive and competitive than alternative airports (Alhussein, 2011; Harding et al., 2011). In many cases, drivers experience most difficulty in understanding the complete wayfinding process, resulting in distraction while driving (Bhise and Rockwell, 1973; May, Ross and Bayer, 2005) in airport areas. This distraction (e.g. too much advertising signage) can increase drivers' confusion and raise the risk of accidents (Cuenen et al., 2015; Fofanova and Vollrath, 2011; Mitchell, 2010; Wener and Kaminoff, 1983) in airport road networks. For example, 90 per cent of drivers found that there are too many signs on the road (conventional and motorway) in UK (Mature Times, 2015).

The improvement of airport roadway signage has been made in response to travellers complaints at Bristol International (Bristol International Airport, 2006). The improvement of airport roadway signage also has been made in subsequent of growth in traveller number to the airport. Similarly, in order to increase passengers travelling to and from London Luton Airport, a proposed action plan has been highlighted to improve wayfinding and onward travel facilities for passengers as well as to increase the attractiveness and visibility of road access navigation (London Luton Airport, 2012). In addition, Southampton Airport agreed that due to the finite capacity of airport road space within the vicinity of the airport affects the operation of all airport road access modes. For instance, traffic movements associated with the airport are generated by and respond to a host of variables including passenger choices of access mode and clear directional signage. Therefore, Southampton Airport proposed that a clear directional signage and information on airport road access network is necessary (Southampton Airport, 2012).

Wayfinding has been intensively investigated in previous studies (Baskaya, Wilson and Özcan, 2004; Fewings, 2001; Golledge, 1992; Passini, 1981, 1996; Raubal and Winter, 2002; Woollett and Maguire, 2010). It is only briefly mentioned in urban landscape design studies, in which the functions, design principles and guidelines, and the importance of wayfinding are not described or explained sufficiently. Therefore, more vehicle trips are generated, congestion on roads increases, and communities become more isolated and less liveable (Department for Transport, 2015d); in addition, travellers experience an inadequate airport environment and poor street facilities making wayfinding more difficult.

Previous studies highlighted that the number of signs can have a large impact on airport road surface access. Good positioning is more important than quantity. Having many signs in one place can be ineffective, creating ambiguity and confusion for airport drivers and being visually intrusive (Charles and Haddad, 2007). Two signs that are poorly positioned can be less effective than one that is well positioned. Airport travellers can only absorb a limited amount of information while moving, so overload can lead to confusion and the possibility of drivers executing dangerous manoeuvres (Fofanova and Vollrath, 2011); thus it is better to provide fewer signs of better quality.

In addition, many airport complexes have been developed in a manner that has resulted in unusual roadway layout and design when compared to typical roadway systems (Harding et al., 2011). Airport roadway users (e.g. senior drivers) often have unique characteristics due to their unfamiliarity with the roadway system and integrated facilities, coupled with potentially high levels of driver stress (Matthews et al., 1998; Taylor and Dorn, 2006) caused by tight flight schedules, security warnings, and other factors (Harding, 2012; Harding et al., 2011).

1.3 Senior Drivers and Road Accident Statistics

DfT (2015e) defines three different casualties in road accidents; slight, serious and fatal. A slight casualty relates to an accident which involves at least one person who is slightly injured but no person is killed or seriously injured. It is also recorded as an injury of a minor character such as a sprain (including neck whiplash injury), bruise or cut, which are not judged to be severe or slight shock requiring roadside attention but no further medical treatment.

A serious casualty relates to an accident that includes at least one person who is seriously injured but no person (other than a confirmed suicide) is killed. Serious injury indicates the person is detained in hospital as an “in-patient”, or incurs any of the following injuries whether or not they are detained in hospital: fractures, concussion, internal injuries, crushing, burns (excluding friction burns), severe cuts, severe general shock requiring medical treatment and injuries causing death 30 or more days after the accident. An injured casualty is recorded as seriously or slightly injured within a short time of the accident. This generally will not reflect the results of a medical examination, but may be influenced according to whether the casualty is hospitalised or not. Hospitalisation procedures will vary regionally.

A fatal casualty relates to an accident in which at least one person is killed. In UK, there were a total of 1,775 reported road deaths, 22,807 people reported seriously injured and 194,477 people reported killed or injured in road accidents in 2014 (Department for Transport, 2015a, 2015b, 2015f). The most common contributing factors of road accidents were drivers who failed to look properly (44 per cent of accidents) (Department for Transport, 2015c). This factor has remained the most frequently occurring one since 2005 (Department for Transport, 2015c). The following are the contributing factors to road accidents; failure to judge other person’s speed (22 per cent of accidents); being careless, reckless or in hurry (18 per cent) and performing a poor turn or manoeuvre (16 per cent).

The definition of the road exposure and risk is much less well-defined. The measure of exposure is generally defined as the amount of travel (e.g. by vehicle) (Hakkert and Braimaister, 2002). The number of crashes are associated with the road activity or population, in which, associated risk can be calculated. Risk assessments can be used to improve transport safety and determine public health priorities (Department for Transport, 2015a, 2015b, 2015f; Taylor and Dorn, 2006). Risk is a hazard, chance of bad consequences, loss and exposure to mischance (Table 1-2). The concept of risk is used as a way to quantify the level of drivers’ safety relative to the amount of exposure, as opposed to the absolute level of safety as measured by the absolute number of accidents or casualties (Hakkert and Braimaister, 2002).

Table 1-1, Figures 1-2 and 1-3 show the total number and percentages of senior drivers (aged 50 and above) involved in road traffic accidents in Great Britain from 2010 to 2014. The figures show that the reported number of senior drivers involved in accidents rose between 2010 and 2011 and the number of accidents drastically increased in 2014. Total accidents involving senior drivers increased up to 48,787 in 2011. By comparison, total accidents of senior drivers increased upwards by 0.3 per cent between 2010 and 2011.

From 2012 to 2013, the number of accidents fell by nearly 2,000 from 69,335 to 67,326. The road accidents reduced to 47,377 and casualties decreased to 19,949 in 2013. The total number of accidents fell by 2.9 per cent during this period. However, the number of accidents then drastically rose to 72,545 which indicate drivers involved in road accidents increased to 51,055 and the number of casualties increased to 21,490 in 2014. On average, total accident numbers increased 7.8 per cent in 2014. Table 1-2 shows the contributory factors of the high road accidents rate in 2014 (Department for Transport, 2015c).

Table 1-1 Total number of senior drivers involved in road accidents and casualties from 2010 to 2014 (Source: DfT, 2015)

Accident	Year				
	2010	**2011**	**2012**	**2013**	**2014**
Involved	48419	48787	48737	47377	51055
Casualties	20990	20836	20598	19949	21490
Total	**69409**	**69623**	**69335**	**67326**	**72545**

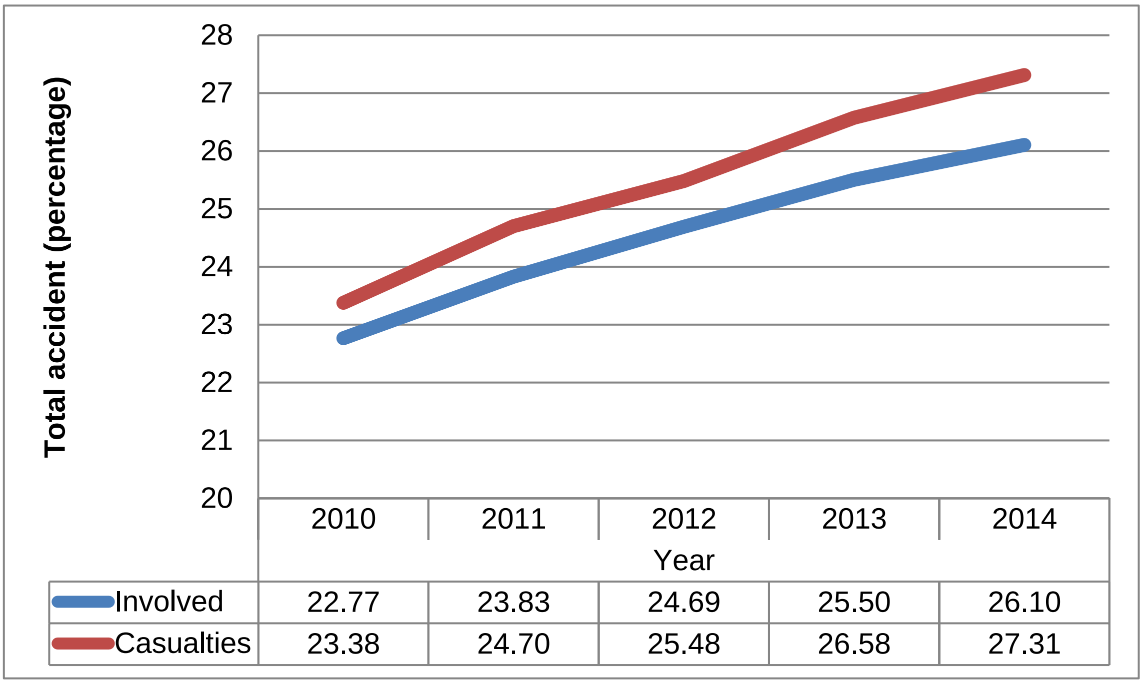


Figure 1-2 Car accidents, casualties and total road accidents in driving by senior drivers (percentage) from 2010 to 2014 (Source: DfT, 2015)

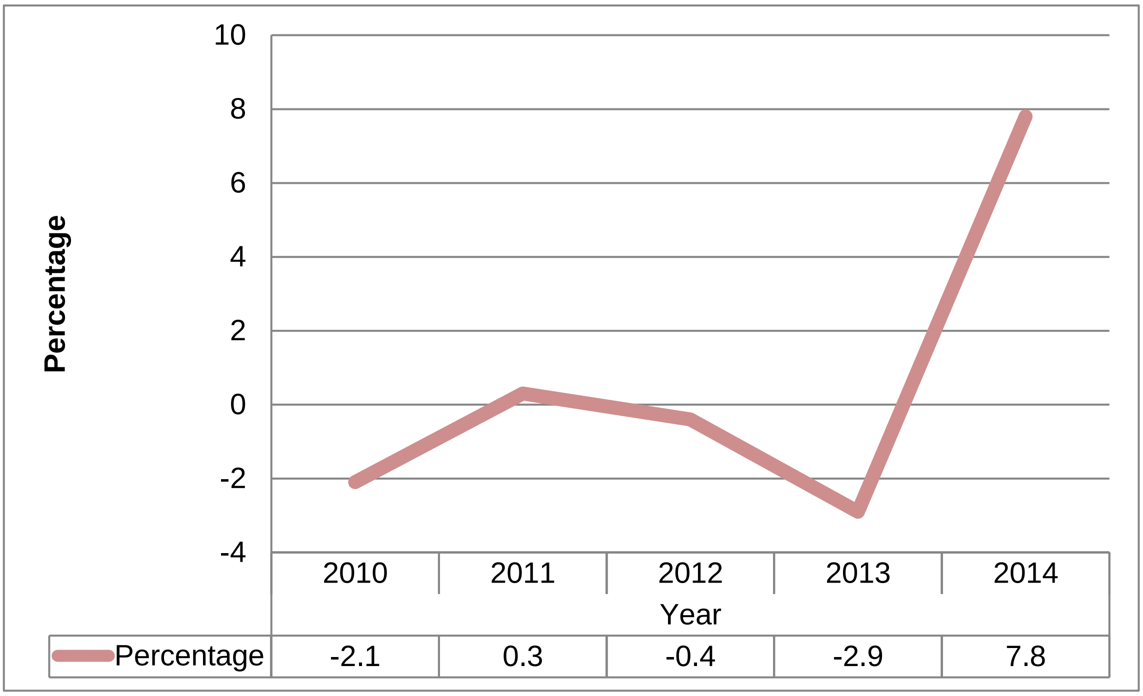
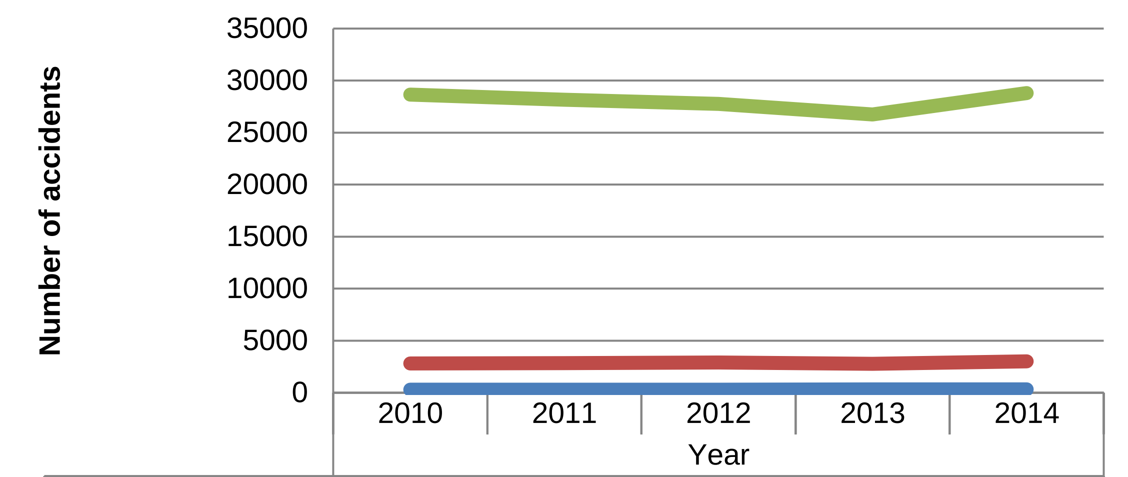


Figure 1-3 Total accidents in driving by senior drivers (percentage) from 2010 to 2014 (Source: DfT, 2015)

Table 1-2 Contributory factors of road accidents by senior drivers in 2014 (DfT, 2015)

Contributory factors	Number	Per cent
	Vehicles	
Failed to look properly	27,264	33.7
Poor turn or manoeuvre	21,392	26.4
Failed to judge other person's path or speed	4,728	5.8
Following too close	6,174	7.6
Slippery road (due to weather)	5,069	6.3
Disobeyed 'Give Way' or 'Stop' sign or markings	2,711	3.3
Loss of control	2,594	3.2
Travelling too fast for conditions	4,270	5.3
Swerved	1,912	2.4
Exceeding speed limit	3,307	4.1
Aggressive driving	1,574	1.9
Total accidents	**80,995**	**100**

Figure 1-4 shows the trends in road accidents and casualties involving senior drivers. It also shows that the number of people killed, seriously injured and severities on roads in Great Britain from 2010 to 2014. The trends of seriously injured and killed on roads are constant each year. The number of all severities fluctuated between 1,000 accidents a year from 2010 and 2013 before rising to 28,798 in 2014. The number of people killed slightly increased every year up to 325 in 2014. In contrast, the pattern of seriously injured has increased fairly steadily and then declined between 2010 and 2014. This pattern is emphasised by the line representing an increase by 0.6 per cent in 2011 as the number of seriously injured increased to 2,841 in 2011. The number of seriously injured then increased to 2,918 people (2.7 per cent) in 2012 before slightly fell to 2,779 in 2013. However, in 2014, the number of causalities and seriously injured drastically increased to 3,017 on the roads.



	2010	2011	2012	2013	2014
Killed	294	301	302	309	325
Seriously injured	2824	2841	2918	2779	3017
All severities	28646	28172	27754	26744	28798

Figure 1-4 Road accident statistics by severities (including passengers) from 2010 to 2014 (Source: DfT, 2015)

1.4 Research Scope

The research focuses on the evaluation of senior drivers' behaviour. It also evaluates the effectiveness of airport road access wayfinding provision, as well as determining the importance of wayfinding (including signage) provision at airports. The aim of airport road access is to provide safe and efficient movement of people and goods using an effective mode of transport. Two basic facilities, which are nodes and routes in transport systems, will be explored in the research. Airports are nodes (terminals) that connect surface access segments with airway segments (routes). In order to connect nodes and routes, wayfinding is the main element in the network. Transport users (e.g. senior drivers) must be able to access the airport using wayfinding, including the provision of safety messages and associated information.

In this research, drivers' wayfinding is defined as a process in which people make a decision (choose) to navigate using information support systems (clues) such as maps, lighting, sight lines, and signage, to arrive at the destination (results) successfully (Chapter 4, Section 4.2). In addition, some design guidelines focus on technical aspects (i.e. dimensions, choice of materials, installation methods, etc.) of signage and wayfinding. Although a number of papers have been written on traffic signs and wayfinding in general, a detailed evaluation of airport road access wayfinding is regarded as original research and adequate for the scope of this study.

1.5 Research Aims, Research Objectives and Research Questions

The aim of the research is to evaluate senior drivers' behaviour of alternative airport road access designs.

Research objectives and research questions are as follows:

1. To measure the impacts of alternative airport road systems on driving behaviour.
   a. What are the key factors that may influence safe driving behaviour?
   b. How should the impacts of alternative airport road access design on driving behaviour be measured?
   c. What are the impacts of alternative airport road access wayfinding design on driving behaviour?

2. To assess the effects on drivers' wayfinding of alternative airport road access design solutions.
   a. Does road access design have an effect on wayfinding?
   b. How should the effects of airport road access design on wayfinding be measured?
   c. How does the receipt of wayfinding information affect driver navigation?

Table 1-3 shows the research contents and the relationship between them.

Table 1-3 Research contents

Research Objectives	Research Questions	Hypotheses	Research Instruments	Analysis Techniques	Source of Data	Respondents
1. To measure the impacts of alternative airport road systems on driving behaviour **(Chapter 3)**	1. What are the key factors that may influence safe driving behaviour? 2. How should the impacts of alternative airport road access wayfinding design on driving behaviour be measured? 3. What are the impacts of alternative airport road access wayfinding design on driving behaviour?	**Null Hypothesis (H_0):** There is no significant effect of airport road access complexity design on driving behaviour. **Alternative Hypothesis (H_1):** There is a significant effect of airport road access complexity design on driving behaviour.	Simulation	1. Frequency Analysis: Mean and Standard Deviation (SD) 2. Two-Way ANOVA	Primary data: Simulation	Senior drivers
2. To assess the effects on drivers' wayfinding of alternative airport road access design solutions **(Chapter 4)**	1. Does road access design have an effect on wayfinding? 2. How should the effects of airport road access design on wayfinding be measured? 3. How does the receipt of wayfinding information affect driver navigation?	–	Questionnaire	Frequency Analysis: Mean and Standard Deviation (SD)	Primary data: Questionnaire	Senior drivers

1.6 Thesis Structure

The thesis consists of five chapters organised as follows:

Chapter Two focuses on a literature review of airport road access wayfinding, its definition and design principles. This is followed by a review of road furniture associated with airport road access wayfinding, the necessity to understand airport users, and definitions of senior drivers in an ageing population. Generally, this chapter explains the characteristics of basic airport road access wayfinding concepts.

Using the driving simulation, Chapter Three evaluates and interprets the results of drivers' behaviour during navigation on airport road access. A driving simulator was used to test the variables and involved several steps during the selection of analytical techniques. Details of the driving simulation, procedures, simulation design and sampling technique are discussed. The simulation model is then explored to access the relationship between drivers' skills, behaviour and accident involvement. The assessment also focuses on driving ability and willingness to take risks on the road. The discussion includes the importance of the current provision of wayfinding (including signage) and drivers' influence on airport road access wayfinding design.

Chapter Four explores airport road access wayfinding in depth. This involves an evaluation of the selected analytical technique discussed in Chapter Three. The questionnaire results are analysed and interpreted, taking into consideration drivers' general experience. By using statistical tests to extract data (from a questionnaire), findings are presented in the form of tables, charts and figures. This chapter also discusses the quantitative method in the research process, which aims to increase the validity and reliability of the research. The discussion includes the importance of the current provision of wayfinding (including signage) to assist navigation, which in turn will influence the design of airport road access wayfinding in the future. The resulting questionnaire is explained, used as a supporting study of the research, in light of current and future provision of airport road access wayfinding design.

Chapter Five concludes the research and provides a summary of the main findings of the research. The findings are used to support the recommendations for future road access and road furniture design. The chapter also evaluates the original aims and objectives and answers the research questions. Figure 1-5 shows the research structure of airport road access wayfinding design.

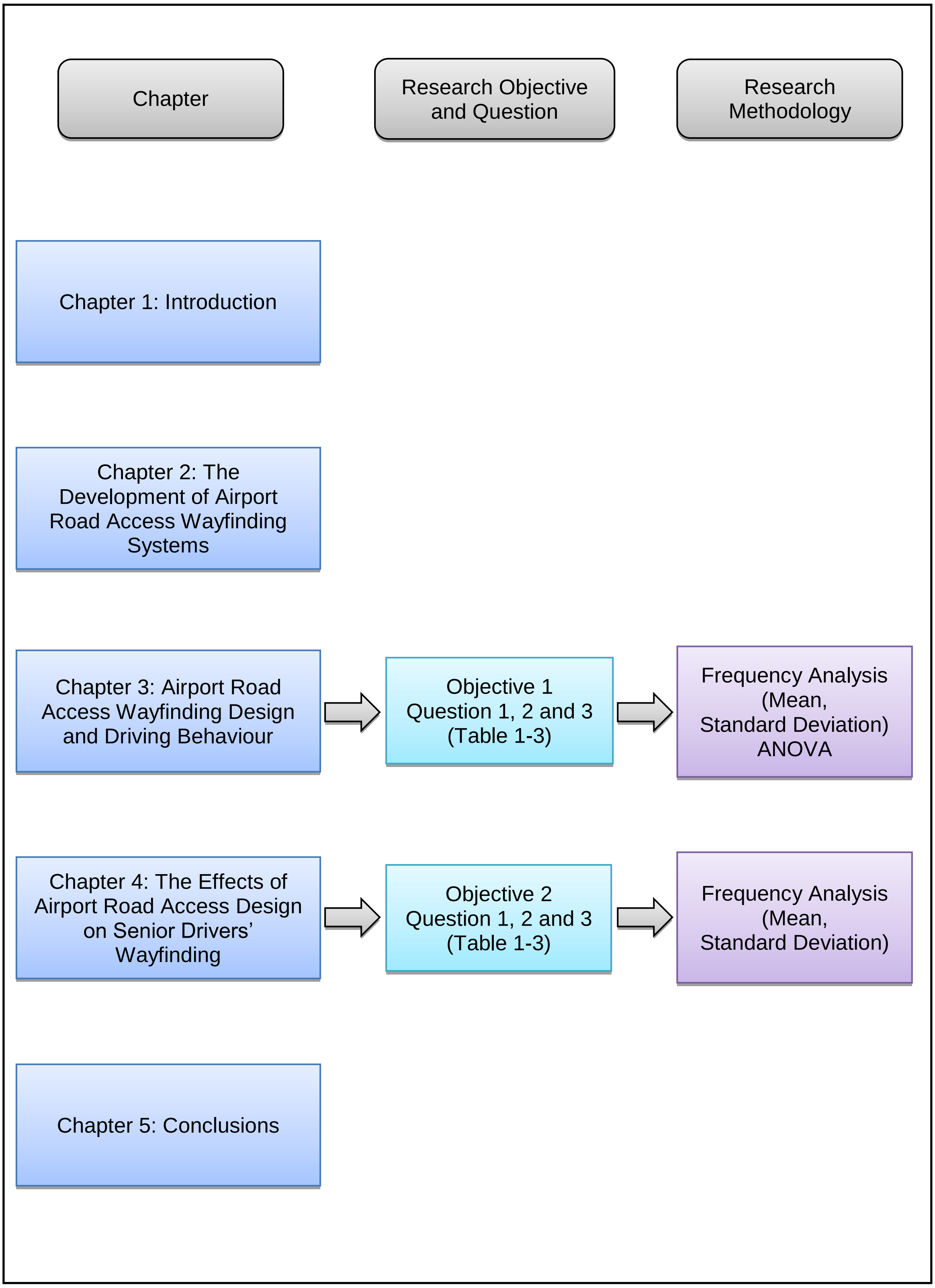


Figure 1-5 Research structure

2 THE DEVELOPMENT OF AIRPORT ROAD ACCESS WAYFINDING SYSTEMS

2.1 Introduction

This chapter discusses the concept and theory of airport road access wayfinding. As discussed in Chapter 1, airport road access wayfinding, accident and incident statistics related to driving behaviour will be further discussed in this chapter. It is important to understand that the aim of this research is to evaluate senior drivers' behaviour of alternative airport road access designs. Section 2.2 defines the road access wayfinding in general, with Section 2.3 then describing the historical review of traffic signs in the United Kingdom. Section 2.4 describes the traffic signs system which encompasses three types of traffics signs such as regulatory, warning and informatory. Section 2.5 describes the airport road access wayfinding design. The concept of airport road advertising being a major revenue source to the airport is discussed in Section 2.6, with Section 2.7 then describing the type of road furniture associated with airport road access wayfinding. Section 2.8 defines senior drivers' mobility and airport road access wayfinding. Chapter 2 concludes with a concept of airport road access wayfinding and the impact on senior drivers' driving behaviour.

2.2 Road Access Wayfinding

Wayfinding is a natural skill which people gradually learn, through using common-sense knowledge of geographic space. They navigate by relying on knowledge that is mediated by structures and categories of people's daily experiences in the space[3] they live (Johnson, 1987, cited in Raubal and Egenhofer, 1998). Wayfinding is intrinsically linked to all forms of transport (i.e. road, rail, sea and air). It is a natural skill that people begin to learn as a child and develop as they grow up. The skill is embraced in many ways such as driving across a country, walking in a city or moving through a building (Piaget,

[3] Space in transportation terminology acts as a generator that supports mobility as it will shape the nature and structure of the transportation system (Rodrigue, 2013).

2013). As technological advances were made, new ways of controlling wayfinding (e.g. including traffic signs) were necessary. Traveller behaviour, environmental design features, operational policies and practices in wayfinding systems are the key elements to efficient road navigation.

Wayfinding is defined as a process in which people navigate an environment using information support systems such as architectural clues, lighting, sight lines and signage as people are interested to find the way from one place to another (Raubal and Egenhofer, 1998). There are various studies (Table 2-1) concerned with the history, process and provision of wayfinding such as those of Emo et al. (2012); Farr et al. (2012); Laurier, Brown and Hayden (2012); Harding et al. (2011); Ahn (2006); Darken and Sibert (1996); Montello and Sas (2006); Baskaya et al. (2004); Lam et al. (2003); Fewings (2001); and Burns (1998). The terminology of wayfinding was described by Lynch (1960) as an attempt to embrace the sequential process that individuals use to reach a destination. Wayfinding occurs when people need to travel along the intended route and direction without having accidents or getting unnecessarily delayed and successfully reaching their destination (Montello and Sas, 2006).

Table 2-1 Summary of previous wayfinding literature

No.	Author	Year	Title	Research Finding
1	Rudolph P. Darken and John L. Sibert	1996	Wayfinding strategies and behaviors in large virtual worlds	Wayfinding strategies and behaviours were strongly influenced by the environmental cues in ways suggested by the basic design principles.
2	Peter C. Burns	1998	Wayfinding errors while driving	Wayfinding errors were caused by a lack of appropriate information and constraints on driver decision-making. Insufficient information, in relation to a lack of signs, was the most common reported cause of drivers getting lost on road.
3	Rodney Fewings	2001	Wayfinding and airport terminal design	Different environmental cues are used depending on whether wayfinding is undertaken outdoors or indoors, and whether the wayfinding conditions are recreational, resolute or emergency.
4	W.H.K. Lam, Mei-ling Tam, S.C. Wong and S.C. Wirasinghe	2003	Wayfinding in the passenger terminal of Hong Kong International Airport	Passenger orientation (wayfinding) is one of the important aspects in airport terminal layout and planning. An evaluation of the ease of passenger orientation in the terminal is necessary to achieve successful passenger orientation.
5	Aysu Baskaya, Christopher Wilson and Yusuf Ziya Özcan	2004	Wayfinding in an Unfamiliar Environment: Different Spatial Settings of Two Polyclinics	A symmetrical layout with repetitive units should be used in accordance with landmarks and spatial representations, which may help a person to recognise places when plan configuration is complicated.
6	Daniel R. Montello and Corina Sas	2006	Human factors of wayfinding in navigation	Human factors were associated to wayfinding design; (1) factors related to human psychology (such as orientation, attention and the automaticity of wayfinding tasks); (2) factors related to the environment (such as differentiation, visual access, layout complexity and sign placement); and (3) factors related to technology (such as the design of information displays in vehicle navigation systems).

7	Joowon Ahn	2006	Wayfinding at the East Campus of Cayuga Medical Center in Ithaca, NY	An effective wayfinding system with intrinsic spatial cues and consistency begins in the initial process of facility planning and development. For instance, directional sign should be available as early as possible before the decision points.
8	James R. Harding Marshall Elizer, Jr. Jim Alderman Matthew J. Frankel, Susan T. Chrysler Christopher M. Poe Laura L. Higgins Curtis Beatty LuAnn Theiss, Alison Smiley Thomas Smahel, James A. Pangburn, Craig Berger and Tom Esch	2011	ACRP Report 52: Wayfinding and signing guidelines for airport terminals and landside	The guidelines propose a wayfinding strategy such as the use of technology and visual displays, colour, fonts, and sizes for airport terminal and landside.
9	Anna Charisse Farr, Tristan Kleinschmidt, Prasad Yarlagadda and Kerrie Mengersen	2012	Wayfinding: a simple concept, a complex process	Human and environmental elements of wayfinding are vital in allowing the elucidation of the factors that have an impact on effective wayfinding.
10	Beatrix Emo, Christoph Hölscher, Jan M Wiener and Ruth Conroy Dalton	2012	Wayfinding and spatial configuration: evidence from street corners	Spatial configuration is an important factor in individual spatial decision-making during wayfinding process.
11	Eric Laurier, Barry Brown and Hayden Lorimer	2012	What it means to change lanes: actions, emotions and wayfinding in the family car	Wayfinding process is associated with the social relationships between passengers, in particular families caring for one another and showing their epistemic and emotional stance.

2.3 Historical Review of Traffic Signs in United Kingdom

Traffic signs were first used by the Romans in United Kingdom (UK) (Department for Transport, 2007) to mark off road distances at one thousand paces (i.e. about one mile) with stones called “milliaries” (miles). Most of the traffic signs’ regulation and its purpose have been implemented based on the recommendations of the Report of the Traffic Signs Committee[4] dated 18 April 1963 (Department for Transport, 2013). The system recommended that the local authorities be responsible for placing approved warning and prohibitory signs (i.e. regulatory) (Local Government Chronicle, 2006). Quadhurst (2016) confirmed that originally, prohibitory signs were designed as a solid red disc, commonly 18” in diameter mounted on a black and white striped pole with a rectangular plate underneath explaining in writing the prohibition, whereas warning signs had a red triangle above the oblong metal plate that had on it both a symbol of the hazard and the hazard in writing beneath.

Realising that signage at the new high speeds demanded far greater standards of legibility from a distance, the government[5] introduced a new road signs system for motorways in 1963 (Parker, 2013). Speed signs were originally in the same format as warning and prohibitory signs but were changed to 18” circular plates with an outer 3” thick red circle and an inner white disc with the maximum speed written in the middle, and have been used until today (Quadhurst, 2016). Table 2-2 displays a chronological review of British traffic signs.

Later development of British traffic signs include the use of yellow box markings at busy road junctions, special signs and road markings at pedestrian crossings, mini roundabouts and bus lanes. Warning signs and a simplified yellow line system were originally introduced in the 1950s. Warning signs then have been used widely to deliver better information on hazards, delays and diversions to road users. As motoring activities became more complicated, the traffic signs

[4] This report is widely known as the Worboys Report, taking its name from the Committee Chairman, Sir Walter Worboys.

[5] The British Government Commissioned Jock Kinneir to develop new signs at Gatwick Airport, UK. The black-on-yellow colour scheme proved to be the airport standard wayfinding.

were adapted to keep pace with the changing traffic demands by the drivers (Parker, 2013).

Table 2-2 Traffic signs chronological review (Source: Local Government Chronicle, 2006)

Year	Description
1903	The Motor Car Act made local authorities responsible for placing approved warning and prohibitory signs. Local authorities, The Royal Automobile Club (RAC) and The Automobile Association (AA), cyclists clubs and concerned individuals initiated traffic signs to warn of dangers ahead.
1904	Regulations set out the form that approved signs should consider the standard design. Traffic signs (i.e. hollow red triangle for warnings, a solid disc for a prohibition, and a hollow ring for a speed limit) were introduced.
1921	The Committee of Traffic Signs recommended additional standard warning signs and a standard format of directional signs for road users. The A and B numbering for roads were introduced.
1922	Britain's first reflecting road sign was installed in Surrey by the AA. Britain's first illuminated road sign was erected in Wrotham by the RAC.
1930	Additional warning signs were authorised such as advance direction signs; 'keep left' and 'keep right'; and warning signs for narrow roads and bridges. Instructions (e.g. 'halt at major road ahead') were given in words.
1964	Implemented regulations[6] on major overhauls of the road signs system were recommended.
1968	The first computerised motorway matrix warning signs were introduced on the M4.
1970	Bilingual signs were authorised for Wales.
1987	The Guildford Rules recommended the best practice of road infrastructures to the public. The Guildford Rules is a colour coding system indicating information on different categories of a route on a single sign (Department for Transport, 2013).

With regards to evolution of traffic signs systems, road designs correspond to drivers' limitations and expectations. Traffic signs systems are also responding

[6] Worboys Report advised replacing the 1904 signs with the continental-style road signs with pictograms (Local Government Chronicle, 2006).

to situations correctly and quickly. For instance, where drivers are not provided with information in a timely fashion and are overloaded with information, their expectations are not met and errors may occur.

In order to assist drivers to make a quick decision, an accuracy of the signage information is required. AASHTO (2010) highlighted four important elements (Table 2-3) when designing traffic signs.

Table 2-3 The elements of signage design (Source: AASHTO, 2010)

Element	Description
Primary	Justification of signs placement in accordance with the importance of information to the driver. For example, speed limit signs should be placed as far as drivers can see.
Spreading	Where the information required cannot be placed on one sign, or, on a number of signs at one location, spread the signage along the road, so that the information is given in small chunks to reduce information overload.
Coding	Where possible, information should be organised into larger units. Specific messages based on the colour of the sign background and the shape of the sign panel should be considered (i.e. warning signs are yellow, regulatory signs are white).
Redundancy	State the same thing (e.g. message) in more than one way. For example, the ‘stop sign’ in North America has a unique shape and message, both of which convey the message to stop. A second example of redundancy is to give the same information by using two devices (e.g. “no passing” message is indicated on both signs and pavement markings).

2.4 Types of Traffic Sign

Traffic signs play a vital role in directing, informing and controlling road users' behaviour in order to make roads safe. The necessity of signs is not just for new drivers needing to pass their driving test, but for all road users, including experienced professional drivers. According to the Department for Transport (DfT, 2013), a sign is a device that delivers a clear visual message, is efficient, readable and is an essential device to road and traffic engineering. The purposes of signs are to control and guide traffic, and promote safety to users (De Ceunynck et al., 2014). For instance, road users are dependent on signing for information and guidance while driving. Highway authorities are dependent on signing for the efficient working and the enforcement of traffic regulations (Road Safety Observatory, 2012). A traffic sign system, therefore, should meet the changing needs of road users and provide effective tools for better management of the road network by incorporating new technologies and minimising the impact on the environment (Department for Transport, 2011a).

As an important device for the road, traffic signs should be able to guide road users from the beginning of the journey until arrival at their destination safely (Harding et al., 2011). Apart from signs on posts, traffic signs should be included on road markings, bollards, beacons, traffic lights and other related road access facilities. The sign information system should have clear information at the right time when needed, not be too complex or too long and be easily understood to enable a quick decision to be made by road users. In addition, the traffic signs' information should appear not too soon or too late to avoid confusion and for safe driving performance of consequent manoeuvres.

Traffic signs are the most numerous type of road furniture and have the potential to create visual effects almost everywhere to road users. When considering signage provision into road access design, the following principles should be applied (Transport Scotland, 2006):

1. The fewest possible signs, of the smallest adequate size, in the clearest and simplest form;
2. Signs should appear to 'float' through the appropriate design of supports, the use of backdrops and colour; and
3. Increasing the number of signs at a hazard can cause more ambiguity and confusion to drivers.

The number of signs creates a huge impact. Having many signs in one place can be ineffective, create ambiguity, confusion and look visually intrusive to drivers. Good positioning is more important than quantity. Two signs that are poorly positioned would be less effective than one that is well positioned. It is better to provide fewer signs for road users. Drivers absorb a limited amount of information while moving, so, overload information leads to confusion and the possibility of drivers executing dangerous manoeuvres. There are three main categories of road signs; regulatory, warning and informatory (Department for Transport, 2013, 2016). Each category has its basic design and function as follows:

2.4.1 Regulatory Signs

These include all signs which give notice of requirements, prohibitions or restrictions. The regulatory signs may be either mandatory or prohibitory. These signs are basically circular in shape and may be supplemented by plates beneath them augmenting the message given by the sign. Figure 2-1 shows examples of regulatory signs.

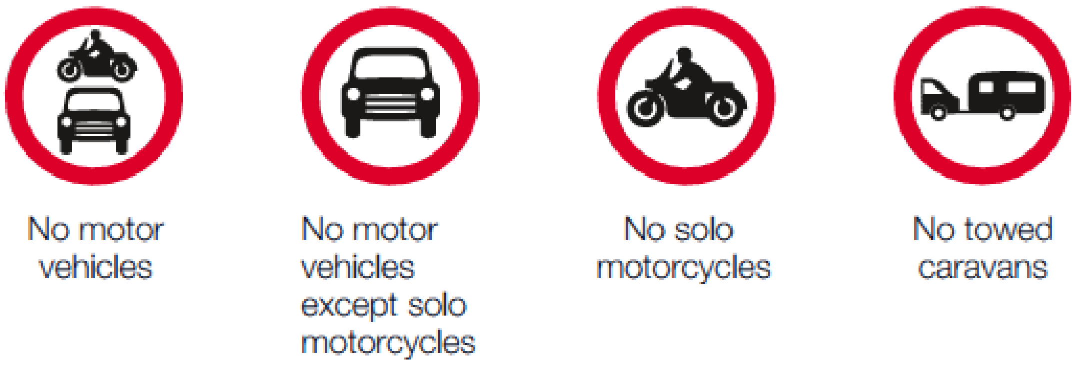


Figure 2-1 Examples of regulatory signs (Source: DfT, 2016)

2.4.2 Warning Signs

Figure 2-2 shows examples of warning signs of a hazard ahead. The design of most warning signs is based on an equilateral triangle having its apex uppermost. The signs are sometimes supplemented by rectangular plates giving additional information to the road users.

Figure 2-2 Examples of warning signs (Source: DfT, 2016)

2.4.3 Directional Informatory Signs

Figure 2-3 displays traffic signs that normally give road users information about the route, places and facilities of particular value or interest. The directional informatory signs are in rectangular shape with one or more arrows pointing to specific locations or attractions. The primary purpose of directional informatory signs is to indicate straight ahead destinations or those reached by a road which does not make a sharp turn from the main carriageway, such as an exit slip road at a grade-separated junction (Department for Transport, 1994).

Figure 2-3 Examples of directional informatory signs (Source: DfT, 2016)

2.5 Airport Road Access Wayfinding Design

Airport road access is defined as the journey that passengers face in getting to and from airports that can be a significant part of the cost of any flight (Civil Aviation Authority, 2015b). There are three categories of airport road access users such as workers, passengers and meeter-greeters (Humphreys et al., 2005). The number in each category will vary between airports depending on such factors as airport size, geographical location and type of airline operations. For instance, UK airports which serve international operations would attract a larger proportion of meeter-greeters (Budd, 2016). An alternative mode of ground transportation for airport surface access could reduce traffic bottlenecks; i.e. the inclusion of a range of public transport options such as taxi, bus and rail

(Coogan, MarketSense Consulting LLC and Jacobs Consultancy, 2008; London Heathrow Airport, 2014; Ryley et al., 2013). Ryley et al. (2013) found that the travellers' behaviour in airport surface access is different from other transportation contexts. For instance, travellers may not use public transport as they have to carry luggage with them (Chang, 2013). Hence the need for sufficient luggage storage capacity on board public transport that is visible throughout the journey or, where appropriate, off-site luggage drop-off facilities. Airport employees needing to access the airport regularly, rely on private car journeys which need high attention from airport management.

With the rapid development of the air transport industry, the ability of passengers to travel worldwide is significantly increased. Airport management receives different challenges to meet the expectation of airport users and roadway designer in order to improve airport passenger experiences such as airport road access networks. For example, airport road access development aims to reduce the traveling time and delay to the airport. The following are the viewpoints of airport management regarding road access wayfinding (Harding et al., 2011):

1. Airport signs are an identity or branding of the airport (i.e. use of similar colour and style of signs), providing a sense of arrival and the beginning of the airport user's experience; and
2. Airport signs should look different to motorway signs.

In contrast, the viewpoints of road sign design professionals are as follows:

1. Airport signs should comply with all traffic signs' regulations and design criteria; and
2. The more an airport road can be made to look and function like a regular road, the more it will conform to driver expectations which will lead to safe behaviour and less frustrating driving experience.

ACI and DKMA (2012) revealed the airport location has a large influence on ground transportation infrastructure development. Airports which are located in the city or very near to the centre faced different challenges to those which are located in a remote area. Many developments of airport road access took into consideration the surrounding areas and the formation of airport cities (Saldıraner, 2013). Even though airports are generally not responsible for managing ground transportation, it is still an essential part of the passengers' experience and will influence their satisfaction, even before they have entered the airport (ACI and DKMA, 2012). Airport management should have authority regarding the planning of surrounding airport landside areas (Saldıraner, 2013). The airport road access needs to be developed with respect to:

1. An airport's areas having business and trade centres, hotels, shopping centres, and adequate public facilities;
2. An airport having multiple transport links (e.g. road, rail and air routes) with all other important cities in regions connect to the surrounding areas (e.g. Heathrow Airport is linked to underground service); and
3. An airport having close relationships with government, local authorities and trade organisations by providing efficient transportation systems, public utilities, and infrastructure. The demand of airport ground transportation gives airport management a major responsibility for the development of airport road access networks.

The transportation access system is one of the important factors affecting airport service quality (Jou, Hensher and Hsu, 2011). Airport service quality contributes to overall airport attractiveness (Fodness and Murray, 2007; Lubbe, Douglas and Zambellis, 2011). Therefore, airport service quality is a function of the convenience of airport staff and travellers to drive to or from the airport. The airport authorities and road planners are responsible for providing a good airport ground access transportation systems (Neufville and Odoni, 2003). According to Tsamboulas and Nikoleris (2008), travellers prefer to have a short distance journey, even though they may have to pay more for the service. The transportation service providers and operators need to review the passengers preferences related to access modes' characteristics and service levels in order to develop airport road access wayfinding to and from the airport (Coogan, MarketSense Consulting LLC and Jacobs Consultancy, 2008).

Given the capacity of an airport landside transportation system, the growth of aviation industry produces road congestion which, in turn, worsens the quality of the landside environment and has the consequence of limiting the convenience of travellers arriving at and departing from the airport. The provision of a rapid and convenient access transportation system delivers significant benefits to the operation of an airport and its potential users. As a result, the development of efficient airport road access wayfinding is required to thereby provide better access to the airport terminal building.

Figure 2-4 shows that there are large regional variations in terms of ground transportation modal splits (percentage of passengers) by mode of transport to get to the airport. The use of private cars in the Middle East (56 per cent) is the highest, followed by North America (49 per cent) and Africa (47 per cent). In Europe and Asia, 37 per cent and 34 per cent of travellers used the car to get to an airport, respectively. Latin America and Caribbean travellers were frequent users of taxis (27 per cent) and buses (21 per cent).

Holiday destinations packages regularly include bus transfers between the airport and the hotels. Train and subway were the most popular (16 per cent) in Europe where distances are smaller, and population density is higher, and where use of public transportation is most widespread. The vast majority of passengers, employees and visitors used the road system at some point, whether they arrive by car, taxi, coach or bus.

For example, car (includes private car and taxis) is by far the most important means of access to the airport, accounting for 88 per cent of passenger trips and 73 per cent of employee trips. As a result, it generated nearly 11 million vehicle trips in 2005 (Birmingham International Airport, 2006). According to Birmingham Airport (2006), around 85 per cent of passenger miles were travelled by private car. Jou et al. (2011) and Budd, Ison and Ryley (2011) confirmed that travelling to the airport with their own car gave travellers the most convenience and independence. However, travellers preferred not to pay higher travelling costs (such as parking fees and fuel cost) imposed by airport authorities Jou et al. (2011).

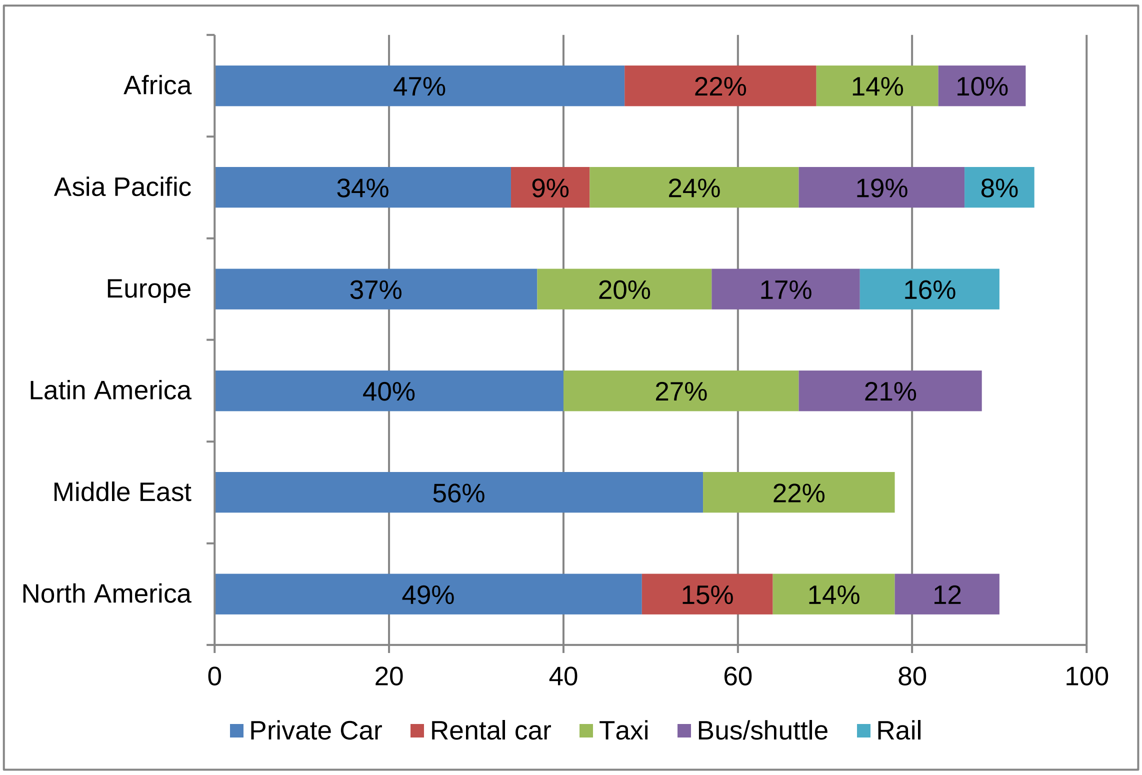


Figure 2-4 Ground transportation mode by region (Source: ACI and DKMA[7], 2012)

2.6 Advertising and Airport Road Access Wayfinding

Airport road advertising is one of the important signs that serve as an airport identity and branding in order to generate commercial revenue for the airport (Harding et al., 2011). Advertising as a landmark (Watanabe, Kaji and Kawaguchi, 2012) at the airport landside is important to both business and leisure passengers. Mitchell (2010) stated that road advertising is useful both

[7] DKMA is a leading provider of passenger research and advisory services.

for business, in terms of suppliers of goods and services, and for the road users as consumers. Eye Airports (2014) found that airport road advertising gives positive impacts to the airport brand and revenue. A survey conducted by Eye Airports in November 2014 at Manchester Airport found that of 207 passengers who were travelling for business purposes, 93 per cent were influenced by the advertising information.

Advertising is a legitimate form of roadway sign design that takes a few seconds only for people to read (Queensland Government Department of Main Roads cited in Mitchell, 2010). With regards to leisure purposes, adverts transfer useful information to airport users (i.e. drivers, pedestrians and the public) while they are navigating to the airport. In order to draw travellers' attention to read it, the advertising should be attractive and effective.

There should be a clear distinction between airport road access wayfinding and advertisement information. The use of logos and branding should not be used on any airport road access wayfinding (i.e. traffic signs). Adding logos to these will only add to drivers' confusion, and remove any subconscious association with the primary, secondary or tertiary messages on the wayfinding signage. However, there is an exception when displaying the logo of regulatory information (National Passenger Facilitation Committe, 2011). For example, 'no parking' signs with the Driver and Vehicle Licensing Agency (DVLA) logo on such regulatory signs is acceptable to endorse the regulator (Figure 2-5). This is important to deliver a clear message to drivers to avoid any traffic law violation that may increase the risk of collision.

The following suggestions may apply for advertising activities on the airport road access (National Passenger Facilitation Committe, 2011) (Chapter 4, Section 4.6.6):

1. Road advertising information should never impede or distract a passenger from wayfinding or the operational information;

2. The needs for advertising should not be more important than airport road access wayfinding signage (i.e. directional signs);
3. Advertising should not obstruct a navigational route or clear sight lines; and
4. Advertising should be identical in terms of colours.

Although, advertising is an important signage for airport, it must not be a trade-off with road users' safety. Drivers do not attend to every sign and it is probably not cognitively manageable or safe for them to do so. Instead, the wayfinding should be available in a useful form to help the driver. A well-designed airport road access wayfinding should be appropriate to all types of drivers under a variety of driving conditions.

Figure 2-5 An example of symbols or logos on regulatory signs (Source: Mirror, 2015)

2.7 Road Furniture Associated with Airport Road Access Wayfinding

Surface access refers to structures found within a road corridor, whether the road is a motorway or a country lane (Transport Scotland, 2006). It includes road signs of all descriptions such as variable message signs (VMS)[8] and signs to provide directions to tourist destinations (e.g. lighting, safety fences, barriers, bollards and verge marker posts, bus shelters, telephone kiosks, telephone and other control pillars), and related objects placed by utility companies, the most recent being mobile phone masts. For example, the Motorcycle Council of New South Wales (NSW) (2015) stated that the surface access includes fixtures on the road access such as steel covers, traffic domes (i.e. silent cops) and lane markers, all of which can create a hazard for a motorcycle.

Road furniture relates to the objects and facilities that provide various services and functions in public spaces and road access. Road furniture includes that introduced for comfort and convenience for the road users in urban environments. Safe road furniture (i.e. in relation to automotive and motor vehicles, bicycles and any other means of going along the road) increases the awareness of safe driving behaviour to transport users (Department for Transport, 2015g). Road furniture indicates locations to road users, such as traffic signs to identify public highway location; however, the instalment of road furniture (e.g. light poles, signposts, bus shelters and crash barriers) may cause injuries if a motorcyclist is thrown against them.

Road access to and from the airport through the provision of a convenient and safe wayfinding for the road user is crucial (Ryley et al., 2013). A well-designed airport road access wayfinding (including road furniture) represents a good image of a city and country and plays as an important role in establishing the identity of the city and country in the mind of tourists and business visitors.

A number of guiding principles associated with airport road access wayfinding design have been developed that help travellers to find their way instinctively through the airport process by using; landmark and airport identity, creation of

[8] STISIM Driving Simulator Version 2 was built without VMS application.

well-structured roadways, surface access sight lines, decision points, maps, street lights, and lighting on wayfinding routes (National Passenger Facilitation Committe, 2011 updated by Author, 2016).

2.7.1 Landmark and Airport Identity

The use of landmarks (either visual or sound) would increase the chance of a driver remembering a particular area in an airport road access. The landmarks serve as a navigational clue and drivers' orientation by determining the present location within the airport area (Farr et al., 2012; Siegel and White, 1975, cited in Raubal and Worboys, 1999). An important aspect of a landmark is visibility; ability to stand out and be seen from a long distance. Landmarks are useful in order to remember the distinctive location and required decision when they drive on the same route in the future. Visual landmarks vary in size, from large-scale landmarks in wide open areas, or local landmarks which are smaller in size, to be seen only in the immediate vicinity.

Building design and structures enable a driver to intuitively move towards a particular area or zone of the journey through the use of road access and road furniture. Distance before decision points is important for a driver to be able to absorb and process information that has been presented to them, whether this is a signage, map or by other sources. The driver must be able to relate the information to the space they are in. Each location in the airport landside should be unique for the driver's perception of each location related to the greater surrounding space to and from the airport. It will increase driver's capacity to identify the exact location and orientation by linking it to the larger space. An identifiable feature increases the chance to remember aspects of the road path and assists in rebuilding a cognitive map when making decisions throughout the journey.

2.7.2 Create Well-structured Roadways

A roadway should be well-structured and continuous, with a clearly defined start, middle and end from each direction. A roadway should link to the current position in the path and show how far drivers have progressed, including the distance to the destination, along the roadway. A clear signage, road marking and reaffirming environment ahead could assist drivers to navigate.

2.7.3 Surface Access Sight Lines

Sight lines as shown in Figure 2-6 are an important feature for an access or junction which provides a wide and extensive view in a particular direction to the drivers. The use of long sight lines maximises the outlook of the onward journey. For instance, first-time drivers to an airport may have uncertain expectations as to its extent and purpose; therefore, visibility splays and sight lines are valuable means of giving enough information about the road environment ahead. A sight line assists the driver to understand that environment ahead, especially in an unfamiliar space, or to make a quick decision to continue road navigation. Sight lines encourage drivers to steer forward in a particular direction and are a cue for the senior driver. Baskaya et al. (2004) stated that when people navigate within an unfamiliar area, they will use cognitive and spatial knowledge to find the direction with few errors. However, past experience and knowledge helps them to navigate in such unfamiliar areas. Raubal (2001) confirmed that people are dependent on external information which resides in the environment and communicated through signs and architectural clues.

Sight lines are useful as an alternative to a sign. Instead of informing drivers of a destination using a sign, they can view the area (even if it may be far away). A sight line is used to reduce the amount of information that needs to be displayed at a decision point. It helps drivers to move ahead farther by providing selective views into a larger space.

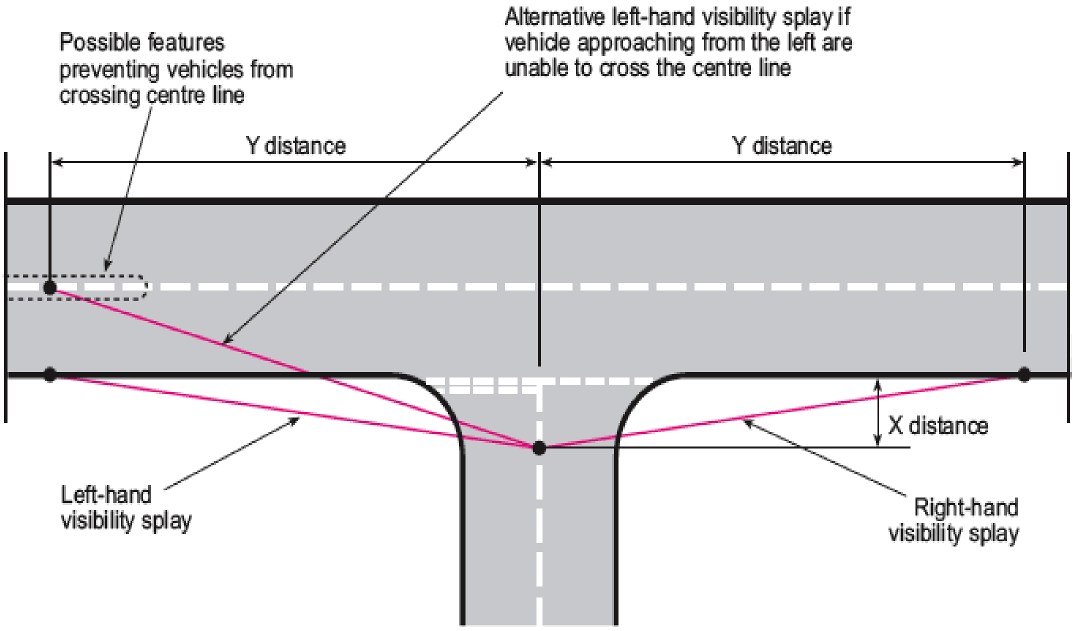


Figure 2-6 Visibility splays and sight lines (Source: Speed Survey, 2016)

2.7.4 Decision Points

Decision points are where a driver should make a decision regarding which path they should take on their onward journey (Raubal and Egenhofer, 1998). Signage is critical at decision points and should contain enough information to confirm which way they need to navigate to the airport. When a driver approaches a decision point, combined observations of the road characteristics and information previously gained is important to make their next directional step. As such, drivers who have no experience on their visited route, and do not have reference tools such as a map, may need to rely on navigational information provided (such as directional traffic signs) to know that they are on the correct route.

The following are suggestions to improve the effectiveness of decision points in airport road access wayfinding design:

1. Place an airport road access wayfinding sign where it is necessary or important to ease drivers' navigation and make an accurate decision;
2. Use colour, height and dramatic lighting to break the repetitiveness and define zones;
3. Prepare a driver and then notify them with the range of options available before they reach a decision point. This could be created by a gradual change in the colour or lighting before they approach a decision point; and
4. Avoid any distractions directly prior to a decision point (e.g. signs that may confuse the driver should be removed).

DfT (2013) suggested the following guidelines of signs placement at decision points as:

1. Signs contain navigational information that is authoritative and unambiguous. The signs are necessary to be placed at a decision point if the cost of making a wrong choice is higher or sufficient information is unavailable for drivers to make a correct choice;
2. Signs provide direction information which ease drivers (including senior drivers) to reach the final destination;
3. Landmark is important as a memorable place that could be used as a point of reference;
4. Immediacy – the closeness of the next destination; and
5. Utility – the goal of wayfinding is to complete the navigational task.

2.7.5 Maps

A map is a valuable navigation aid when driving in complex environments. It places the entire space within the navigator's view. There are several kinds of considerations that can be readily made in order to improve wayfinding performance (Hölscher et al., 2007; Pohlmann and Traenkle, 1994) of drivers' navigation:

1. The drivers' location and immediate vicinity;
2. The availability of alternative routes; and
3. The size of the space and distance on the chosen routes.

Although, it may seem beneficial to provide a map, there may be sufficient wayfinding aids (i.e. signs and landmarks) already embedded in the space to make a map unnecessary. Maps or directories are 'stop and read' resources and are not good for large numbers of drivers moving in the same direction. Ishikawa et al. (2008) agreed that a map requires a great understanding of its relationship and the represented space on the map, which are not tasks to accomplish. Maps can be beneficial to people who have more time to stop and determine where they are or want to go to (for instance, on entry to the airport or in the departures area). Therefore, drivers are only able to look at the bigger picture and also demand secondary and tertiary information, such as road furniture or other landmarks.

2.8 Senior Drivers and Airport Road Access Wayfinding

Airport road access wayfinding will be beneficial to senior drivers as well as to first time travellers and frequent flyers. There are three major environmental factors that affect the ease of senior driving orientation and wayfinding to the airport (Harding et al., 2011). Firstly, the sign design of the driving environment should be distinctive and different. Airport 'directional arrow' signs should be bigger, with bold text, using different colours and symbols than other signs. The airport landside signs should be identical in term of size, colour and style to be compared with current motorway signs. Therefore, it is very important that airport signs adhere to copy, styles and sizes, consistent terminology and symbols and uniform colours of the basic guiding principles standard functions. Message contents should be easily understood by airport travellers. For instance, first time drivers require different information to navigate to the airport compared to frequent flyers.

Secondly, some attributes in the driving environment can be seen from various viewpoints (Leversen, Hopkins and Sigmundsson, 2013). For example, the less complex road design with a 'comfort' driving environment allows senior drivers to view the routes and landmarks more easily and distinctively. Adding more to that, in some attributes of complex road design, senior drivers required sign direction to be displayed as far as possible along the route to the airport.

Thirdly, as age increases, it is certain that general health and fitness will begin to deteriorate, which leads to road accident risks. Senior drivers felt that their driving experience skills and driving abilities may not be as good as they once were (Leversen, Hopkins and Sigmundsson, 2013). As a result, senior drivers likely to control their driving experience and develop a more defensive and cautious driving behaviour as they grow older. The senior drivers are commonly involved in collisions, occurring often because they misjudge the speed or distance of other vehicles or fail to see a hazard (National Institute on Aging, National Institutes of Health and U.S. Department of Health and Human Service, 2011).

2.9 Chapter Conclusion

A complete airport road access wayfinding allows senior drivers and airport users to find their direction to the airport intuitively. Senior drivers instinctively search the road and cues as to where to go next on their journey. If a journey unfolds in an understandable way, senior drivers are able to read the environment and make a quick decision to continue their journey. The key points from this chapter are summarised as follows:

1. Using landmarks to provide orientation cues and memorable locations is highly recommended. Landmarks help senior drivers to visualise their present position (i.e. location) and next intended destination. A landmark can be of a large scale so that senior drivers are able to view it from a wider area or a series of well-located architectures, such as significant street trees, a park or distinctive building.

2. Consistent signage at decision points should be provided in order to help senior drivers' wayfinding and with minimum signage installed to avoid confusion.

3. Clear visual lines should be enhanced to allow the senior drivers to see what is ahead and how to get there easily and with safe navigation from that point to the destination.

4. Avoid excessive signs information which can be confusing during navigation to the airport.

5. Navigating to unfamiliar spaces or a first-time drive to an airport consumes a lot of time and creates a stressful journey if drivers are unable to make a quick decision at decision points. Airport road access wayfinding should be efficient to facilitate and navigate senior drivers to the airport.

Airport road access is the portion of the public right-of-way that provides a separated area for people or senior drivers travelling. Safe, accessible and aesthetical roadways may encourage driving to the airport. Creating a complete airport road access environment involves more than laying down a road lane or installing a traffic sign. A truly viable road access system involves both the big picture and the smallest details, from how and why the road is built, to what type of traffic signs are installed and with a consideration of the architectural design.

Accessible design is the foundation for airport road access wayfinding and should be planned, designed, operated and maintained so as to be usable by all drivers including senior drivers.

In order to develop airport road access wayfinding which is accessible to senior drivers, several functions of road transport should be considered as follows; (1) *Linkage*; Airport road access connects cities to the airport area, an airport building to another, and to activities and places (e.g. roadway, traffic signs, pavement, information board and wayfinding); (2) *Transportation;* Airport road access provides the surface and structure for a variety of road transport modes (e.g. private car, taxis and buses). Airport road access for motor vehicles, emergency services, and maintenance services for airport purposes should be developed; (3) *Access*. Airport road access provides public access to the airport terminal, car parking space or other airport buildings; (4) *Public right-of-way;* Space for utilities and other infrastructure is usually a hidden function of the street. Airport users have the right to access some roadway in the airport ground's area; and (5) *Sense of place;* The street is a definable place which is a place for people to interact; it is the heart of a community.

Finally, the traffic signs (element of wayfinding) for car drivers (including senior drivers) should be considered fundamentally differently than to the terminal interiors design (Harding et al., 2011). The traffic signs' users are in moving vehicles at much higher speeds. The focus should primarily be directed at road lanes and safe driving manoeuvres, including interaction with other objects such as pedestrian crossings and warning signs. Therefore, senior drivers will be safer and find it easier to navigate by using their previous experience of the airport roadway signs. Harding et al. (2011) also highlighted that by making airport roadway wayfinding (i.e. traffic signs) look, feel and operate like other roadway signs, the needs of the drivers (including senior drivers) are better served.

3 AIRPORT ROAD ACCESS WAYFINDING DESIGN AND DRIVING BEHAVIOUR

3.1 Introduction

Research objectives and research questions are revisited as follows:

To measure the impacts of alternative airport road systems on driving behaviour.

1. What are the key factors that may influence safe driving behaviour?
2. How should the impacts of alternative airport road access design on driving behaviour be measured?
3. What are the impacts of alternative airport road access wayfinding design on driving behaviour?

Chapter 3 reveals the research on airport road access wayfinding design and driving behaviour. It discusses standard designs of airport road access wayfinding, which take into account the senior drivers' preferences to navigate to the airport and the importance of safe driving behaviour in the airport area.

Section 3.2 generally discusses accident rates at selected UK airport road access. Drivers' characteristics mainly being focused on drivers' attention, ability to process wayfinding information and vision will be discussed in Section 3.3. The impact of airport road access wayfinding design on senior drivers' safe behaviour are covered in Sections 3.4 and 3.5, with Section 3.6 considering the factors to be measured in simulated driving scenario tests. Research methodology focussed on airport road access wayfinding design and the impact on senior drivers' behaviour is measured in Sections 3.7, 3.8 and 3.9. An analysis of driving simulation data using Frequency Analysis and Two-Way ANOVA tests is presented in tables and graphs in Sections 3.10 to 3.13. Contributory factors that lead senior drivers to suffer road accidents and perform unsafe driving behaviour are identified in Section 3.14. Chapter 3 concludes with a validation of the driving simulator in airport road access wayfinding research with an inclusion of a summary of the drivers' mistakes and performance during the simulated driving trial.

3.2 Business and Leisure Travellers and Accident Rates at Airports

Airport travellers are basically categorised into two groups; business and leisure. Business travellers are likely to know the most efficient, reliable and cost-effective means of accessing the airport (i.e. they attach a higher value to time and their willingness to pay for trips to and from the airport (Coogan, MarketSense Consulting LLC and Jacobs Consultancy, 2008; Shaw, 1985, cited in Pagliari, 2005; Ryley et al., 2013). Leisure travellers (i.e. includes holidaymakers, visiting friends and relatives, and weekend with friends) have been traditionally regarded as time-rich, highly price sensitive people with preferences exhibiting a strong seasonal pattern peaking during holidays and festive periods of the year (Papatheodorou and Lei, 2006).

Business and leisure travellers expect the ground transportation to be efficient, comfortable and not stressful while they make use of the airport. ACI and DKMA (2012) stated that the business and leisure passengers preferred ground transportation (i.e. private car) to reach the airport area. Travellers satisfaction with ground transportation is influenced by some factors such as cost, duration and comfort. Coogan, MarketSense Consulting LLC and Jacobs Consultancy (2008) agreed that frequency of trips, duration of trips and sensitivity of passengers to time will affect a passenger's decision to use ground transportation to the airport. Harvey (1986) cited in Jou et al. (2011) and Tsamboulas and Nikoleris (2008) also agreed that the time and cost were the main contributing factors to making a better choice of airport access mode. For instance, business travellers may have more information available on access options at specific airports because they make more trips by air than travellers for leisure purposes (Coogan, MarketSense Consulting LLC and Jacobs Consultancy, 2008). The travellers who visit airports to use commercial airlines are likely to be travelling for business purposes than long distance travellers as a whole (Coogan, MarketSense Consulting LLC and Jacobs Consultancy, 2008). In addition, 41 per cent of passengers on commercial airlines are travelling for business purposes (Coogan, MarketSense Consulting LLC and Jacobs Consultancy, 2008). Generally, travellers (i.e. for vacations or visiting friends and relatives) have a high propensity to undertake their journey by car rather than by airplane, as 64 per cent of UK national long distance trips are for leisure purposes. In contrast, 49 per cent of travellers who visit an airport to use commercial airlines are doing so for leisure purposes.

Table 3-1 shows the number of road accidents at UK airports from 2010 to 2014. Ten airports with the highest road access accidents and incidents have been highlighted. Table 3-2 shows road accident statistics per passenger from 2010 to 2014 at UK airports**.** Traffic accidents on airport roads are influenced by human, vehicle and environment (Mamais, 2009). From Table 3-1, six airports show more than 100 reported casualties on airport roads. London Heathrow Airport (LHR) has the highest reported casualties in five years (542 casualties), followed by Gatwick Airport (199 casualties), Edinburgh Airport (190 casualties), Glasgow Airport (160 casualties), Manchester Airport (137 casualties) and London Luton Airport (100 casualties).

In 2014, London Heathrow Airport experienced 129 reported accidents (0.00103881 per cent per passenger) on the airport road which was higher than other airports in the UK. There were 542 reported accidents in five years (484 of slight casualties, 49 of serious casualties and 9 of fatal casualties). As a comparison, total casualties increased by 38 per cent in 2013. Table 3-1 also shows higher casualties reported at Heathrow road access in 2014. Heathrow is the biggest and busiest airport in the UK and Europe by passenger traffic, and the third busiest airport in the world by total passenger traffic (London Heathrow Airport, 2016). Heathrow was also the most visited airport by all modes of transport (e.g. private car, taxi and bus) in 2014 (Department for Transport, 2015f). Travelling by private car (i.e. 29 per cent) is the second largest mode of transport preferred by travellers to reach Heathrow Airport after taxi (30 per cent). As the busiest airport in the UK with 7.5 million visitors as at March 2016, Heathrow Airport is exposed to the risk of road access accidents. The contributory factors to road accidents at Heathrow could be of failure to look properly and failure to judge other person's path or speed (Department for Transport, 2015c, 2015f) which led to the development of the research objective (Chapter 1, Section 1.5).

Gatwick Airport notified as having 199 reported casualties in five years (zero fatal casualties and 18 serious casualties). For example, accident per passenger at Gatwick Airport road access declined to 0.00029677 per cent in 2014 (Table 3-2). Edinburgh Airport, in contrast, shows zero fatal casualties in five years and zero serious casualties in 2014. Serious casualties have gradually declined since 2012 at Edinburgh Airport. Reported serious casualties at Glasgow, Manchester and London Luton Airport have been gradually declining since 2010.

In addition, the serious casualties dropped by 80 per cent at Glasgow Airport and 63 per cent at Manchester Airport in 2014. However, the fatal accidents rose 100 per cent at Glasgow Airport in 2014. London Luton Airport reported one serious and fatal casualty, respectively, in five years. For instance, accident per passenger at Luton Airport road access reduced to 0.00028942 per cent in 2014 (Table 3-2). Accidents at the airport road access are mainly due to increased traffic near an airport area (AEF, 2008). AEF (2008) suggested that using public ground transportation such as bus and train would help to reduce road accidents at the airport road access.

Figures 3-1, 3-2 and 3-3 show slight, serious and fatal casualty rates at UK airports road access from 2010 to 2014.

Table 3-1 Road accident statistics at UK airport landside from 2010 to 2014 (Source: CrashMap, 2015)

Airport	Incident Severity	Year / Pax					Total (Pax)
		2010	2011	2012	2013	2014	
London Heathrow	Slight	102	84	109	71	118	484
	Serious	11	12	10	7	9	49
	Fatal	0	4	1	2	2	9
	Total	**113**	**100**	**120**	**80**	**129**	**542**
Gatwick	Slight	31	29	39	41	41	181
	Serious	3	7	6	0	2	18
	Fatal	0	0	0	0	0	0
	Total	**34**	**36**	**45**	**41**	**43**	**199**
Edinburgh	Slight	43	33	27	33	39	175
	Serious	2	8	4	1	0	15
	Fatal	0	0	0	0	0	0
	Total	**45**	**41**	**31**	**34**	**39**	**190**
Glasgow	Slight	22	34	20	12	22	110
	Serious	10	27	4	4	2	47
	Fatal	0	0	0	1	2	3
	Total	**32**	**61**	**24**	**17**	**26**	**160**
Manchester	Slight	34	27	16	21	16	114
	Serious	8	3	5	3	3	22
	Fatal	0	1	0	0	0	1
	Total	**42**	**31**	**21**	**24**	**19**	**137**
London Luton	Slight	22	24	22	15	15	98
	Serious	0	0	0	1	0	1
	Fatal	0	0	0	1	0	1
	Total	**22**	**24**	**22**	**17**	**15**	**100**
East Midlands	Slight	16	14	18	15	18	81
	Serious	1	2	6	0	2	11
	Fatal	0	0	0	2	0	2
	Total	**17**	**16**	**24**	**17**	**20**	**94**
London Stansted	Slight	10	17	10	20	13	70
	Serious	3	0	2	1	2	8
	Fatal	0	0	0	0	0	0
	Total	**13**	**17**	**12**	**21**	**15**	**78**
Birmingham	Slight	11	10	15	7	10	53
	Serious	2	0	0	0	11	13
	Fatal	1	0	0	0	0	1
	Total	**14**	**10**	**15**	**7**	**21**	**67**
Bristol	Slight	7	2	2	10	3	24
	Serious	0	0	1	0	1	2
	Fatal	0	0	0	0	0	0
	Total	**7**	**2**	**3**	**10**	**4**	**26**

Table 3-2 Road accident statistics per passengers at selected UK airports from 2010 to 2014 (Source: CAA, 2015; DfT, 2015; CrashMap, 2015)

Airport		Year				
		2010	2011	2012	2013	2014
Gatwick	Total accident	34	36	45	41	43
	Total of car user	12,572,961	12,932,373	12,527,630	13,168,330	14,489,485
	Percentage	0.00027042	0.00027837	0.00035921	0.00031135	0.00029677
Heathrow	Total accident	113	100	120	80	129
	Total of car user	13,249,772	13,449,371	12,743,034	12,161,043	12,418,075
	Percentage	0.00085284	0.00074353	0.00094169	0.00065784	0.00103881
Luton	Total accident	22	24	22	17	15
	Total of car user	4,044,802	4,385,488	4,320,388	4,588,661	5,182,853
	Percentage	0.00054391	0.00054726	0.00050921	0.00037048	0.00028942
Stansted	Total accident	13	17	12	21	15
	Total of car user	6,957,451	6,587,557	5,957,216	6,088,341	6,927,774
	Percentage	0.00018685	0.00025806	0.00020144	0.00034492	0.00021652
Manchester	Total accident	42	31	21	24	19
	Total of car user	9,768,073	10,411,761	10,576,946	10,908,935	11,323,858
	Percentage	0.00042997	0.00029774	0.00019855	0.00022000	0.00016779

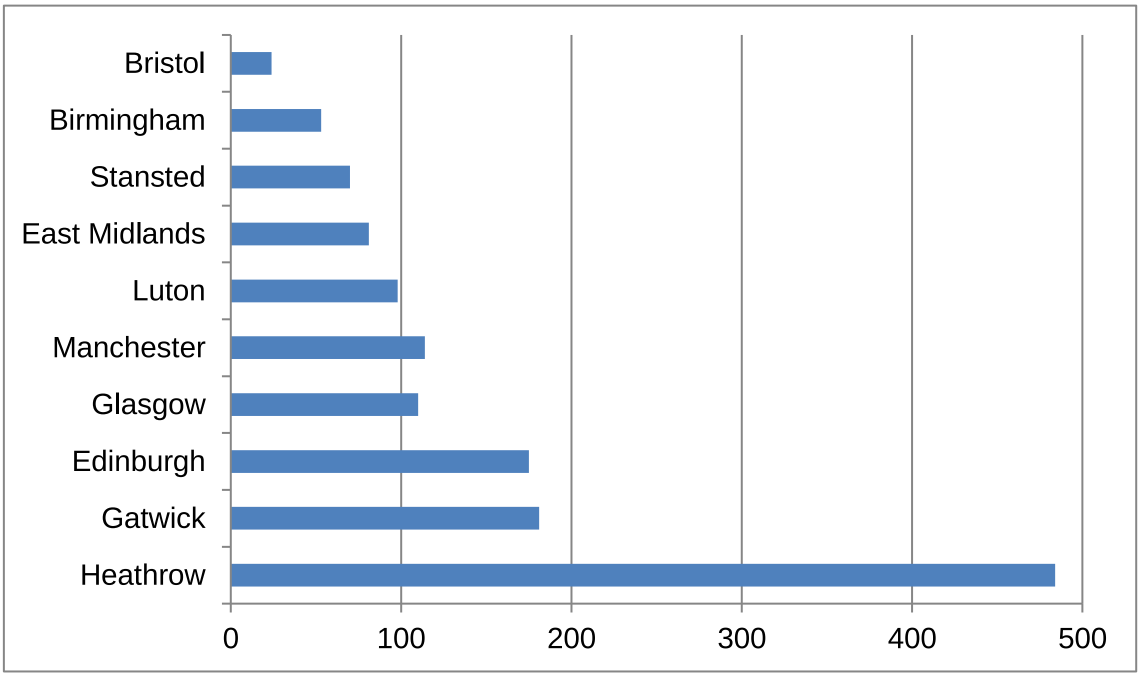


Figure 3-1 Total slight casualties at UK Airports from 2010-2014 (Source: CrashMap, 2015)

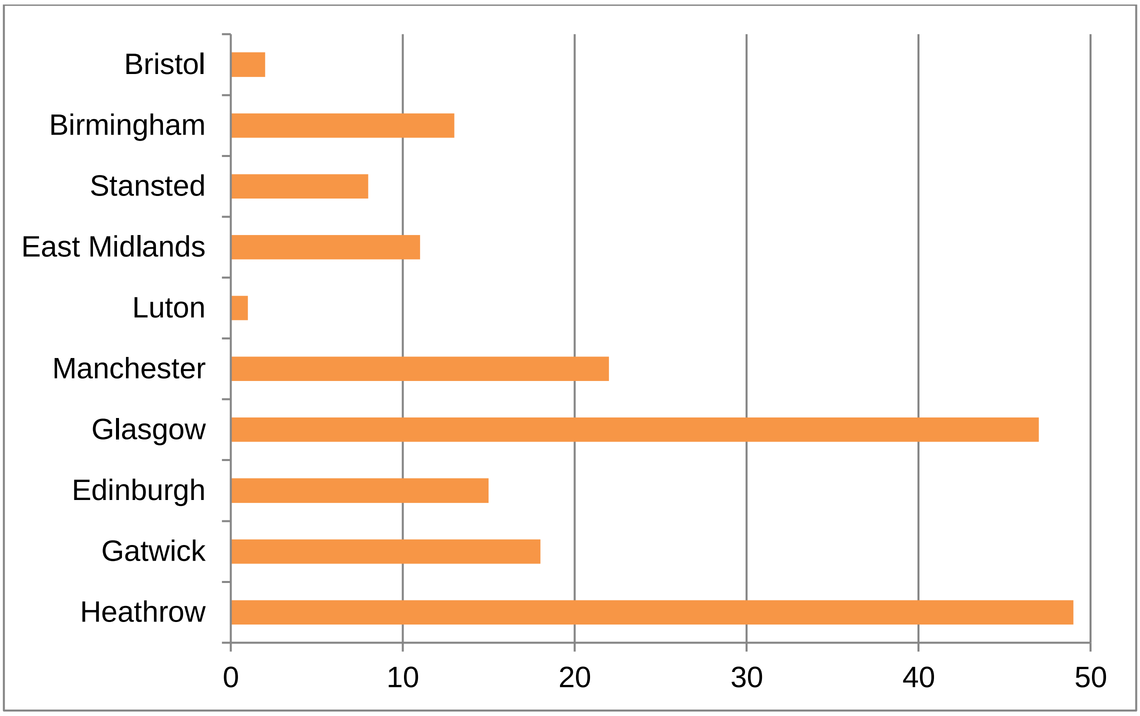


Figure 3-2 Total serious casualties at UK Airports from 2010-2014 (Source: CrashMap, 2015)

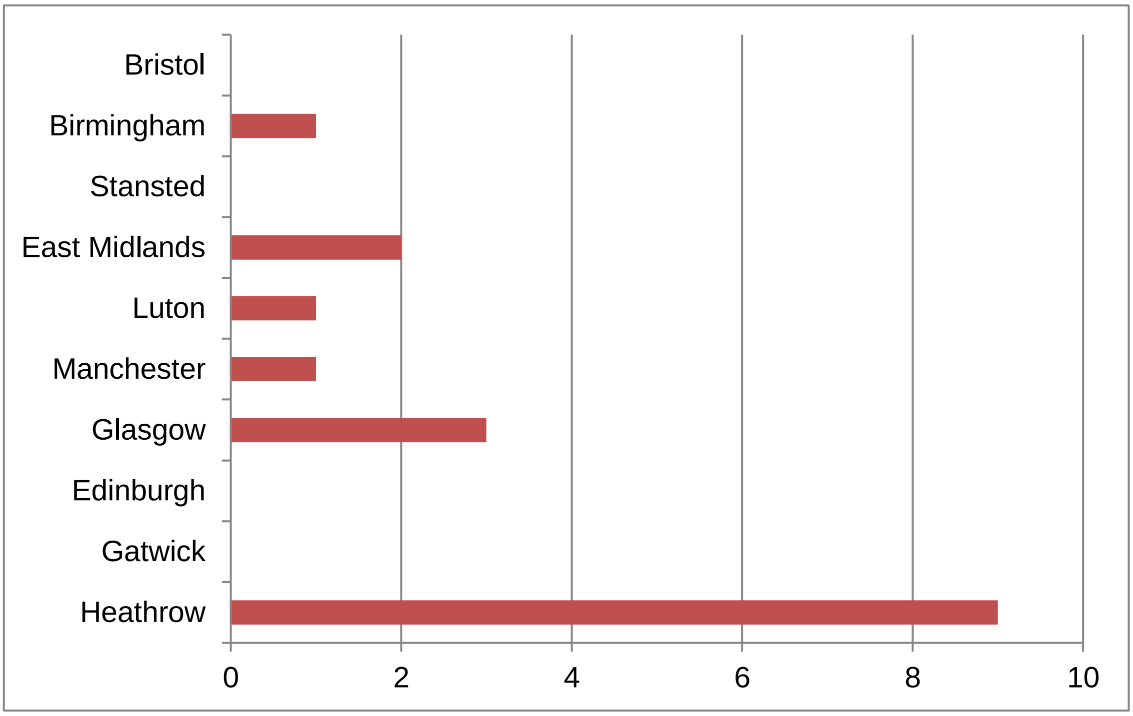


Figure 3-3 Total fatal casualties at UK Airports from 2010-2014 (Source: CrashMap, 2015)

3.3 Driver Characteristics and Limitations

Driver capabilities and limitations in performing the driving tasks influence safe driving behaviour on the road. Past research (Alosco et al., 2012; Bella, 2008; Godley, Triggs and Fildes, 2002; Horswill and Coster, 2002; RoSPA, 2010) have examined the characteristics of safe drivers' behaviour. The research outcomes confirmed that change of behavioural adaption to the road environment (e.g. road design, human errors and drivers' age) have an impact on driving performance. In this section, two main characteristics that lead to senior drivers' wayfinding have been discussed; (1) attention and wayfinding information, and (2) vision. These two important characteristics of airport road access wayfinding design were based on previous literatures and contributory factors (Department for Transport, 2015c). Attention limitation, ability to process wayfinding information and visual awareness (Matthews et al., 1998) where failing to look properly, poor turn manoeuvre, 'disobeying' of traffic signs, travelling too fast and exceeding speed limit are examples of these (Chapter 1, Section 1.3).

In addition, numerous driving situations require drivers to estimate movement of vehicles based on the rate of change of visual angle created at the eye by the vehicle. These situations include safe following of a vehicle in traffic, selecting a safe gap on a two-way stop-controlled approach, and passing another vehicle with oncoming traffic and no passing lane. The primary cue that senior drivers use to determine their closing speed to another vehicle is the rate of change of the image size. Senior drivers use the observed change in the size of a distant vehicle, measured by the rate of change of the visual angle occupied by the vehicle, to estimate the vehicle's travel speed. Senior drivers have difficulty detecting changes in vehicle speed over a long distance due to the relatively small amount of change in the size of the vehicle that occurs per second. This is particularly important in overtaking situations on two-lane roadways where drivers must be sensitive to the speed of oncoming vehicles. When the oncoming vehicle is at a distance at which a driver might pull out to overtake the vehicle in front, the size of that oncoming vehicle is changing gradually and the driver may not be able to distinguish whether the oncoming vehicle is traveling at a speed above or below that of average vehicles. In overtaking situations such as this, drivers have been shown to accept insufficient time gaps when passing in the face of high-speed vehicles, and to reject sufficient time gaps when passing in the face of other low-speed vehicles. Limitations in driver perception of closing speed may also lead to increased potential for rear-end crashes when drivers traveling at airport roadway speeds approach stopped or slowing vehicles and misjudge the stopping distance available. This safety concern is compounded when drivers are not expecting this situation. An approaching driver may not detect the stopped vehicle. In this circumstance, the use of turn signals or visibility of brake lights may prove to be a crucial cue for determining that the vehicle is stopped and waiting to turn.

3.3.1 Attention and Wayfinding Information Processing

Drivers' attention and ability to process signage and wayfinding information is limited. These limitations create difficulties for drivers as driving require the division of attention (Taylor and Dorn, 2006) between control, guidance and navigational tasks in order to navigate AASHTO (2010) to the airport. Drivers prefer to attend to one of these at a time as the driver's attention can be easily switched from one wayfinding information source to another. For example, drivers (including senior drivers) can only extract a small proportion of the available information from the road scene to navigate to the airport. With regards to limited information processing capacity while driving, these drivers subconsciously determine acceptable information loads that they can manage. They are unaware that important information has been neglected when the incoming information load is exceeded, which leads to the driving errors during this process. AASHTO (2010) agreed that a driver may neglect a piece of information that turns out to be critical, while another less important piece of information was retained.

In addition to information processing limitations, drivers' attention is not fully within their conscious control (e.g. driving is a highly automated task for experienced drivers). Most drivers, especially on a familiar route, have experienced the phenomenon of becoming aware that they have not been paying attention during the last few miles of driving. Inattention may result in unintentional movements out of the lane, or failure to detect a stop sign, a traffic signal, or a vehicle or pedestrian on a conflicting path at an intersection. Roadway wayfinding information systems have been developed in order to reduce driver workload as follows:

1. Presenting information (including signage design) in a consistent manner to maintain appropriate driving workload;
2. Presenting information in sequence for each of the control, guidance, and navigation tasks; and
3. Providing wayfinding information clues to help drivers prioritise the most important information and to assist drivers in reducing driving errors when travelling to the airport.

3.3.2 Vision

Visual awareness is the most familiar aspect of vision related to driving, and this in respect of wayfinding is equally important for safe driving behaviour (Matthews et al., 1998). Hills [(1980) (cited in AASHTO, 2010)] stated that around 90 per cent of the driving information is visual. AASHTO (2010) agreed that drivers' peripheral vision such as moving vehicles on an intersecting path, pedestrians, signs, wayfinding and signals are important to be noticed while driving. In general, targets[9] best detected by peripheral vision are objects that are closest to the focal point; that differ greatly from their backgrounds in terms of brightness, colour and texture; are large and moveable. Studies show the majority of targets were noticed when located less than 10 to 15 degrees from the focal point and that even when targets were conspicuous, glances at angles of over 30 degrees are rare (AASHTO, 2010; Smiley, Houghton and Philp,

[9] A target is an image that generates the thought that the vehicle should be stopped.

2004). Target detection in peripheral vision is also dependent on demands placed on the driver.

Table 3-3 shows the aspects of drivers' vision in the wayfinding process (AASHTO, 2010). The driving task requires active visual search of the rapidly changing road scene, which requires collecting and processing road information. By understanding where drivers fix their eyes while performing a particular driving task, information can be placed in the most effective location and format. Driver-eye movements recorded by highly specialised cameras have revealed how drivers distribute their attention amongst the various driving sub-tasks, and the very brief periods of time (fixations) drivers allocate to any one target while moving.

Table 3-3 Drivers' vision characteristics

Aspect	Description
Visual acuity	The ability to see details at a distance.
Contrast sensitivity	The ability to detect slight differences in luminance (e.g. brightness of light) between an object and its background.
Peripheral vision	The ability to detect objects that are outside of the area of most accurate vision within the eye.
Movement in depth	The ability to estimate the speed of another vehicle.
Visual search	The ability to search the road changing scene to collect information.

During curve negotiation, visual demand is essentially doubled, as the location of street signs and roadside information is displaced (to the left or to the right) from the lane position information. Eye movement studies show that drivers change their search behaviour several seconds prior to the start of the curve. These findings suggested that advisory curve signs placed just prior to the beginning of the approach zone may reduce visual search challenges (AASHTO, 2010).

3.4 Impact of Navigation and Wayfinding Systems on Behavioural Adaption

Navigation defines as a process or activity for maintaining the movement which involves adaptive displays as directional signs and accurately following the planning and route (Kray, Kortuem and Krüger, 2005; May, Ross and Osman, 2005). The navigational process involves a combination of traditional and modern wayfinding elements. These elements turn to effective wayfinding if up to date information is loaded sufficiently. Woollett and Maguire (2010) agreed that drivers (i.e. even an expert driver) are unable to memorise road layouts and environments in unfamiliar areas.

Drivers have difficulties recognising scenes among similar looking environments and are unable to make a quick decision before properly adapting to the environment. Streeter et al. (1985) agreed that several traditional navigation methods (e.g. paper maps, recorded vocal directions, customised route maps and a combination of the latter two) help drivers in their journey. Driving in an unfamiliar area has resulted in 50 per cent fewer cases of unsuitable driving behaviour than those using conventional navigation methods (TNO, 2007)[10]. The navigation system conveys route guidance to the driver using visual displays (such as traffic signs). Research has long found that the navigation will direct and produce the shortest routes (in terms of distance and time) to drivers, and result in the fewest navigational errors. Senior drivers may have difficulties in following the correct routes and find navigation particularly difficult due to degradation of their cognitive, perceptual and motor skills (Dingus et al., 1995; May, Ross and Osman, 2005). Burnett (2000) stated that the display of the navigation system affected the frequency of glances and increased the number of navigational errors. Bhise and Rockwell (1973) supported that the duration of glances towards road traffic signs were almost twice as long in low density traffic as were in high density.

[10] Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek (TNO) is an independent research organisation bridging technological developments into practical applications for industry and government in the Netherlands.

The traffic signs assist senior drivers to know where they actually are on the road, the layout of the environment and the location of their destination for their driving plans. In many cases, drivers have difficulties following the traffic signs system due to fewer obstacles (e.g. too concentrating on signage and focussing on the road) which causes stress, delay and potentially risky road behaviour (e.g. late lane changes or attempting to read paper or screen maps) while driving (May, Ross and Bayer, 2005).

As discussed in Section 3.2, drivers' behaviour is dependent on the type of traveller, purpose of travel, level of service and drivers' circumstances. Despite their differences, all these passengers have the sole purpose of transferring from ground based to air transportation as the airport is a transition point for air travellers (Fodness and Murray, 2007). Underlying health conditions, and some types of medication taken to treat those problems, are common factors in accidents involving senior drivers. Indeed, a proportion of senior driver fatalities occur when a senior driver dies of natural causes while driving. Senior drivers are commonly involved in collisions at junctions, because of misjudging the speed or distance of other vehicles or failing to see a hazard (Devlin and McGillivray, 2016). They are likely to drive slowly and in some circumstances, they probably stop driving completely, particularly when approaching junctions. Although this may appear to be safe behavioural adaptation, their speed reduction can occur without consideration of traffic regulations. However, not all senior drivers do this, and there is little guidance for drivers. A major deterrent to self-regulation or stopping driving is the lack, or perceived lack, of viable alternatives to the car.

There are several cognitive and physical conditions which affect the ability to drive safely and which, therefore, could act as indicators of increased risk. One important question is how best to test for these conditions, as it is crucial that interventions do not unfairly cause senior drivers to lose their licence. There is comprehensive guidance for medical practitioners on how to assess fitness to drive, and what measures they can take to help their patients who are, or are becoming, unfit to drive. Age-related conditions eventually mean that there is a point when senior drivers should give up driving for their own safety. Due to fragile health and physical condition, senior drivers are more likely to suffer injuries when an accident happens (Devlin and McGillivray, 2016).

In the five years from 2010 to 2014, 11,439 senior drivers and, in total, 15,910 senior people (i.e. combined drivers and passengers) were seriously injured or killed in crashes on Britain's roads (Department for Transport, 2015a). A large number of road accidents (i.e. including at airport roads) (Chapter 1, Section 1.3) in the UK has also been reported. Thus, drivers (including senior drivers) are exposed to the risky driving on the roads every day and more likely to die on the roads (Hill and Starrs, 2011). Road crashes remain the leading cause of death amongst senior drivers (RoSPA, 2010). In 2014, 60 drivers (aged of 50 to 59 years) and 183 drivers (over the age of 60 years) were killed in road accidents, 744 and 1,461 of drivers were seriously and slightly injured in these age groups, respectively (Department for Transport, 2015a). Reported statistics indicate that the risk of an accident increases after the age of 60 up to 70, and they are no more likely to cause a crash than to be the victim of another road user's mistake. However, drivers over 70 are more likely to be at fault when they crash (Chapter 1, Section 1.3).

Senior drivers' behaviour is connected to the driving abilities and willingness to take risks on the road (Leversen, Hopkins and Sigmundsson, 2013). The contrast between the safety performance expected of road transport and the management of all other risks is stark, not least when compared with other transport modes (e.g. rail and sea) in terms of fatality and the total of all casualty categories (Department for Transport, 2015b; Evans, 2003; Gayle, 2014). Senior drivers felt that their driving experience skills and driving abilities may not be as good as they once were, which in turn, means that they start to have difficulties in assessing complex problems or high-speed traffic situations and required additional information process time to make a decision (Casutt et al., 2014; Hassan, King and Watt, 2015; IAM, 2010).

Safe driving behaviour plays a fundamental role by decreasing the risk of being involved in an accident. Engineering measures such as a road design can prevent accidents and injuries to senior road users (RoSPA, 2010). RoSPA suggested that due to a higher number of accidents at junctions involving senior drivers, road planners should redesign areas in which high crash rates are reported. An important aspect of senior drivers' safety is being able to accurately identify which drivers are significantly more likely to be involved in crashes, and ultimately to help them give up driving and adapt to life without a car. As discussed in Chapter 1 (Section 1.3, Table 1-2), driving behaviour that led to risk of road accidents (i.e. failing to look properly, poor turn manoeuvre, speeding, aggressive driving, overtaking and tailgating the car in front, failing to stop for traffic lights, and unable to process information on signs) has appeared as a critical factor distinguishing different crashes (Matthews et al., 1998) involving senior drivers (Department for Transport, 2015b; Elander, West and French, 1993; Godley, Triggs and Fildes, 2004; Mårdh, 2016; Oltedal and Rundmo, 2006; RoSPA, 2010), which are caused by poor wayfinding on current road designs.

Elander et al. (1993) claimed that the relationship between drivers' skills, behaviour and accident involvement is complex. Safe driving is clearly a complex skill in which various cognitive processes such as perception, attention and motor control are involved (Jamson and Merat, 2005). Elander, Jamson and Merat found that the association between drivers' skills and crash involvement were related through the changes in the way drivers are trained and tested. Therefore, this research intended to measure the relationship between complexity of airport road access wayfinding design and driving behaviour in the virtual environment.

Driver education programmes that are specifically tailored to senior drivers are considered to have potential, although it can be hard to make sure the programme reaches senior people. Exercise programmes help this group to maintain their health and their driving ability. A key question is how and when drivers should be relicensed? In the UK experience, this occurs at 70 years (and every three years thereafter) and requires only the driver to self-certify that they are fit to drive (DVLA, 2015). However, there is no research that suggests a mandatory driving test would be effective to overcome incidents for senior drivers.

3.5 Impacts of Airport Road Access Design on Senior Drivers

Harding et al. (2011) suggested that by making airport roadway signs look, feel and operate like other roadway signs, the needs of the driver are better served. For instance, senior drivers are able to easily and safely navigate when they can rely on their previous experience of airport roadway signs. As discussed in Chapter 1 (Section 1.1), senior drivers preferred to drive to the airport and spend 'extra' time in the vehicle (Chang, 2013). However, high road accident rates (including in the airport road access area) involving senior drivers were reported every year (Department for Transport, 2015a, 2015b). Thus, a study on airport road access wayfinding design and safe behaviour for senior drivers and airport users need to be conducted.

3.5.1 Intersections and Access Points

Intersections place high demands on senior drivers in terms of visual search, gap estimation and decision-making requirements that increase the potential for errors (Polders et al., 2015c). Road crash statistics show that, although intersections constitute a small portion of the highway network, 50 per cent of all urban crashes and 25 per cent of rural crashes are related to intersections (Zwahlen, 1987 cited in AASHTO, 2010). At intersections, the following elements present challenges:

1. *Navigation* - Changes in driving direction are usually made at intersections. Traffic signs are likely to be difficult to locate, read and process at the same time to accomplish any required lane changes;
2. *Control* - The path of intersection is typically unmarked and may involve turning into any road lanes; and

3. *Guidance* - There are numerous potential conflicts (e.g. pedestrian or cyclist roadway crossings) with other vehicles, pedestrians and cyclists on conflicting paths.

In the negotiation process of wayfinding at intersections, drivers are required to; (1) detect the intersection; (2) identify signalisation and appropriate paths; (3) search for vehicles on a conflicting path; (4) assess adequacy of gaps for turning movements; (5) make a quick decision on either to stop or continue driving; and (6) successfully complete through or turning manoeuvres. Three errors at intersections and access points were identified such as errors leading to rear-end crashes (Polders et al., 2015c), errors leading to turning crashes and errors leading to angle crashes. Drivers' behaviour (e.g. tailgating) leading to rear-end crashes has been recorded as a contributory factor to road accidents. Based on previous literature (Chapter 1, Section 1.3) the assumptions of drivers' errors were made as follows:

1. Senior drivers are likely to drive forward to the stop sign and brake immediately once they recognise, late, that there was a vehicle or pedestrian on a conflicting path;
2. As the speed increases, greater concentration on the road (including navigation) is required. Drivers are likely to decelerate without noticing the following vehicle and the probability of a rear-end crash could increase;
3. Senior drivers are likely to continue driving through a yellow light. The senior driver slows or stops due to a vehicle entering or exiting an access point prior to the intersection; or a vehicle exiting an access point suddenly intrudes into the lane; or a pedestrian crossing against a red light;
4. Drivers are likely to make sudden swerves to change lanes to avoid a slowing or stopped vehicle;

5. Failing to look properly and judge other drivers' speeds distracts senior drivers. Distracting situations could include; (a) personal thoughts concern; (b) attention directed to non-driving tasks within the moving vehicle; (c) distracted by an object on the roadside; and (d) anticipation of a downstream traffic signal.

AASHTO (2010) highlighted several driving turning movements that may lead to crashes at intersections or access points as follows:

1. Perceptual limitations

   Perceptual limitations in estimating vehicle speeds could lead to left- or right-turning drivers selecting an inappropriate gap into oncoming traffic. Drivers left- or right-turning on a permissive green light may not realise that an oncoming vehicle is moving at high speed.

2. Visual blockage

   A visual blockage may limit the visibility of an oncoming vehicle when making a turn at an intersection as 40 per cent of intersection crashes involve a view blockage (Treat, 1977 cited in AASHTO, 2010; Treat et al., 1979). Windshield pillars inside the vehicle, utility poles, commercial signs, and parked vehicles may block a driver's view on a conflicting path at a critical point during the brief glance. Visual blockages occur when visibility splays or sight lines are blocked, which affects drivers' fast decision making of turning on required junctions.

3. Inadequate visual search

   For example, in the United States, drivers who are turning right may concentrate their visual wayfinding search on vehicles coming from the left and fail to detect other vehicles, cyclists or pedestrians crossing from the right (Alexander and Lunenfeld, 1989). This is especially likely if drivers do not stop before turning right on a red. As a result, the drivers fail to make a fast decision in making a right turn at the junctions or roundabouts.

Drivers may miss seeing a signal or stop sign because of inattention, or a combination of inattention and a lack of road message elements that would lead drivers to stop. The manoeuvre would cause angle crashes. The driving errors may be due to; (1) delayed detection of an intersection (e.g. sign or signal) at which a stop is required; (2) delayed detection of crossing traffic which violates the traffic signal; and (3) inadequate search for crossing traffic or appropriate gaps.

3.5.2 Interchanges

An interchange is a road junction that permits traffic on at least one highway to pass through the junction without directly crossing any other traffic stream. At airport road interchanges, senior drivers can be traveling at appropriate speeds, and at the same time experience high demands in navigational, guidance and control tasks. Driver errors are influenced by the following elements of road design; entrance ramp and merge length; and decision sight distance.

Entrance Ramp and Merge Length. Drivers are unable to accelerate speed due to lane length, the grade of the ramp, driver errors or heavy truck volumes. Entering drivers merge to the mainline at too slow a speed and may risk accepting an inadequate gap on the roadway. Alternatively, if the roadway is congested or if mainline vehicles are tailgating, it may be difficult to find an appropriate gap into the lane to merge.

Decision Sight Distance. Risk of errors occurs in exit locations as drivers try to read signs, change lanes, and decelerate comfortably and safely. Drivers may try to complete all tasks simultaneously, thereby increasing the willingness to accept smaller gaps of road edge while changing lanes or decelerating at greater than normal rates. The error is reported higher at two road points which are road corners and road lane width.

The potential for a vehicle to leave the road or trespass onto the shoulder is much greater than on straight roads, and the consequences generally are more severe. While driving with careful attention to the geometric road design, skid resistance, and the use of other safety devices, such as pavement markings and traffic signs, drivers do occasionally run off the road. This situation will happen especially at busiest roadways such as an airport road access because of; (1) driver fatigue, distraction or inattention; (2) excessive speed; (3) surface conditions (e.g. snow, rain, or diesel spillage); (4) medical conditions (e.g. heart attack); (5) collision avoidance; (6) vehicle element failure (e.g. steering or braking); and (7) poor visibility (e.g. rain or fog). With a minor road encroachment, the vehicle may easily return to the road (Jamieson, 2012). The vehicle may well be able to stop without hitting anything and then return to the road, or be towed back to the road. Major encroachment of the vehicle may result in striking an obstacle or hazard, of which there are often a large variety (e.g. road signs, cliffs, poles, trees, fences, bollards, or bridge abutments). Jamieson (2012) also highlighted the impacts of road design which should be alerted to while driving at road corners as follows:

1. The crash rate on corners is higher than straight roads;
2. Crash severity on corners is higher than straight roads;
3. A larger proportion of fatal crashes occur on the corner of roads;
4. The proportion of crashes on wet roads is high on the corner of roads; and
5. Crashes on corners occur primarily where the largest changes in speed and steering action occur (e.g. on the entry to and exit from the corner).

Vehicles have rights of way of space on the road (UK Government, 2016), 2016) whether stationary or moving. Geometric design features, specifically lane width and road user safety, should be considered in respect of the capability of all vehicle types using the road. Road design standards are usually dependent on the characteristics of passenger vehicles, with operating speeds often the critical input used to determine the safety of the road (Schramm and Rakotonirainy, 2009). It is assumed that from the design and operating ability of private vehicles, drivers would be able to navigate safely on lanes that provide for the requirements of heavy vehicles.

Godley, Triggs and Fildes (2004) investigated the relationship between lane width and difficulty rate of the driving task. They found that painted and gravel road centre markings, various lane widths, and combinations of markings and widths, influenced driving behaviour and in particular driving speed. In addition, using a driving simulator, various lane width configurations were examined. An established instrument, for example, NASA Task Load Index (i.e. TLX is a multi-dimensional rating procedure designed to obtain workload from operators while they are performing a task or immediately afterwards), was used to measure the mental, physical and temporal demand, driving performance, effort and frustration level of different roadway environments (NASA-TLX, 2016). Research results demonstrated that narrow lane widths were rated more difficult to drive, with subjective difficulties ratings shown to be reduced when lane widths were increased.

A reduction in speed choice has several follow-on effects which may also increase drivers' safety. Research stated that speed variability decreases when mean driving speed is reduced (Knapp, Giese and Lee, 2003). It has explained the greater variability in travel speeds is associated with an increased risk of a crash. Therefore, a reduction in lane width that induces a reduction in speed would lower the crash risk of vehicles. Lower travel speed also has an effect on vehicle control. Similarly, speed increases in driving in line with the variability in vehicle lane position within lanes (Sinclair, Chung and Smiley, 2003).

3.6 Factors Influencing Safe Driving Behaviour

In order to increase reliability of driving simulation results, Table 3-4 shows main factors that may contribute to safe driving behaviour.

Table 3-4 Definition of driving errors in simulated driving (Source: Shechtman et al., 2009)

Term	Definition	Drivers' Mistakes[11] (Variables)	Driver's Performance[12] (Variables)	Errors
Vehicle position	The anterior and posterior position of the vehicle in relation to other vehicles and/or objects and pavement markings	Tailgating	Lane position	Inadequate space during merge or lane change, stopping too close or too far back from pavement markings and other vehicles
Lane maintenance **(Knowledge and compliance to traffic regulations)**	The lateral positioning of the vehicle during turns, straight driving, and lane changes. Reflects ability to maintain steering control and entering the road shoulder	Centreline crossing Road edge excursions	Steering wheel rate Longitudinal acceleration	Drifting out of a driving lane, encroachments on perpendicular traffic, and/or wide turns
Speed regulation **(Speed perception)**	The ability to follow and maintain speed limits, having adequate control of acceleration and braking	Speed exceedances Traffic light tickets	Longitudinal speed	Not stop completely at stop signs, traveling too slow/fast, inadequate merging speed, abrupt or inappropriate braking and acceleration
Adjustment to traffic signs **(Compliance to traffic signs)**	Ability to appropriately respond to driving situations including adjusting to traffic or pedestrian movements and changing road sign information, as well as recognising potential hazards			Not adjusting speed to the posted limits, choosing improper lane from posted signage, and improper response to traffic or pedestrian movement
Collision and accident	Off road accidents occurring when the driver steers the vehicle too far off the road and runs into another vehicle. It includes vehicles in either lane of traffic, cross traffic vehicles, and vehicles in the rear view mirror	Risk to collisions	Steering wheel rate	When the driver collides with another vehicle, the pedestrian, or a vehicle approaching from the rear and displayed in the rear view mirror
Decision and judgement (Rapid decision under pressure at decision point)	Demonstrating visual scanning of the driving environment and ability to quickly scan the signage information	Risk to collisions	Longitudinal acceleration Longitudinal speed	Not able to make a quick decision at decision point

[11] Drivers' mistakes recorded the common driving behavioural errors made during the simulation run.

[12] Drivers' performance is the performance index used to identify drivers' predetermined set of criteria and the data is averaged over the entire segment.

3.7 Research Methodology: The Driving Simulation

Research objectives and research questions are revisited as follows:

To measure the impacts of alternative airport road systems on driving behaviour.

1. What are the key factors that may influence safe driving behaviour?
2. How should the impacts of alternative airport road access design on driving behaviour be measured?
3. What are the impacts of alternative airport road access wayfinding design on driving behaviour?

There are two possible research methods that can be considered; (1) observation of on road driving (in-vehicle testing); and (2) driving simulation.

On road driving test require participants to hold a valid UK driving license and have acquired experience driving to the airport. Traditionally, the procedure of on road test requires participants to enter the car, fastened the seatbelt and makes appropriate adjustments to the mirrors (Reed and Green, 1999). The researcher needs to be present during the test to ensure participants are not distracted by the researcher movements. As this research aimed to evaluate senior drivers' behaviour of alternative airport road access designs, the participants was required to drive from departure point (e.g. Cranfield University) to the nearest airport (e.g. Luton Airport). Instructions were be given to participants such as driving to the airport with the aids of road signage and wayfinding systems (i.e. buildings and landmarks) within the timeframe (e.g. 20 minutes). Participants should be aware on road regulations (i.e. speed limits and safe driving behaviour) and driving conditions. In order to perform on road test, the challenges and risks related to the participants' safety and data collection will be considered (Table 3-5). Data was collected as the subject drove to the airport (e.g. speeding, decision making and behaviour) at decision points. The data can be collected in three ways; (1) on-site observation; (2) in-vehicle observation with trained observers on board; and (3) means of an instrumented vehicle or 'naturalistic driving studies' (De Ceunynck et al., 2014).

Bella (2008) agreed that on road driving test are expensive to conduct and characterised by the complexities involved in collecting field data and difficulties encountered in making the measurements under controlled environmental and traffic conditions. De Ceunynck et al. (2014) claimed that on road testing is highly realistic, however, the researcher has only limited control and the safety of participants and other road users might be compromised especially when being exposed to complex test situations.

A driving behaviour test can be validated by comparing on the road and simulated driving regarding a very specific driving task such as speed (Blaauw, 1982; Godley, Triggs and Fildes, 2002), distraction (Cuenen et al., 2015; Fofanova and Vollrath, 2011), crash avoidance (McGehee, Mazzae and Baldwin, 2000) and traffic safety (Antonson et al., 2009; Yan et al., 2008). The standard of validating driver behaviour in a simulator involves comparing it to driving performance on the road (Blaauw, 1982; Godley, Triggs and Fildes, 2002; Reimer et al., 2006).

According to Reed and Green (1999), and Winter, Leeuwen and Happee (2012) the following are the justification of driving simulation development:

1. Safety

   Collision avoidance and effects of road design on driving performance in a natural environment are too risky. The driving simulator can be used as an alternative to assess multiple-vehicle scenarios as similar as the conventional road.

2. Equipment cost

   Driving simulators allows senior driver responses without changing performance characteristics; potentially at less cost and more quickly than the road assessment.

3. Experimental control

   A wide variety of scenarios was applied and their consistency tested in a driving simulator. For example, weather influences on driving conditions were controllable in the simulator.

4. Ease of data collection

   Accuracy and efficiency of driving performance can be measured by the driving simulator. With a real vehicle testing, it is difficult to obtain complete, synchronized, and accurate measurement data. Measurement of lateral position is challenging and requires visible lane markers while weather conditions, reflection, and shades may affect the quality of the measurement.

5. Opportunity for feedback and instruction

   Driving simulators offer the opportunity for feedback and instruction that is not easily achieved in real vehicles. For example, it is possible to freeze, reset, or replay a scenario in in simulated driving scenario. Feedback and instructions can be delivered in other modalities besides speech, such as visual overlays to highlight critical features in the environment.

The decision to use driving simulator and simulation scenarios was developed after taking into account of the advantages and disadvantages of on the road test (Table 3-5). In addition, the following measures were identified to improve validity and reliability of the simulated airport road access; the driving simulation test was subjected to a pilot study in order to enhance research quality.

Table 3-5 Comparison between on road and driving simulation testing

Factors	On Road (Real vehicle)	Driving Simulation
Safety	Expose to risky driving lead to collision	Collision could be avoided
Equipment cost	High equipment cost	Less equipment cost
Experimental control	Behaviour of virtual traffic, weather conditions and the road layout were not easy to be manipulated	Behaviour of virtual traffic, weather conditions and the road layout can be manipulated as a function of the experiment needs
Ease of data collection	Cumbersome to obtain complete, synchronized and accurate measurement data	Driving performance was measured accurately and efficiently
Opportunity for feedback and instruction	Not easy to achieve	Easy to deliver

However, driving simulation has several known disadvantages that need to be considered; (1) cost; (2) validity; and (3) driving simulator discomfort. Firstly, driving simulator requires higher initial acquisition, operating and maintenance costs because of complexity of driving simulation. Secondly, there will always be the issue of validity, i.e. of to what extent behaviour in a simulator corresponds to that in the real life. Low-fidelity simulators may evoke unrealistic driving behaviour and therefore produce invalid research outcomes. Simulator fidelity is known to affect user opinion. Participants may become demotivated by a limited-fidelity simulator and prefer a real vehicle instead (or a more costly high-fidelity simulator for that matter). Thirdly, simulator sickness symptoms may undermine training effectiveness and negatively affect the usability of simulators. Research shows that simulator sickness is less of a problem for young drivers. Previous literature stated that by limiting the horizontal field of view, avoiding sharp curves, stops during driving, and using short sessions (less than 10 minutes) with sufficient rest breaks improves or even eliminates simulator sickness (Brooks et al., 2010).

3.8 Research Instruments

3.8.1 Driving Simulation: STISIM Drive's Scenario Definition Language (SDL) Development

Driving simulation for field experimentation uses a model building technique to determine the effects of changes and computer-based simulations (Sekaran, 2003). It was developed to test drivers' performance in a virtual environment. Architectural clues (e.g. signs, maps and buildings) were included in the wayfinding simulation (Raubal, 2001).

STISIM Drive is an interactive driving simulator that allows the driver to control all aspects of driving including the vehicles speed and steering. STISIM Drive is developed by Systems Technology, Inc. (STI) for creating virtual driving experiences relevant to the psychomotor and cognitive of participants. STISIM Drive allows the development of driving scene with simple ASCII text commands. The software able to measure the driver decision making and divided attention behaviour and response to traffic control devices in simulated environment. Therefore, the researcher able to manage time for designing and building various roadway situations for this study.

Figure 3-4 shows the simulation mapping applied in this research. As stated by Raubal and Egenhofer (1998), the combination of drivers' choice (decision) and clues (e.g. sign message) in the real world can be measured through virtual simulation. A well-developed driving simulation was selected as a primary measuring instrument of the study. The simulation experiment required a real-world environment and information taking into account drivers' knowledge and experiences. The driving simulator been established at the Driving Simulator Room, School of Aerospace, Transport and Manufacturing (SATM), Cranfield University, since 2001. The STISIM Version 2 was applied to perform a virtual simulation to the study upgraded in 2010.

The research intended to develop an environment that depicts a realistic roadway which senior drivers can navigate through while interacting with the various events. For instance, drivers' interaction with warning signs at unsignalized intersections (Hopkins, Parseghian and Allen, 1997) and drivers' behaviour when speeding (Polders et al., 2015a; Wilmots et al., 2016) in a rural lane (Bella, 2008) were measured in the simulation.

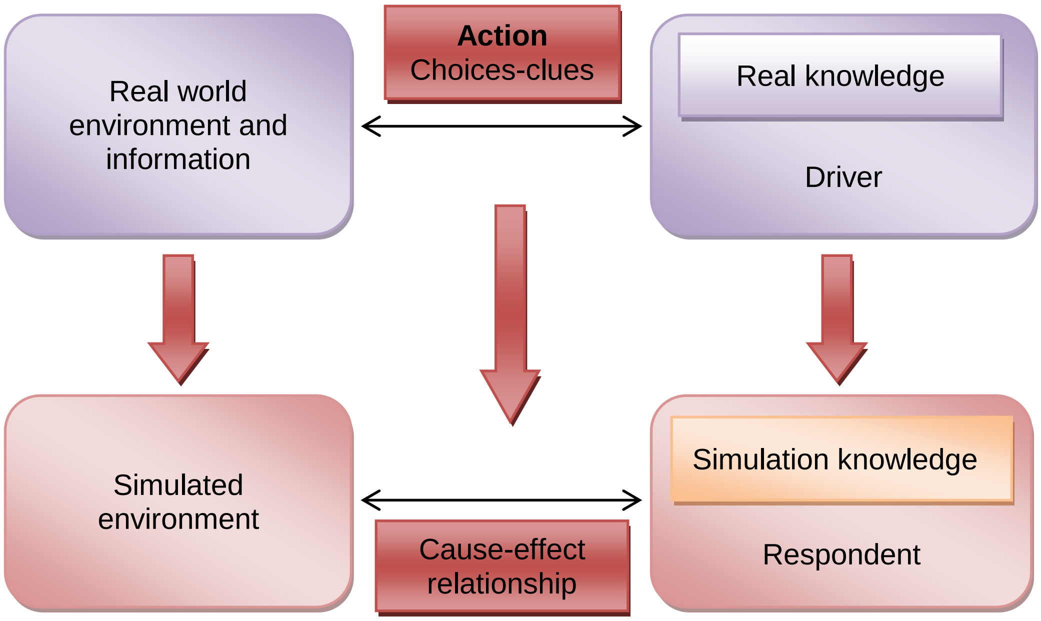


Figure 3-4 Real-world to simulation experiment (virtual) (Source: Raubal, 2001; updated by Author, 2016)

Figure 3-5 shows the STISIM Drive Software was comprised of six components; simulator configuration file, scenario event file; open module object file; control console; display devices; and a simulation kernel that bring all these components together in order to create a realistic driving experience.

The hardware components (control console and display devices) of the driving simulator were developed and installed at the beginning of the study. Less control of the driving simulation was required after the installation and the software was able to function effectively without an additional support system. The configuration and scenario definition files acted as two primary components to adjust the driving environment which was presented to the respective senior drivers. The simulator configuration consists of the entire simulator parameters set which can be modified. These parameters include simulation colours and textures, graphics modes, various hardware configurations and other parameters related to the driving environment. These parameters are grouped and saved in a single configuration file.

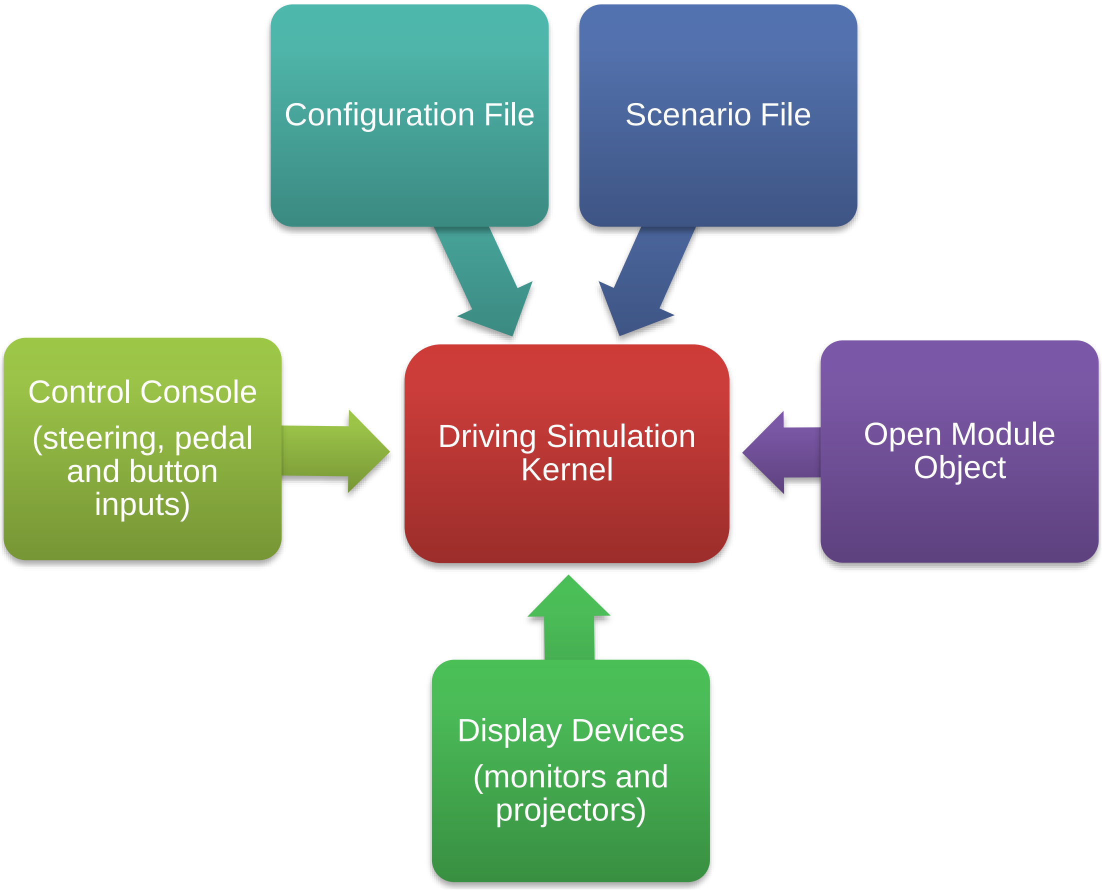


Figure 3-5 Driving simulator components (Source: STISIM Driving simulator instruction manual)

The simulated driving scenario was developed by using STISIM Drive's Scenario Definition Language (SDL) Software. The individual events (e.g. road lane types, traffic signs, advert signs, road furniture and architectural objects) were grouped into a scenario file as well as being readable to the STISIM Drive memory. An infinite number of scenario files were created and saved during simulation runs, and successfully generated the virtual navigation environment.

At this stage, Simple ASCII[13] text of scenario files were created and saved using text editor (Appendix F). Figure 3-6 shows the basic driving simulation scenario development.

The driving simulator or 'Drive' software offers in several different configurations including a simple single screen simulator, a wide field of view simulator and an advanced dynamics option. Additional support systems to manage a wide field view were required in order to make sure the advanced dynamics systems ran efficiently. The driving simulator linked to the main machine so that participants were able to network and communicate before and during the simulation exercise.

Program files, models, projects and others components related to the driving simulation were stored in the central computer system and accessed by the side computer system through a network map. The system support files were inserted in the side machines to keep track and update the simulation software easily. Apart from that, related files to the advanced dynamics system were located in the dynamics (or main) computer. STISIM Drive allows the software to start the necessary applications of other machines, when they are required (start of a run). Therefore, in order to make sure the driving simulation runs effectively, the central system was directed and interacted with other computers to start the driving simulation.

A well-developed driving simulation is used for realistic interpretation of safe driving behaviour. STISIM Driving Simulator Version 2 was used for developing the scenario. STISIM Drive allows the driver to control and experience motor and behavioural aspects of driving (including steering, speed control and situational awareness). STISIM Drive is interactive, flexible and robust. The hardware configurations of STISIM Drive ranges from a simple single monitor display to a complex wide field-of view display with dynamic steering and throttle inputs.

[13] ASCII refers to American Standard Code for Information Interchange.

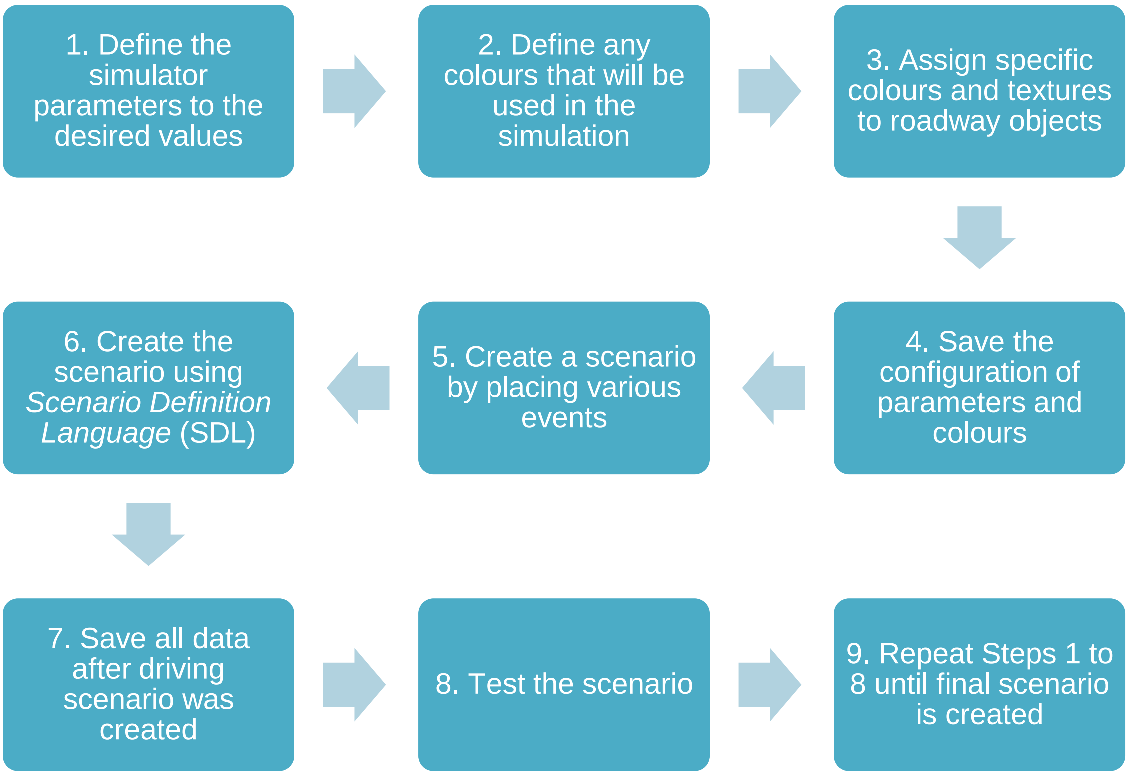


Figure 3-6 Driving simulation scenario development

Figure 3-7 shows the steps of simulated airport road access driving development. Previous literature (Chapter 1, 2 and 3) described driving behaviour and road incidents for the wayfinding process requires rapid response from drivers (i.e. senior drivers, passengers and road users). After stating the problem associated with driving behaviour, road accident and wayfinding were identified, primary data were gathered. The information was kept in a database where it was sorted into groups after valuable information was extracted. The parameters were designed and identified as follows; (1) name for each simulation (simulation 1, 2 and 3); (2) type of drivers (senior drivers and age group); (3) timestamp (from exit motorway to airport); (4) road length (3.8 miles of each simulation); (5) vehicle type; (6) pedestrian type; (7) road lane type; and (8) vehicle overtake and description.

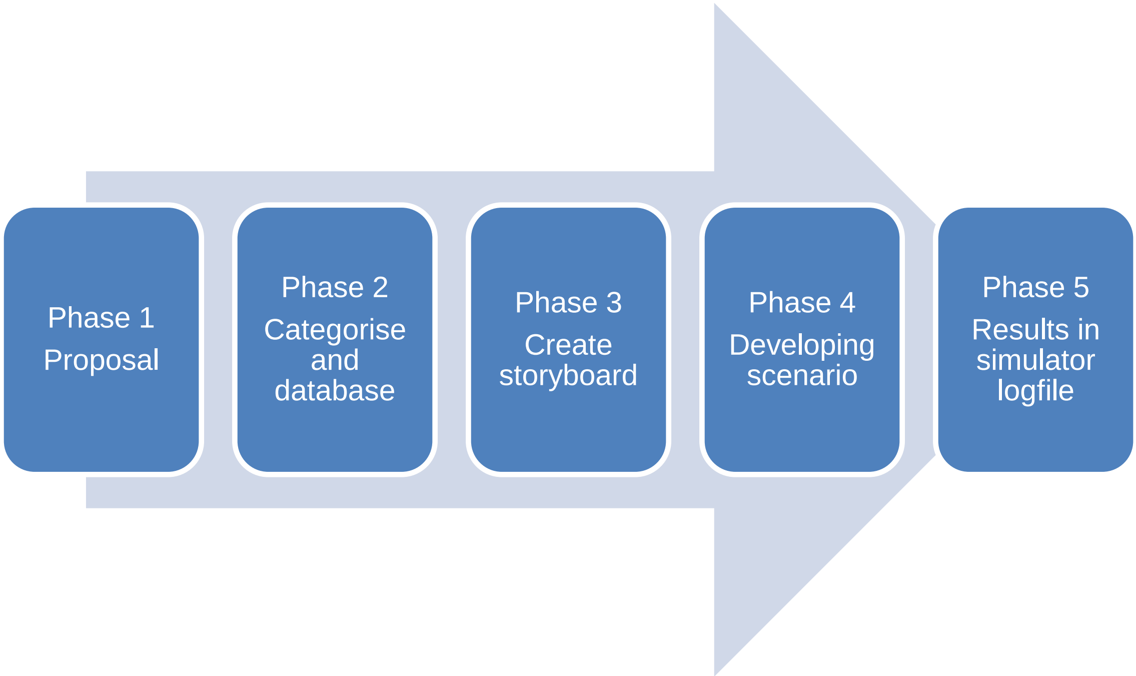


Figure 3-7 Steps of driving simulation research development

Storyboards were developed after intensive evaluation of the driving simulation parameters were conducted. Storyboards are a series of illustrations or images in a row of pre-visualizing animation, motion graphic and interactive media sequence. The storyboard allows the user to experiment with changes in the storyline and focus on the imperative parts. Storyboards were sketched using a template and visually illustrated by the computer. Storyboards were translated and coded into driving simulation scenario by Scenario Definition Language SDL code (Appendix F). SDL is the language used to write the scenarios, and represents objects in a .3ds format. The objects specified are then used to create a scenario. A scenario is a list of different objects that are called events. Examples of events include roadways, intersections, roundabouts and interactive traffic (Section 3.8.4). There were difficulties in coding a roundabout because of the road design scenario being based on the United States' driving environment. As the study is mirrored to the United Kingdom's driving environment, a lot of time and effort were spent in order to obtain an accurate SDL code. In order to overcome this challenge, the researcher made an extensive revision of previous research and wrote a dummy code. Trial and error method was used to get an accurate SDL code before the preferred roundabout can be used in simulated driving scenarios.

The results were extracted from log files. The Mean, Standard Deviation and Two-Way ANOVA test were used to analyse the results and discussed with reference to the use of driving simulation.

3.8.2 Pilot Study Validation

A pilot study was conducted between February and May 2015 (i.e. 15 participants participated in a pilot driving simulation test). In order to improve the quality of the research, the simulated driving was pre-tested. Validity is an important procedure that was used to ascertain that the instrument (e.g. driving simulation) was designed to measure the research variables (Beins and McCarthy, 2012; Frankfort-Nachmias and Nachmias, 1996; Sekaran, 2003). Simulated driving scenarios were developed using the STISIM Driving Simulator. Fifteen senior drivers (mean=58.07, SD=4.50) holding a valid driving license volunteered to participate in the pre-simulation test. Complete instructions were given before commencement of the simulation. Drivers were instructed to drive to the airport with the aid of wayfinding and signage in each driving scenario. The simulation scenario consisted of 6.0 miles long and took approximately 15 to 20 minutes to complete. Participants decided which route to navigate based on the signage and wayfinding systems provided.

The pilot test caused 6 of the participants to feel nauseous and dizzy in the middle and after the simulation completed. Sickness and discomfort among senior drivers during and after simulated driving was due to the high resolution of the simulator screen. Participants took a short break of 5 to 10 minutes and refreshment was provided. Based on the pilot test feedback and observation, 3.8 miles of three different simulated scenarios were considered as an appropriate length of road to be tested.

The pilot test process was vital to this research because the airport road access wayfinding design using a driving simulator had never been tested before.

However, the subsequent experiments used the same technique in order to maintain the validity and reliability of the research. The participants were asked to answer the questionnaire after the simulation ended. The questionnaire used as a supporting study and aimed to measure the effect of road access design on driving behaviour (Wåhlberg, Dorn and Kline, 2011) and wayfinding design. Therefore, senior drivers' experiences of new simulated road design were evaluated and interpreted (Chapter 4). The questionnaire was pre-tested in order to improve the validity and reliability of research.

3.8.3 Evaluating Wayfinding: Airport Road Access Design Simulation

The use of driving simulations to test driver perception and driving behaviour is expanding rapidly as such simulations save engineering time and costs (Kemeny and Panerai, 2003). Driving simulators have become an essential means to improve knowledge in the field of driving behaviour. It allows investigation concerning in particular drivers' behaviour, vehicles and road infrastructures conception (Espié, Gauriat and Duraz, 2005).

The simulator has several advantages over comparable vehicle testing: driving behaviour, ease of data acquisition, the convenience to change vehicle models and simulated surroundings in software rather than testing hardware (Gruening et al., 1998). Three specific goals while developing driving simulations (Green, 2005) were considered as follows:

1. Replicate real driver behaviour and performance;
2. Make the driving simulation studies easy to conduct with a good plan, execute, reduce, and analyse; and
3. Ensure the subjects were not being threatened or harmed.

Three types of scenarios were developed to provide a variety of driving situations in order to reach the airport. The error types of simulated driving were identified as follows; (1) vehicle position (2) change of lane (3) speed (4) response to traffic signs (5) collision and accident and (6) decision and judgement (Section 3.6). The driving simulator is useful to create the impression of driving a vehicle as well as replicate road complexity into virtual environment. High-risk drivers can be tested in a driving simulator under safe conditions in which errors can be made without cost to life or property (Shechtman et al., 2007). Shechtman et al. (2009) also stated that the lack of monitoring over driving scenarios such as change of weather or task conditions (e.g. pedestrian and traffic) led to driving simulators with computer-based technology to be established.

3.8.4 Evaluating Wayfinding: Purposes and Assumptions

Highway authorities in many countries of the world have been using variable message panels mounted above or beside the roadway or motorway to communicate short messages to motorists (Wardman, Bonsall and Shires, 1997), such as hazard warnings and speed signs. The signs are normally used to deliberately affect route choice and to provide drivers with supplemental information as to traffic conditions (Hopkins, Parseghian and Allen, 1997). It is recognised that the signs have a potential role in managing demand that matches the capacity available, not only to alleviate acute problems caused by roadworks and accidents, but also to contribute to satisfactory performance of networks' operation (Dutta, Fisher and Noyce, 2004). Wardman et al. (1997) stated that the installation and operation of the panels is not cheap and there is a widespread belief that overuse, or inappropriate use, of the messages may lead to them losing their credibility with the motorists and ceasing to be effective. Therefore, it is important to understand the expected response of motorists to various messages before displaying them and even before selecting sites for the installation of panels (Fuller, 2002).

This research evaluates the effect of different airport roads which indicates wayfinding design and driving behaviour using driving simulation. It measures the number and type of driving errors committed during a driving assessment performed by senior drivers. The simulated driving scenarios were designed from motorway exits to an airport entrance point (airport terminal) with three different driving scenarios being tested (Chapter 1, Section 1.4). The simulation test was about 3.8 miles long for each scenario and took approximately 20 minutes to complete (without a break). The decision of the length and development of three simulated scenarios were based on a pilot test that had been conducted. The road length was 6.0 miles long in the simulated scenario (for the pilot). Senior drivers drove for 15 to 20 minutes. 25 of participants (17.24%) [9 respondents (Simulation 1), 8 respondents (Simulation 2 and 3, respectively)] were discontinued as they experienced nauseous and dizzy in the beginning and middle of the simulation study. These participant's data were excluded in the final analysis. Based on pilot test's feedback and observation, 3.8 miles of three different simulated scenarios were considered as an appropriate length of road to be tested.

3.8.5 Airport Road Access Wayfinding: Driving Scenario Design

Driving scenarios were designed to evaluate the detection of the effectiveness of wayfinding systems (including signage) which were allocated from the starting point until the end of the simulation. A unique aspect of the scenario design was the inclusion of direction, warning and information signage, roundabouts, pedestrians, trees, moving cars, buildings and road furniture (e.g. street lights and bollards).

3.8.5.1 Scenario Specifics

The simulated driving was scripted using a Scenario Definition Language (SDL) provided by the STISIM Drive Software Version 2. The authoring software was used to add the necessary objects (e.g. direction and advertisement signs, bollards and pedestrians) and auditory cues which provided the driver with instructions (e.g. “That is the end of the simulation”). Scenarios were scripted within a general purpose of the simulator that was a mixture of dual carriageway, buildings, static objects, pedestrian pavement and vegetation.

Three scenario types were designed to provide a variety of driving scenarios and complexity of the road designs to the airport. The complexity of wayfinding varied to assess the safe driving behaviour on alternative airport road access design. Drivers’ decisions and judgement are extremely important while driving especially when they have to make a rapid decision or whilst making decisions under pressure at decision points (Casutt et al., 2014; Hassan, King and Watt, 2015). Drivers need to demonstrate visual scanning of the driving environment. They also must be able to make a quick scan of the signage information. Drivers often will face degrees of pressure and anxiety on journeys to airports in order to ensure that flights are not missed.

Figure 3-8 shows the example of driving scenario (i.e driving simulator) in STISIM driving simulator Version 2.

Figure 3-8 STISIM Driving simulator

Three scenario types (Table 3-6) were designed to provide a variety of driving scenarios and complexity of the road designs to the airport. The complexity of wayfinding varied to assess how senior driver behaviour reacted to changes in road design complexity.

1. Scenario 1 (S1) – ‘Less Complex’

   Scenario 1 or ‘Less Complex’ scenario (Figure 3-9 and 3-10) was designed to have low traffic density as possible to test the effect of road design on drivers’ wayfinding to the airport. Drivers’ behaviour during navigation was also tested. The signage placement and road furniture were included to assess drivers’ adaption to the actual airport road design with accurate wayfinding (including signage) provided (Table 3-6).

Figure 3-9 An example of airport road access (airport way) in Simulation 1

Figure 3-10 An example of airport road access (approaching airport terminal) in Simulation 1

2. Scenario 2 (S2) – ‘Complex’

   Scenario 2 or ‘Complex’ scenario (Figure 3-11 and 3-12) was designed as a busy road and more complex in terms of road access design and wayfinding (including signage). Curved roads and warning signage were included in order to measure the impact of airport road design on driving behaviour. Multiple signage types (e.g. diamond and rectangle signs) in the simulation design were considered (Table 3-6).

Figure 3-11 An example of airport road access (roadway) in Simulation 2

Figure 3-12 An example of airport road access (approaching airport terminal) in Simulation 2

3. Scenario 3 (S3) – 'More Complex'

Scenario 3 or 'More Complex' scenario (Figure 3-13, 3-14 and 3-15) was designed to represent a busy airport road with different types of direction and warning signs (e.g. diamond and rectangle signs), dual carriageway speed limit and complexity of airport road design provided with accurate wayfinding systems (including signage).

Advertisement signs are important to the airport as an airport identity or branding (Harding et al., 2011) were included in the simulation scenario. Roundabouts were created in the scenario in order to give way to present traffic in the circle and to increase safe driving behaviours. As part of traffic calming, in some countries a roundabout is starting to replace traditional traffic control devices such as traffic lights. Another purpose of the roundabout is to improve the operation of an existing junction (Department for Transport, 2011a).

Figure 3-13 An example of airport road access (airport way) in Simulation 3

Figure 3-14 An example of airport road access (airport entrance) in Simulation 3

Figure 3-15 An example of airport road access (roundabout) in Simulation 3

The Federal Highway Administration (FHWA) (2010) highlighted that roundabouts mainly have two functions. Firstly, as a traffic calming device because as the straight length of the road (in all directions) is broken by a curve, it forces drivers to slow down. It is also because of the road rules regarding giving way which may require drivers to stop altogether. Secondly, it acts as a traffic control device. A roundabout is designed to make it necessary for a driver to stop for any vehicle. It has a way of controlling the flow of traffic. Other benefits of roundabouts include being able to make across-the-traffic turns, having cars going in multiple directions at once with lower risk of collision (Polders et al., 2015b) and not having to wait at lights.

There were three scenarios developed in order to evaluate the impact of wayfinding on drivers' behaviour. Different types of signage were considered in three scenarios to reduce accidents due to crossing paths, left turn movements and to be more effective than conventional signs (Hopkins, Parseghian and Allen, 1997). Road speed limit is important in order to assess driver behaviour. Godley et al. (2002) found that driving at appropriate speeds for existing road conditions is related to a driver's confidence. It is also related to driving safety because rear-end collisions are more likely to occur when driving at low speeds.

In addition, Shechtman et al. (2007) stated that a greater forward acceleration may indicate variable speed during the turn; and increases the likelihood that they need to speed up again. They also found that driving at a variable speed through an intersection could potentially increase the possibility of rear-end collisions (Polders et al., 2015c). Therefore, several types of speeding were allocated in the scenario (e.g. 30 mph, 40 mph and the national speed limit) on airport road access wayfinding design. The scenario was not restricted to the straight road (drive) only. Participants decided which route to use based on the wayfinding systems provided. Thus, if a participant chose to turn right or left at an intersection, the test would take a longer distance and time at approximately 30 minutes to complete. Table 3-7 shows the total number of signs and road furniture in the driving simulation scenarios.

Table 3-6 Airport road access wayfinding design[14]

Simulation Scenario	Airport road complexity	Airport road design	Type of signage	Distance / Time	Speed (mph)	Intersection/ Roundabout	Moving car	Curve and Hill	Pedestrian	Other road furniture
Scenario 1	Less Complex	Dual carriageway	Directional Information Warning Regulatory Advertisement	20000 feet (3.8 miles) / 5 minutes	20 30 60	Yes	Same traffic	No	Yes	Bus stop, street light, zebra crossing, pelican beacon, building, tree
Scenario 2	Complex	Dual carriageway	Directional Information Warning Regulatory Advertisement	20000 feet (3.8 miles) / 5 minutes	20 30 40 50 60	Yes	Same traffic	Yes	Yes	Bus stop, street light, zebra crossing, pelican beacon, traffic light, bollard, building, tree
Scenario 3	More complex	Dual carriageway	Directional Information Warning Regulatory Advertisement	20000 feet (3.8 miles) / 5 minutes	20 30 40 50 60 70	Yes	Same traffic	Yes	Yes	Bus stop, street light, zebra crossing, pelican beacon, traffic light, bollard, building, tree

[14] The simulated driving scenarios were based on wayfinding complexity design (differences in total number of traffic signs and road furniture) (Table 3-7). A similar number of other objects related to road design (e.g. trees and traffic) were included in the simulated driving scenario.

Table 3-7 Total number of signs and road furniture in the driving simulation scenarios

Road furniture type	Simulation 1 (S1)	Simulation 2 (S2)	Simulation 3 (S3)	Total
Directional sign	129	145	160	434
Regulatory sign	8	8	8	24
Warning sign	36	36	36	108
Advert	8	21	28	57
Bollard	68	68	68	204
Traffic light	2	2	2	6
Pelican beacon	2	2	2	6
Street light	45	45	45	135
Pedestrian	218	326	513	1057
Intersection	11	11	11	33
Building	90	101	111	302
Vehicle	199	199	199	597
Roundabout	3	3	3	9
Bus stop	2	2	2	6
Total	**821**	**969**	**1188**	**2978**

3.8.6 Target Population and Sample Size

Target population of the study were senior drivers in the UK. An 'element' defines a single member of the population, with the senior drivers being selected as an element of a population for this study (Chapter 1, Section 1.1).

A sampling is a process of selecting a sufficient number of elements (subset) from the population. The purpose of sampling is to select a representative and non-biased sample to ensure the reliability and validity of findings (Zainul Abidin, 2005). Sekaran (2003) and Robson and McCartan (2016) stated that validity of research outcomes can be established after taking into account that the 'element' has the knowledge, ability, capacity and willingness to participate in the research.

Based on the previous studies (Table 3-8), a selection of 40 senior drivers as the participants was appropriate to represent the 'population'. The results from the sample can be inferred to the population which is exactly the purpose of inferential statistics[15].

3.8.6.1 Sampling Design (Sampling Frame and Methods)

Non-probability methods were chosen in order to achieve the aim and objectives of the research. Non-probability samplings were categorised as; convenience sampling, quota sampling, purposely sampling and snowball sampling. In this research, convenience sampling was used in order to obtain adequate data from the population. Convenience sampling is the most appropriate sampling design for this research because the information is collected from members of the population (participants) who are conveniently available to provide it (Beins and McCarthy, 2012).

Table 3-8 shows the comparison of sample size that has been conducted in previous simulated driving studies.

[15] Inferential statistics allows the researcher to make decisions or inferences about characteristics of a population based on observation from a sample taken from the population (Frankfort-Nachmias and Nachmias, 1996).

Table 3-8 Comparison of sample size based on previous literature

No.	Author	Year	Title	Sample size	Procedure
1	Germaine L. Odenheimer, Marie Beaudet, Alan M. Jette, Marilyn S. Albert, Laura Grande and Kenneth L. Minaker	1994	Performance-based driving evaluation of the elderly driver: safety, reliability and validity	30 participants	All subjects were recruited by word-of-mouth
2	Jennifer Hopkins, Zareh Parseghian and Wade Allen	1997	A driving simulator evaluation of active warning signs	8 participants (4 males, 4 females. Age range between 20 and 70 years)	Participants held a valid driving licence
3	Matthew P. Reed and Paul A. Green	1999	Comparison of driving performance on-road and in a low-cost simulator using a concurrent telephone dialling task	12 participants (6 were aged over 60 years, 6 were between ages of 20 and 30 years)	Subjects were recruited by word-of-mouth
4	Stuart T. Godley, Thomas J. Triggs and Brian N. Fildes	2002	Driving simulator validation for speed research	24 participants (12 males and 12 females. Age range of 22-52 years)	All participants were recruited through personal contact
5	Arup Duttaa, Donald L. Fisherb and David A. Noyce	2004	Use of a driving simulator to evaluate and optimize factors affecting understandability of variable message signs	48 participants	All participants were recruited from the University of Massachusetts and held valid driving licence in the US
6	Lisa Dorn and Jenny Stannard	2004	Simulator performance differences between experienced and novice bus drivers	24 participants	12 novice bus drivers with 2-3 weeks of driver training, and 12 experienced drivers who had held their PCV (Public Commercial Vehicle) license for at least three years
7	Hans Antonson, Selina Mardh, Mats Wiklund and Goran Blomqvist	2009	Effect of surrounding landscape on driving behaviour: A driving simulator study	18 participants (9 men of age range 25–60, and 9 women of age range of 27–43)	Subjects were recruited using VTI's official recruitment form at www.vti.se. The subjects were then selected by phone from those who registered on the recruitment form

Sekaran (2003) stated that even though it may not be possible to control all variables, the treatment can be still manipulated in the experimental research. Therefore, in most ex post facto and experimental research, a sample of 30 or more is recommended (Roscoe, 1969; VanVoorhis and Morgan, 2007). In this research, driving simulation was used as a validation of the airport road access wayfinding research.

Based on the previous studies (Table 3-8), 40 respondents were selected and participated in the driving simulation study. The subjects were selected using convenience sampling from the total population of the United Kingdom (UK) driving licence holders or equivalent to the UK driving licence standard. Driving simulation scenarios development ('Less Complex', 'Complex' and 'More Complex') was based on the UK environment (Section 3.8.5.2). For instance, the roundabouts, speed limit, number of lanes and architectural design were selected after taking into consideration UK motorway and airport road access design.

3.8.6.2 Participants and Procedures

Approval of the research subject was gained from the Science and Engineering Research Ethics Committee (SEREC), Cranfield University on 5th September 2014 and the respective supervisors (Appendix A).

As discussed in Section 3.8.5.1, the simulation participants were selected based on convenience sampling and participation in this study was completely voluntary. Participants were invited through open invitation communicated via email, social media platform and a website (Appendix G). The notification email included research background, greetings and a consent statement to the participants. Selected participants then were invited to take part in the study.

Oral and written instructions were given to participants (e.g. general information, simulation driving procedures and right of participant as a research subject). Participants were also notified that they have right to withdraw at any time or refuse to participate entirely, and the information or data collected from the test is strictly confidential. A written consent statement then was collected from participants. Participant’s health conditions were checked before practice session began and after practice session ended (Appendix D).

Senior drivers completed a practice session (i.e. consists of a short simulated scenario) on the simulator. The practice session involved driving on different complexity of road design. This session was necessary to familiarise drivers with the driving simulator and allowed them to acclimatise to the simulated driving environment in order to minimise discomfort and the potential for simulator sickness (Brooks et al., 2010). Senior drivers also had the opportunity to ask questions during the practice session. The driving simulation runs as normal standard of driving practice on the road. Participants were given the following instructions prior to the practice drive as used by Dorn and Stannard (2006) and updated by the researcher:

“This session is a practice drive so that you may get used to the feel and control of the simulator. Please drive the way you would on a real road and deal with the driving conditions if necessary. In the event of a collision the simulator will immediately stop and reset at the last position on road. You must continue driving until the end of driving. Feel free to ask any questions”.

After completion of the short practice trial, participants then were asked about their health condition before the study continued with driving simulation scenarios. This is to ensure that participants were able to continue to run the driving simulation test without sickness symptoms such as nausea and dizziness.

Senior drivers’ judgement and decisions are extremely important as they have to make a prompt and accurate decision under pressure (Fofanova and

Vollrath, 2011; Naveteur et al., 2013) at decision points. Drivers (including senior drivers) need to demonstrate visual scanning of the driving environment (Shechtman et al., 2009). They also must be able to make a quick scan of the signage information. Drivers face degrees of pressure and anxiety on journeys to airports in order to ensure that flights are not missed. Before the simulation began, participants were informed that they have 10 minutes to drive to the airport. The time constraint was introduced in order to simulate similar pressures and stress that would be faced in reality.

Participants were required to perform three different simulated airport road scenarios. The driving scenario were presented randomly to avoid potential bias in responses to simulation scenario. The following instructions (displayed on screen) were given prior to the actual driving simulation study:

> *"Please take your feet off the pedals and centre the steering wheel. Press the green button to start. Please break to stop if you see a red stop sign when approaching traffic lights. Follow the wayfinding provision, for example, road signs to get to the airport terminal".*

Performance on the driving simulation was continually monitored and a short break (5 to 10 minutes) was given after each scenario type ended. At the end of the study, data was extracted.

As discussed in Section 3.8.5.1, the participants were chosen from the total population of the United Kingdom (UK) driving licence holders or equivalent to the UK driving licence standard. The selection of UK senior drivers was based on the literature search and road accident statistics, as discussed in Chapter 1. The UK senior drivers were selected because of:

1. The airport road design and wayfinding research was based in Cranfield University, UK, thus access to UK senior drivers as participants was appropriate;
2. The simulated driving scenarios were designed based on the UK airport road access and roadway environment (e.g. traffics signs and road furniture). In general, the research output was suggested to be appropriate to apply to airport road access outside the UK; and
3. The data management and facilities were accessible (e.g. road accident statistics).

3.8.7 Hypotheses Development

Hypothesis is defined as a logically conjectured relationship between two or more variables expressed in the form of a testable statement (Sekaran, 2003). Trochim (2006) stated two basic principles of hypothesis testing as follows:

1. The formulation of two mutually exclusive hypothesis statements that, together, exhaust all possible outcomes; and
2. The testing of hypothesis, so that one is necessarily accepted and the other rejected.

Table 3-9 shows the mapping of research hypotheses, research variables and analysis techniques in this research.

Table 3-9 Mapping Research Hypotheses and Analysis Technique

Hypotheses	Analytical Techniques
H_0: There is no significant effect of airport road access complexity design on driving behaviour.	Frequency analysis (Mean and standard deviation)
H_1: There is a significant effect of airport road access complexity design on driving behaviour.	Two-Way ANOVA Test

3.9 Analytical Techniques

3.9.1 Mean and Standard Deviation

Data analyses were discussed by a comparison of mean and Standard Deviation (SD). Beins and McCarthy (2012) and Sekaran (2003) stated the mean or the average as the arithmetic average of a distribution of scores, is a measure of central tendency that provided a general data without unnecessarily inundating one with each of the observations in a data set. The mean, as a measure of central tendency, is used frequently when reporting both demographic characteristics of participants and measures of the dependent variable. The mean was computed by taking the difference between each value, summing the absolute value, and dividing the sum by the total number of values (Frankfort-Nachmias and Nachmias, 1996; Sekaran, 2003). Standard deviation is another measure of dispersion for interval and ratio scaled data (Sekaran, 2003), which offers an index of variability or standard distance from the mean and reported in raw score values (Beins and McCarthy, 2012). Standard deviation is commonly used as the square root of the variance.

The mean and standard deviation were used in this research as they are the most common descriptive statistics, and a very useful tool of statistical rules, in normal distribution as follows (Beins and McCarthy, 2012; Robson and McCartan, 2016; Sekaran, 2003):

1. Practically all observations fall within three standard deviations of the average or the mean;
2. More than 90 per cent of the observations are within two standard deviations of the mean; and
3. More than half of the observations are within one standard deviation of the mean.

3.9.2 Two-Way Analysis of Variance (ANOVA)

Analytical techniques used in this research consist of applying the Two-Way ANOVA test to determine the impact of different airport road access wayfinding on driving behaviour.

The quantitative analyses (i.e. statistical techniques to describe and analyse data) were performed on the data. Quantitative analyses leads to enumeration and statistical analysis that are tangible and easily identifiable in the terminal environment (Mumayiz, 1985). The quantitative method seeks to gather factual data in order to study the effect on wayfinding design.

Two-Way ANOVA was used to determine whether there are any differences between the means of two or more independent (unrelated) groups (Sekaran, 2003). Beins and McCarthy (2012) stated that Two-Way ANOVA compares group means to assess the reliability of different means. In this research, Two-Way ANOVA was used to measure the most prevalent importance of driving behaviour and the complexity of road design. The Two-Way ANOVA Test evaluated a null hypothesis which means groups being compared are equal, and produces descriptive statistics called *F* (variance).

The following are the justification of Two-Way ANOVA Test for this research (Lund and Lund, 2013):

1. Dependent variable should be measured at the interval or ratio level (i.e., they are continuous);
2. Independent variable should consist of two or more categorical or independent groups;
3. Independence of observations, which means that there is no relationship between the observations in each group or between the groups themselves. For example, there must be different participants in each group with no participant being in more than one group; and
4. Dependent variable should be approximately normally distributed for each category of the independent variable.

Table 3-10 Interpretation of Two-Way ANOVA Test (Source: Sekaran, 2003)

P-value	Interpretation	Results
$P < 0.05$	There is a significant effect of airport road access complexity design on driving behaviour.	Accept H_1
$P > 0.05$	There is no significant effect of airport road access complexity design on driving behaviour.	Accept H_0

Two-Way ANOVA was used to examine the significant mean difference among more than two groups (e.g. lane position, steering, acceleration and speed) on an interval or ratio scaled dependent variable (Sekaran, 2003) of airport road access wayfinding design. The Two-Way ANOVA results showed significant difference of the means of various groups, as indicated by the *F* statistic. In addition, the *F* statistic shows whether two sample variances differ from each other or from the same population (Beins and McCarthy, 2012; Sekaran, 2003). Type I errors[16] could be minimised by using Two-Way ANOVA as it allows the researcher to test multiple levels of the independent variable using one overall test for significance. Table 3-10 shows the interpretation of Two-Way ANOVA Test.

3.10 Frequency Analysis

3.10.1 Drivers' Ages

Table 3-11 shows the age group of senior drivers who volunteered as participants in this research.

[16] Type I error referred to as alpha, is the probability of rejecting the null hypothesis when it is actually true (Beins and McCarthy, 2012; Sekaran, 2003).

Table 3-11 Range of drivers' ages

	Minimum	Maximum	Mean	Standard Deviation
Age	50	71	58.60	5.31

The minimum and maximum age of the senior drivers are 50 and 71 years old, respectively. Mean and standard deviation of age range was computed as 58.60 and 5.31, respectively. The mean and SD results revealed that most of the participants were aged in the range of 53 to 63 years. As discussed in Chapter 1 (Section 1.1), a minimum age of 50 was selected based on the definition of "senior" people accepted worldwide.

As reported by DfT (2015a), the number of senior drivers killed on the roads increased 16 per cent to 535 in 2014. This increase is statistically significant at the 95% confidence level. It is also the highest level of fatalities of senior people since 2008. In addition, a total of 4,026 senior drivers involved in serious injured casualties rose to 11.1 per cent in 2014. DfT has reported that the road accidents were the highest than any year since 2003 (Chapter 1, Section 1.3).

Figure 3-16 shows the proportion of respondents by age groups; 50 to 54, 55 to 59 and over 60 years old. 25 per cent (10 drivers) of respondents were aged 50 to 54 years old, 45 per cent (18 drivers) out of 40 respondents were aged 55 to 59, and 30 per cent (12 drivers) were aged over 60.

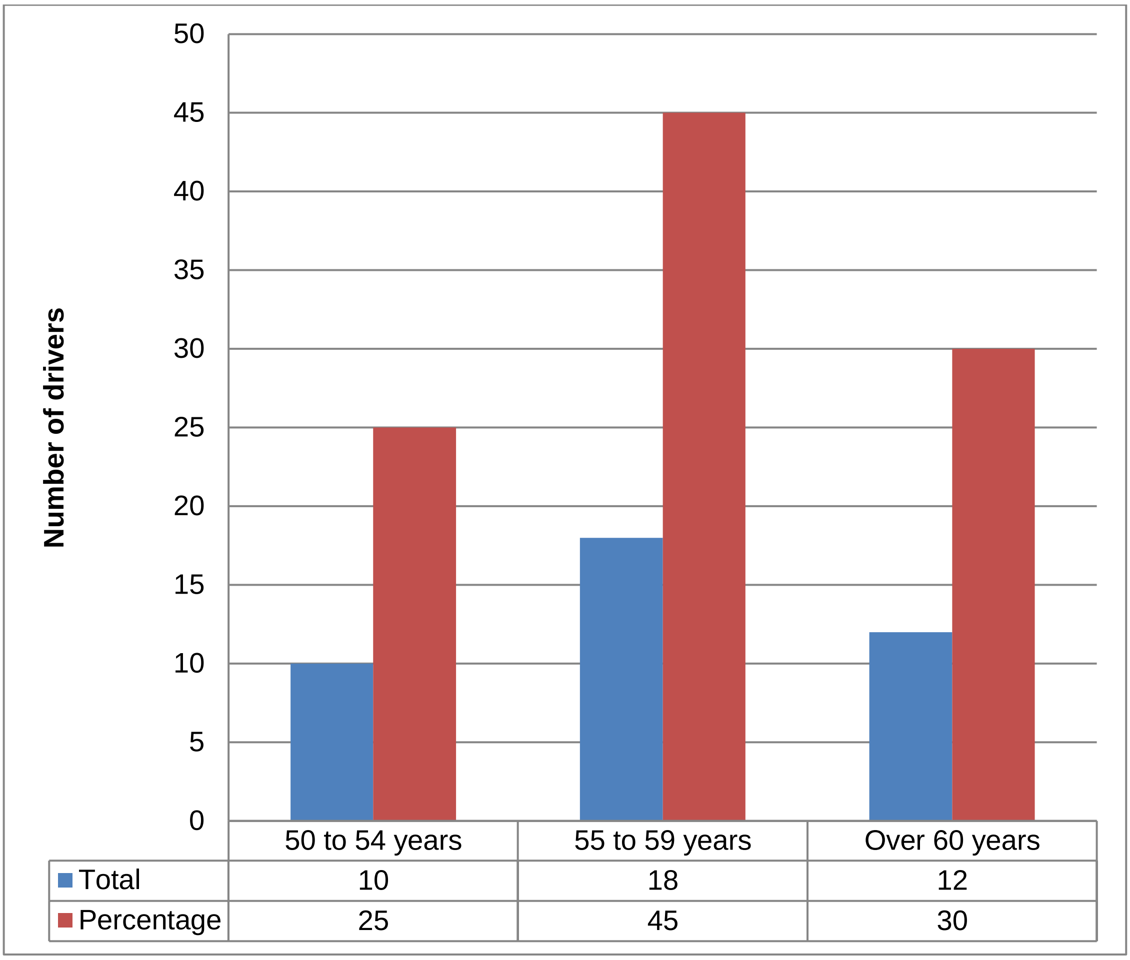


Figure 3-16 Proportion of drivers by age of group

3.11 Results 1: Key Factors Influence Senior Driving Behaviour

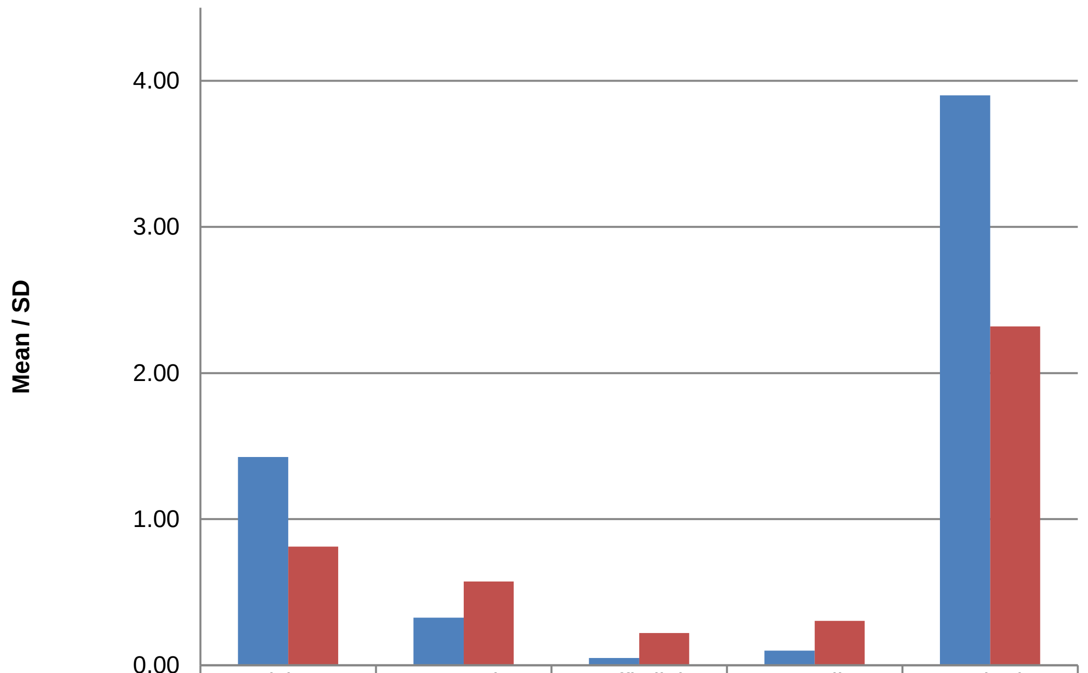
Research objective:

To measure the impacts of alternative airport road systems on driving behaviour.

Research question:

What are the key factors that may influence safe driving behaviour?

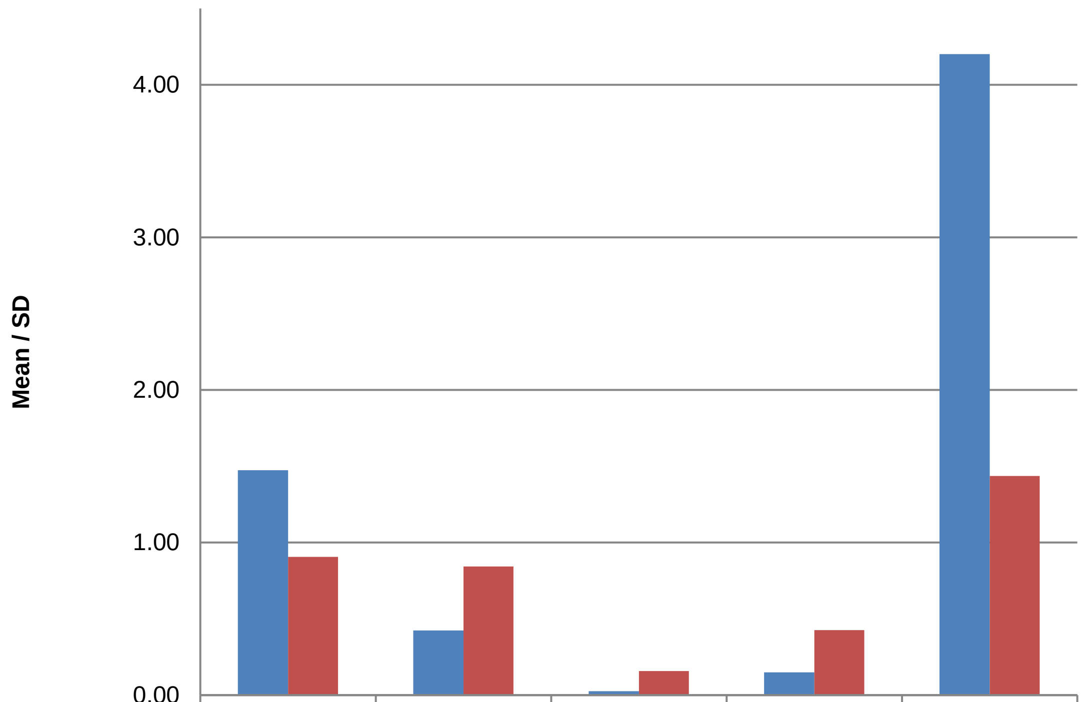
The key factors that influenced safe driving behaviour have been discussed in Section 3.6. Figures 3-17, 3-18 and 3-19 show mean and standard deviation computed for senior drivers' age errors based on 'Less Complex', 'Complex' and ‘More Complex’ road design, respectively. The results show that there is a relationship between road design complexity and driving errors. The results also revealed that the road edge excursions were the most common errors and ‘disobeyed’ red traffic lights had the lowest number of errors made by senior drivers in all simulated driving scenarios. Senior drivers preferred to drive near to the road edges (or road shoulders), ‘too carefully’ at the junctions and roundabouts and surprisingly drove too fast in sections of the road that had lower speed limits. This pattern showed that senior drivers make more errors and are exposed to incidents on the road.



Mistakes	Risk to collisions	Speed exceedances	Traffic light tickets	Centreline crossing	Road edge excursions
Mean	1.43	0.33	0.05	0.10	3.90
Std. Deviation	0.81	0.57	0.22	0.30	2.32

Figure 3-17 Mean and SD of drivers’ age based on ‘Less Complex’ Scenario

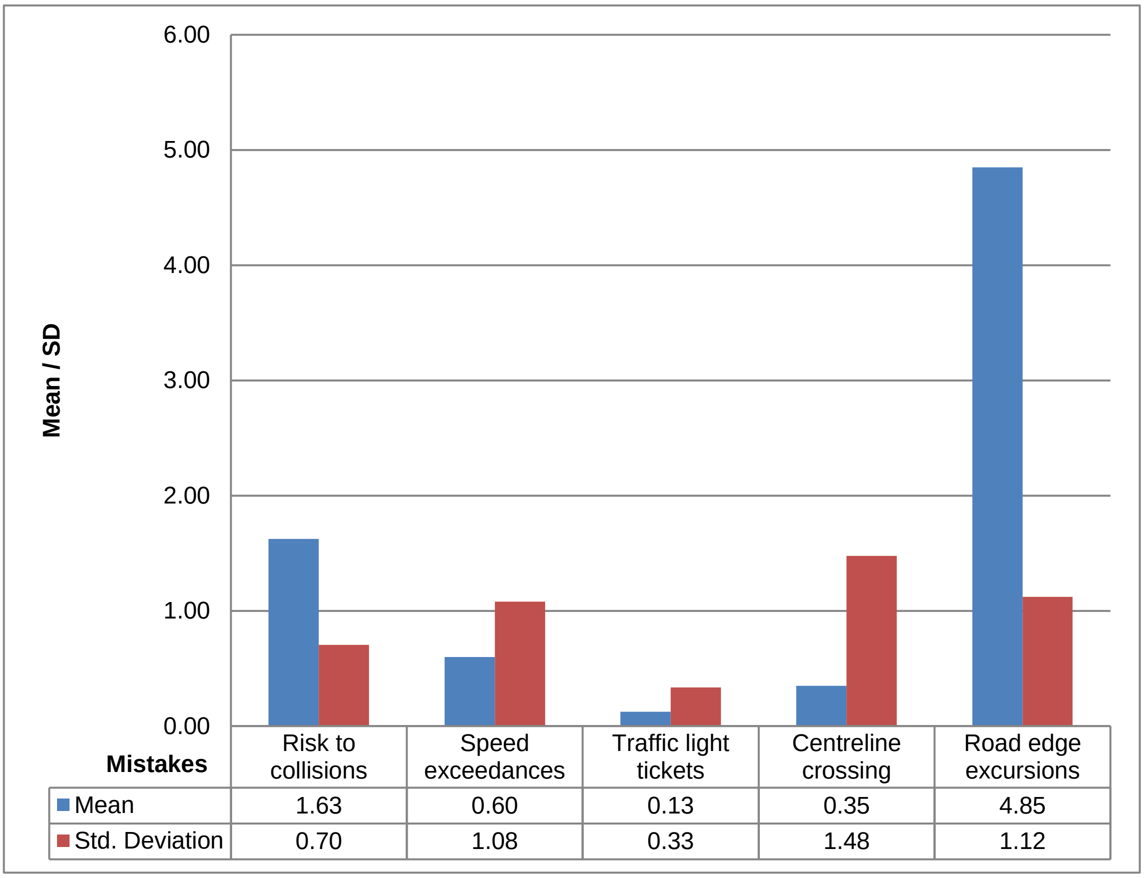
In the ‘Less Complex’ wayfinding design (Figure 3-17), senior drivers were likely to cross the road edge (mean=3.90, SD=2.32), be exposed to the risk of collisions due to driving too close to a vehicle in front (mean=1.43, SD=0.81), exceeding the speed limit (mean=0.33, SD=0.57), cross the centreline (mean=0.10, SD=0.30) and were aware of red traffic lights (mean=0.05, SD=0.22).



Mistakes	Risk to collisions	Speed exceedances	Traffic light tickets	Centreline crossing	Road edge excursions
Mean	1.48	0.43	0.03	0.15	4.20
Std. Deviation	0.91	0.84	0.16	0.43	1.44

Figure 3-18 Mean and SD of drivers' age based on 'Complex' Scenario

In the 'Complex' wayfinding design (Figure 3-18), senior drivers were likely to speed and exceed the standard speed limit (mean=0.43, SD=0.84). They preferred to drive close to the kerb, which resulted in road edge excursions (mean=4.20, SD=1.44). However, they were likely to cross the centreline of the road lane (mean=0.15, SD=0.43) when attempting to turn at the next junctions. Tailgating as one of the major contributors to the road accidents could raise the risk of collision (mean=1.48, SD=0.91). Traffic light ticket (mean=0.03, SD=0.16) rates were low in the ‘Complex’ scenario, perhaps because of their experience from the previous simulated driving test.



Mistakes	Risk to collisions	Speed exceedances	Traffic light tickets	Centreline crossing	Road edge excursions
Mean	1.63	0.60	0.13	0.35	4.85
Std. Deviation	0.70	1.08	0.33	1.48	1.12

Figure 3-19 Mean and SD of drivers’ age based on ‘More Complex’ Scenario

Drivers made more errors in the ’More Complex’ wayfinding design (Figure 3-19); road edge excursions (mean=4.85, SD=1.12), risk to collisions (mean=1.63, SD=0.70), speeding (mean=0.60, SD=1.08), crossing the centreline (mean=0.35, SD=1.48), and less aware of red traffic lights (mean=0.13, SD=0.33) while performing navigation in this scenario. These five errors are the major factors influencing senior driving behaviour on airport roads.

To summarise, there are contributory factors that may influence safe driving behaviour. In order to emphasize the driving simulation results, the preferred key factors leading to road accidents have been considered as shown in Table 3-12. Section 1.3 in Chapter 1 is revisited to associate drivers' mistakes on simulated driving with contributory factors that led to road accidents during navigation to the airport.

Table 3-12 Mapping of contributory factors to drivers' mistakes

Contributory Factors[17]	Risk to collisions	Speed exceedances	Traffic light tickets	Centreline crossings	Road edge excursions
Failed to look properly	X	X	X	X	X
Poor turn or manoeuvre	X			X	X
Failed to judge other drivers' path or speed	X	X			
Following too close	X				
Disobeyed 'Give Way' or 'Stop' sign or markings	X	X	X	X	X
Loss of control	X			X	X
Travelling too fast	X	X	X	X	X
Swerved	X			X	X
Exceeding speed limit	X	X	X		
Aggressive driving	X	X	X	X	X

DfT (2015b) reported that road accidents involving fatalities of senior drivers have only fallen by 15 per cent from the years 2005 to 2009. However, road accidents that involved serious injuries rose 10 per cent over the same period. The higher road accident statistics recorded every year were related to senior driving behaviour as discussed in Chapter 1 (Section 1.3). The proportion of the senior population has increased in recent years (Chapter 1, Section 1.1). DfT reported that in the year 2000, people aged 60 or over accounted for about 20.8

[17] Contributory factors as reported by DfT (2015c).

per cent of Great Britain's population. By 2013, this had risen to 23 per cent, just over a 10 per cent increase. As the number of people in the senior age group increases, a higher number of road accidents involving senior drivers would be expected.

In addition, as people get older their health condition deteriorates (Cuenen et al., 2016; National Institute on Aging, National Institutes of Health and U.S. Department of Health and Human Service, 2011). Thus, it could lead to problems such as poorer depth perception and an increase in mistakes in both cognitive and physical behaviour (Department for Transport, 2015b; Marin-Lamellet and Haustein, 2015; National Institute on Aging, National Institutes of Health and U.S. Department of Health and Human Service, 2011; Oxley et al., 2006; RoSPA, 2010). These factors affected senior drivers' ability to focus on the road while driving to the airport.

3.12 Results 2: The Impact of Airport Road Access Design to Driving Behaviour

Research objective:

To measure the impacts of alternative airport road systems on driving behaviour.

Research question:

1. *How should the impacts of alternative airport road access wayfinding design on driving behaviour be measured?*
2. *What are the impacts of alternative airport road access wayfinding design on driving behaviour?*

3.12.1 Risk to Collisions

The Two-Way ANOVA result of risk to collisions (Table 3-13) shows that there was no statistically significant difference between risk of collisions and senior drivers' age group. It shows that senior drivers had no difficulties to reach the airport in Simulation 1 (F=0.93, p=0.41), Simulation 2 (F=0.73, p=0.49) and Simulation 3 (F=0.16, p=0.86). Therefore, there is no impact to airport road access wayfinding designs on driving behaviour. Based on Table 3-13, the highest possibility of senior drivers being exposed to a road accident was in the 'More Complex' (mean=1.63, SD=0.70), followed by 'Complex' (mean=1.48, SD=0.91) and then 'Less Complex' (mean=1.43, SD=0.81) scenarios. Senior drivers were observed to drive near to the road edges (especially at the roundabouts), had difficulties in making a fast decision at the decision point (e.g. junctions and approaching signs), and failed to respond to speed limit signs at low speed limit roads. These factors are contributory factors that lead to road collisions.

The alternative hypothesis has been rejected at a significant alpha of 0.05. The hypothesis states that there is no impact between airport road access wayfinding design and driving behaviour. The result shows that the risk of collisions was less affected by senior drivers' age while driving to the airport.

Table 3-13 Two-Way ANOVA results for risk of collisions by simulation

Source	Mean Square	F	Sig.
Simulation 1 (Less Complex)	0.62	0.93	0.41
Simulation 2 (Complex)	0.60	0.73	0.49
Simulation 3 (More Complex)	0.08	0.16	0.86

3.12.2 Exceeding the Speed Limit

Table 3-14 shows no significant difference between speed exceedances and age group of senior drivers by road complexity; Simulation 1 (F=0.22, p=0.81), Simulation 2 (F=0.52, p=0.60), and Simulation 3 (F=1.73, p=0.19). The results in Table 3-14 revealed that airport road access wayfinding design was not linked to safe driving behaviour. Drivers preferred to speed in the ‘More Complex’ (mean=0.60, SD=1.08) compared to the other scenarios. Variable speed limit signs were considered in the “More Complex” scenario; however, the results confirmed that the complexity of the airport road access wayfinding design did not affect on speeding. The results also revealed that the speeding was lower in the ‘Less Complex’ scenario (mean=0.33, SD=0.57). The ‘less busy’ and ‘comfortable’ environment led senior drivers to lower speed without thinking of other tasks (Section 3.3). The results confirmed that senior drivers felt it to be comfortable and easy to navigate to the airport (Chapter 4).

Table 3-14 Two-Way ANOVA results for speed exceedances by simulation

Source	Mean Square	F	Sig.
Simulation 1 (Less Complex)	0.07	0.22	0.81
Simulation 2 (Complex)	0.38	0.52	0.60
Simulation 3 (More Complex)	1.94	1.73	0.19

DfT (2015b) and Oxley et al. (2006) reported that exceeding the speed limit and driving too fast are contributory factors to the accidents and casualties statistics. Exceeding the speed limit was reported in around 16 per cent of fatal accidents in 2014, whereas 8 per cent of fatal accidents were caused by driving too fast. A similar pattern was seen for reported road fatalities where exceeding the speed limit contributed to 17 per cent of fatalities and driving too fast contributed to 8 per cent of fatalities. The road statistics also revealed that 7 per cent of serious accidents and seriously injured casualties were allocated to the categories of exceeding the speed limit and travelling too fast. The alternative hypothesis has been rejected and at the same time the null hypothesis was accepted at a significant alpha of 0.05. The null hypothesis states that there is no difference between driving behaviour and airport road access wayfinding design. The result shows that the complexity of road design was not affected the speed limitation in the simulated environment.

3.12.3 Traffic Light Tickets

Table 3-15 shows the airport road access wayfinding design has no significant effect on driving behaviour in terms of traffic light awareness. Senior drivers were less aware of red traffic lights in all scenarios; Simulation 1 (F=0.85, p=0.44), Simulation 2 (F=1.18, p=0.32) and Simulation 3 (F=0.72, p=0.49). Statistical results revealed that senior drivers are more likely to fail to stop at red traffic lights in the 'More Complex' scenario (mean= 0.13, SD=0.33) compared to the 'Complex' (mean=0.03, SD=0.16) and 'Less Complex' (mean=0.05, SD=0.22) scenarios. Polders et al. (2015a) agreed that traffic light may generally be considered as a favourable effect and speeding at traffic lights are considered to be substantive problems, frequently leading to collisions.

Table 3-15 Two-Way ANOVA results for traffic light tickets by simulation

Source	Mean Square	F	Sig.
Simulation 1 (Less Complex)	0.04	0.85	0.44
Simulation 2 (Complex)	0.03	1.18	0.32
Simulation 3 (More Complex)	0.08	0.72	0.49

The null hypothesis was accepted. The hypothesis states that there is no effect between driving behaviour and airport road access wayfinding design.

3.12.4 Centreline Crossings

The Two Way-ANOVA test (Table 3-16) shows the senior drivers' age had no effect on road centreline crossing in all scenarios. Drivers are likely to cross the centreline more often in the 'More Complex' road design ($F=0.83$, $p=0.45$) compared to the 'Less Complex' and 'Complex' roads designs ($F=0.74$, $p=0.48$; $F=0.15$, $p=0.87$), respectively. The Two Way-ANOVA results revealed that the complexity of road design was not significantly affected senior driving behaviour. The complexity of the 'More Complex' scenario led senior drivers to cross road centrelines more often ones (mean=0.35, SD=1.48) compared to the 'Less Complex' (mean=0.10, SD=0.30) and 'Complex' (mean=0.15, SD=0.43). Poor turn manoeuvre at roundabouts and junctions were main factors of unsafe driving behaviour. DfT (2015c) confirmed that poor turn manoeuvre led drivers to road accidents.

Table 3-16 Two-Way ANOVA results for centreline crossings by simulation

Source	Mean Square	F	Sig.
Simulation 1 (Less Complex)	0.07	0.74	0.48
Simulation 2 (Complex)	0.03	0.15	0.87
Simulation 3 (More Complex)	1.82	0.83	0.45

The alternative hypothesis has been rejected and at the same time the null hypothesis was accepted. The hypothesis states that there is no significant effect between driving behaviour and complexity of airport road access wayfinding design. The result shows that the crossing the centreline while driving to the airport was not influenced by senior drivers' age.

3.12.5 Road Edge Excursions

Table 3-17 shows there is no significant effect between the senior drivers' age group and road edge excursions; Simulation 1 (F=0.56, p=0.57), Simulation 2 (F=1.26, p=0.30), and Simulation 3 (F=1.23, p=0.31). The ANOVA test revealed that senior drivers crossed the road edge more frequently in the 'More Complex' scenario (mean=4.85, SD=1.12) compared with the 'Less Complex' (mean=3.90, SD=2.32) and 'Complex' (mean=4.20, SD1.44) scenarios. As similar to centreline crossings, poor turn manoeuvre affected senior drivers' safety which could lead to the risk of collisions. Senior drivers being likely to drive close to the kerb (e.g. to get a close view of traffic signs' information) was the reason for the highest mean value shown in Table 3-17.

Table 3-17 Two-Way ANOVA results for road edge excursions by simulation

Source	Mean Square	F	Sig.
Simulation 1 (Less Complex)	3.10	0.56	0.57
Simulation 2 (Complex)	2.57	1.26	0.30
Simulation 3 (More Complex)	1.53	1.23	0.31

The alternative hypothesis has been rejected. The hypothesis states that there is no significant effect of airport road access wayfinding design on driving behaviour. The result shows that the road edge excursion was not influenced by senior drivers' age while driving to the airport.

3.13 Results 3: The Impact of Airport Road Access Design on Senior Driving Performance

Research objective:

To measure the impacts of alternative airport road systems on driving behaviour.

Research question:

1. *How should the impacts of alternative airport road access wayfinding design on driving behaviour be measured?*
2. *What are the impacts of alternative airport road access wayfinding design on driving behaviour?*

Table 3-18 shows the recommended driving performance parameters that were measured (Dorn and Stannard, 2006).

Table 3-18 Measurement of driving perfomance parameters

Parameter	Description
Lane position	1. Location of the driver's vehicle with respect to the roadway's dividing line. 2. The position of the simulated driving in the road, measured from the centre of the roadway, to the centre of the car. 3. The centre of the roadway is described as 0ft, the left hand kerb edge as –12ft and the right hand kerb edge as +12ft, for a single carriageway road.
Speed	1. The longitudinal speed is the vehicle's velocity. The speed of the simulated vehicle (feet/second). 2. The top speed of the simulated drive is 70 feet/second.
Steering	1. Turning the steering wheel while doing steering manoeuvres. 2. Rate of change of the steering wheel angle (radians/second). This variable is always between 0 and 1.
Acceleration	1. Longitudinal acceleration is the total acceleration due to throttle input, braking and drag (feet/second^2). 2. This variable is always positive.

3.13.1 Two-Way ANOVA Test Results for Simulated Driving Performance

Tables 3-19 and 3-20 show the results of the simulated driving performance by senior drivers; 'Less Complex' (Simulation 1), 'Complex' (Simulation 2) and 'More Complex' (Simulation 3) relation to airport road access wayfinding design. Results of lane position, steering, acceleration and speed were identified in mean and Standard Deviation (SD).

Table 3-19 Mean and standard deviation in driving performance

Measure	Simulation 1		Simulation 2		Simulation 3	
	Mean	SD	Mean	SD	Mean	SD
Lane position (feet)	-11.55	3.36	-11.67	2.97	-12.01	2.08
Steering (degree/secs)	9.02	4.31	10.75	3.15	11.20	3.28
Acceleration (g's)	0.0158	0.0136	0.0193	0.0152	0.0243	0.0253
Speed (miles/hour)	41.65	6.21	41.47	4.85	41.45	4.37

Table 3-20 Two-WayANOVA results for driving performance

Driver's Mistake	Simulation 1		Simulation 2		Simulation 3	
	F	p-value	F	p-value	F	p-value
Lane position (feet)	0.62	0.55	0.41	0.67	1.56	0.22
Steering (degree/secs)	0.08	0.92	0.81	0.45	0.64	0.53
Acceleration (g's)	3.26	**0.05***	2.36	0.11	0.17	0.85
Speed (miles/hour)	2.08	0.14	0.65	0.53	0.94	0.40

*Indicates significant results < 0.05.

Table 3-20 shows the Two-Way ANOVA results for Simulations 1, 2 and 3. The alternative hypothesis has been rejected and the null hypothesis was accepted stating that there is no significant effect between driving behaviour and airport road access wayfinding design. However, the Two-Way ANOVA test shows that the senior drivers were accelerating assertively in Simulation 1 ($F=3.26$, $p=0.05$). It means that the alternative hypothesis has been accepted at a significant alpha of 0.05. The significant result indicates that senior drivers are likely to reduce the speed at some point in the 'Less Complex' scenario (e.g. at junctions and roundabouts) to read and view traffic signs.

Senior drivers were likely to drive closer to the kerb in Simulation 3 ($F=1.56$, $p=0.22$) compared to Simulation 1 ($F=0.62$, $p=0.55$) and Simulation 2 ($F=0.41$, $p=0.67$). They were more likely to steer less sharply in Simulation 2 ($F=0.81$, $p=0.45$) than Simulation 1 ($F=0.08$, $p=0.92$) and Simulation 3 ($F=0.64$, $p=0.53$). In the same table, senior drivers accelerated more assertively in Simulation 1 ($F=3.26$, $p=0.05$) compared to Simulation 2 ($F=2.36$, $p=0.11$) and Simulation 3 ($F=0.17$, $p=0.85$). They also were likely to drive faster in Simulation 1 ($F=2.08$, $p=0.14$) than to Simulation 2 ($F=0.62$, $p=0.53$) and Simulation 3 ($F=0.94$, $p=0.40$). Overall results show that senior drivers' navigation performance to the airport has no impact on airport road access wayfinding design.

Mean and SD results of simulated driving performances by senior drivers are analysed in the next sections. The analyses are focused on the impact of complexity on driving performances (i.e. on safe driving behaviour) by senior drivers while navigation to the airport.

3.13.1.1 Lane Position

Table 3-21 shows the simulated driving results based on Simulations 1, 2 and 3. Drivers aged 60 years and above (mean=-12.32, SD=4.1; mean=-12.31, SD=3.31) being closer to the kerb compared to the 50 to 54 age group (mean=-10.71, SD=3.34; mean=-11.50, SD=2.90) and that of the 55 to 59 year old (mean=-11.50, SD=2.95; mean=-11.33, SD=2.86) drivers while driving in scenarios 1 and 2. Drivers aged 50 to 54 (mean=-12.68, SD=1.68) drove closer to the kerb in scenario 3.

Table 3-21 Age differences in lane position performance

Measure		Lane Position		
Road Design		S1	S2	S3
50-54 years	Mean	-10.71	-11.50	-12.68
	SD	3.34	2.90	1.68
55-59 years	Mean	-11.50	-11.33	-11.39
	SD	2.95	2.86	2.37
Over 60 years	Mean	-12.32	-12.31	-12.39
	SD	4.01	3.31	1.76

Results show that senior drivers tend to have difficulties driving in the complex and more complex scenarios. They are likely to drive closer to the kerb, especially at the roundabouts, and have difficulties making a fast decision at the decision points (e.g. junctions and approaching traffic signs). It may also mean the drivers are trying to have a clear vision to read the signage. Drivers aged 50-54 years (mean=-10.71, SD=3.34) were likely to drive further from the kerb in scenario 1, perhaps to reduce the risk of colliding with objects on the road's shoulder and with pedestrians. It is also perhaps an assertive way of driving (Dorn and Stannard, 2006). However, at the roundabouts and junctions, drivers aged 50-54 appeared not to drive too close to the kerb to avoid kerb collision.

3.13.1.2 Absolute Steering Wheel Rate

Table 3-22 shows the results of absolute steering wheel rate performance. All groups of senior driver ages had a slower steering rate in Simulation 1; 50 to 54 years (mean=8.91, SD=4.70), 55 to 59 years (mean=8.79, SD=4.30), and over 60 years (mean=9.45, SD=4.63), respectively, compared to the other scenarios.

Table 3-22 Drivers' age differences in mean and standard deviation for absolute steering wheel rate performance

Measure		Absolute Steering Wheel Rate (radians/second)		
Road Design		**S1**	**S2**	**S3**
50-54 years	Mean	8.91	11.05	12.22
	SD	4.70	2.63	4.08
55-59 years	Mean	8.79	10.07	10.82
	SD	4.30	3.43	2.73
Over 60 years	Mean	9.45	11.52	10.91
	SD	4.36	3.14	3.44

All age groups of senior drivers were more careful towards the complexity of the road design such as multiple traffic signs and other road furniture on the road's shoulder established in airport road access wayfinding simulations. Drivers aged 50 to 54 were more likely to steer sharply at junctions and roundabouts. From the observation, drivers aged 50 to 54 are likely to drive faster than other groups of drivers, which affect their driving manoeuvre and turning steering more rapidly.

3.13.1.3 Longitudinal Acceleration

Table 3-23 shows the results of acceleration rate performance. The results in mean and SD showed there were no significant difference in all simulated driving scenarios. However, Simulation 1 showed a lower acceleration rate [drivers aged 50 to 54 (mean=0.016, SD=0.015); drivers aged 55 to 59 (mean=0.021, SD=0.013); and drivers aged over 60 years (mean=0.008, SD=0.009)] compared to the other simulations. There is no significant effect between acceleration rate (i.e. way of driving) and drivers' age. Senior drivers aged 50 to 54 [Simulation 1 (mean=0.016, SD=0.015); Simulation 2 (mean=0.028, SD=0.020); and Simulation 3 (mean=0.028, SD=0.030); were likely to accelerate assertively compared to drivers aged 55 to 59 and over 60 years. Senior drivers were likely to drive slowly to avoid centreline crossing and kerb collision at the roundabout.

Table 3-23 Drivers' age differences in mean and standard deviation for longitudinal acceleration performance

Measure		Longitudinal Acceleration (feet/second^2)		
Road Design		S1	S2	S3
50-54 years	Mean	0.016	0.028	0.028
	SD	0.015	0.020	0.030
55-59 years	Mean	0.021	0.017	0.024
	SD	0.013	0.010	0.019
Over 60 years	Mean	0.008	0.016	0.022
	SD	0.009	0.016	0.032

3.13.1.4 Longitudinal Speed

Table 3-24 shows the results of speed rate performance by senior drivers.

Table 3-24 Drivers' age differences in mean and standard deviation for longitudinal speed performance

Measure		Longitudinal Speed (feet/second)		
Road Design		S1	S2	S3
50-54 years	Mean	41.52	41.50	40.88
	SD	5.71	3.14	3.20
55-59 years	Mean	43.53	42.30	42.48
	SD	4.32	4.77	4.37
Over 60 years	Mean	38.94	40.22	40.37
	SD	8.22	6.12	5.17

Based on all scenarios, there is no significant effect in speed based on senior drivers' age range; senior drivers were likely to speed in all simulation scenarios. In comparison, drivers aged 55 to 59 were more likely to speed; Simulation 1 (mean=43.53, SD=4.32, Simulation 2 (mean=42.30, SD=4.77), and Simulation 3 (42.48, SD=4.37), compared to the other age groups.

3.14 Contributory Factors to Safe Driving Behaviour

As discussed in Chapter 1 (Section 1.3) and in Section 3.11 (Table 3-12), the DfT (Department for Transport, 2015b, 2015c) highlighted several factors leading to road accidents. The contributory factor of loss of control was reported as 32 per cent of fatal accidents in 2014. The pair of contributory factors relating to poor wayfinding that were most frequently recorded are (1) failing to look properly and (2) judging the other person's path or speed. Drivers' mistakes or reaction was the most frequently reported, as 73 per cent of all accidents in 2014. These contributory factors were also the most frequent category reported for each severity of accident. Behaviour or inexperience and injudicious actions (which include travelling too fast for conditions, following too close and exceeding speed limit) were the next most frequently reported categories, involving 25 and 23 per cent of all accidents, respectively. The equivalent figures of fatal accidents, for both contributory factors, were higher at 27 and 29 per cent, respectively.

The senior drivers may have more experience behind the wheel, but could be more likely to be nervous and concerned about their own reaction times and eyesight (National Institute on Aging, National Institutes of Health and U.S. Department of Health and Human Service, 2011).

3.15 Chapter Conclusion

The research suggests that driving simulation is a useful tool for testing senior drivers' wayfinding ability in a virtual environment. As the study investigated the impact of senior drivers' driving behaviour on different wayfinding and signage provisions, the Two-Way ANOVA results showed that there were no significant effect of airport road access wayfinding (in terms of age group) and the research parameters of; (1) risk of collisions, (2) exceeding the speed limit (3) traffic light tickets, (4) centreline crossings and (5) road edge excursions.

Although, the age group of senior drivers had no significant linked with driving performance in all simulated driving scenarios, the Two-Way ANOVA test summary shows that the results of the research parameters tested as Tables 3-25 and 3-26 (revisited from Section 3.12 and 3.13).

Table 3-25 Summary of Senior Drivers' Mistakes in Simulated Driving

Driver's Mistake	Simulation 1		Simulation 2		Simulation 3	
	F	p-value	F	p-value	F	p-value
Risk to collisions	0.928	0.405	0.727	0.490	0.158	0.855
Speed exceedances	0.216	0.807	0.523	0.597	1.725	0.192
Traffic light tickets	0.849	0.436	1.177	0.319	0.720	0.493
Centreline crossing	0.742	0.483	0.146	0.865	0.826	0.446
Road edge excursions	0.564	0.574	1.262	0.295	1.228	0.305

The study also confirmed that there is no impact between navigation systems of airport road access and senior drivers age group of. The results show that age group has no impact on the research parameters of; (1) lane position, (2) steering wheel rate, (3) acceleration and (4) speed. However, the age group may contribute to the risky driving behaviour. The study suggested that driving simulation is useful to test drivers' wayfinding process in virtual environments and validated selected research variables (i.e. wayfinding obstacles and contributing factors to wayfinding difficulties).

Table 3-26 Summary of Drivers' Performance in Simulated Driving

Driver's Performance	**Simulation 1**		**Simulation 2**		**Simulation 3**	
	F	**Sig.**	**F**	**Sig.**	**F**	**Sig.**
Lane position (feet)	0.616	0.546	0.407	0.669	1.559	0.224
Steering (degree/secs)	0.083	0.921	0.813	0.451	0.638	0.534
Acceleration (g's)	3.264	**0.049***	2.357	0.109	0.167	0.847
Speed (miles/hour)	2.078	0.140	0.651	0.527	0.942	0.399

*Indicates significant results < 0.05

The researcher had full control of the simulated driving to alternative airport road access wayfinding assessments and in this way the driving simulation saved time and costs. High-risk drivers can be tested in a driving simulation under safe conditions in which errors can be made without cost to life or property (Shechtman et al., 2007).

In conclusions, there are three reasons the driving simulation is beneficial to the study. Firstly, a virtual driving simulation keeps the driver safe from collisions. This research seems too hazardous to be tested in a real environment. Secondly, a driving simulator reveals the driver responses to changes in the vehicle without having to construct a vehicle with those features or performance characteristics. Alternatively, four-wheel steering systems have been studied using simulators, potentially at less cost and more quickly than constructing roadworthy systems. Finally, a wider variety of test conditions can be prescribed and consistently applied in a driving simulator compared with on the road. The influence of the weather on driving conditions is controllable in the simulator room which gives more advantages to the researcher in terms of cost and time saving.

Complexity of road design and the environment or increased traffic congestion contributes to a distracted driver's ability (Taylor and Dorn, 2006) to keep track of wayfinding. Inattention results in diverse movements out of the lane, exceeding the speed limit (Chevalier et al., 2016) and failure to detect a vehicle on a conflicting path at an intersection (Dukic and Broberg, 2012; Mårdh, 2016; Oxley et al., 2006) that exposes drivers to the risk of collisions and increased road accident.

4 THE EFFECTS OF AIRPORT ROAD ACCESS DESIGN ON SENIOR DRIVERS' WAYFINDING

4.1 Introduction

Research objectives and research questions are revisited as follows:

To assess the effects on drivers' wayfinding of alternative airport road access design solutions.

1. Does road access design have an effect on wayfinding?
2. How should the effects of airport road access design on wayfinding be measured?
3. How does the receipt of wayfinding information affect driver navigation?

This chapter discusses the previous literature on the wayfinding provisions at the airport road access area. Standard design of signs and airport road furniture is considered. Chapter 4 gives an overview of current airport road access wayfinding (including signage) and its practicality for road systems. Section 4.2 explains the airport road access wayfinding process on airport road access network. Section 4.3 describes the characteristics and principles of airport road access wayfinding systems. Section 4.4 discusses the factors influencing airport road access wayfinding. The research methodology is briefly discussed in Section 4.5. This is followed with the analysis of results in Section 4.6 which examines the effects of airport road access design on senior drivers' wayfinding. Section 4.7 highlights the recommendation based on survey outcomes. Chapter 4 concludes with a statement on better solutions of airport road access wayfinding design for senior drivers.

An effective airport road access with a systematic traffic signing system is essential for the efficient use of the road network. Wayfinding (including traffic signs) are important elements for airport road access design. Airport users are dependent on wayfinding (including traffic signs) in order to provide them with hazard warnings, road traffic and direction. In order to make the best and safest of airport road networks, clarity of signs and road markings play an important role in wayfinding design. A consistent airport traffic sign system is instantly recognisable and becomes familiar to airport users. This consistency has been delivered through legislation and guidance which ensures that airport traffic signs can be seen and readily understood under all common road conditions.

Wayfinding (including traffic signs) is a communicating tool to airport road users. The wayfinding design should be simple, concise and understandable. Information not only alerts road users to the conditions of the roads, but also stimulates adequate responses (for instance, directional signs contribute to safety by clearly defining the path to be followed through exact road lanes by separating conflicting movements, to continue to the next destination). The way that signage is designed and placed is also critical to the way roads look, how they are used and how restrictions and prohibitions are enforced. The clear information on signs contributes to easy wayfinding.

4.2 Wayfinding Process on Airport Road Access Network

As discussed in Chapters 2 and 3, airport road access wayfinding is defined as a process in which drivers navigate an airport landside environment using information support systems (e.g. signage, architectural clues, street lights and road markings). It includes the process of finding a way in the geographical space and identifies present location, knowing how to get to and from (Farr et al., 2012) the airport. The wayfinding process involves decision making in response to continuing a journey, information received from the environment and which route is the best alternative to continue to navigate (Fewings, 2001). A straightforward design has been adopted in the structure of airport road access wayfinding design. Simplifying wayfinding provision will eliminate the effort in delivering an aesthetic value of signage and to reduce cost of investment in signage.

Wayfinding is useful for making a quick decision due to complex road access design. Figure 4-1 shows a basic wayfinding process which could be applied on the airport road access network. Drivers use two immediate elements of wayfinding; choices and clues. Choices are related to instance decision points[18] in wayfinding (Raubal and Egenhofer, 1998). The choices give opportunity to decide two or more alternative ways of airport road access. Drivers (including senior drivers) prefer to use a clue to make estimation based on road architecture. Clues include any signs and physical architecture along the road. Mitchell (2010) agreed signage should be specific, designed and placed in accordance to national standards which have advantages to drivers in terms of being able to locate, read and understand them within a timeframe.

Figure 4-1 Drivers' wayfinding process

1. Driver (Route decision)

   Complete information concerning alternative ways of airport road access is available and feasible to senior drivers.
2. Environment (Process)

   Senior drivers use alternative surrounding objects (e.g. wayfinding systems) and process into valuable information.
3. Destination (Result)

   Senior drivers eliminate an excess information in travelling based on the amount of information received. Financial costs (e.g. fuel costs and parking charge) and the opportunity costs (e.g. travel time spent) on their journey are included.

[18] Decision points (also refer as choice points) are the points where drivers need to make a quick decision using available information (i.e. exit from highway and split between roads leading to terminal and parking).

According to Harding et al. in ACRP Report 52 (2011), airport road signage needs to be conspicuous, legible, brief, understandable, and located in within a sufficient distance from the choice point to allow enough time to detect, read and make a decision. Thus, drivers have a responsibility to translate traffic signs into valuable information in order to make a right decision. The information might be translated into two impacts; negative and positive outcomes as shown in Figure 4-2 (Department for Transport, 2011b).

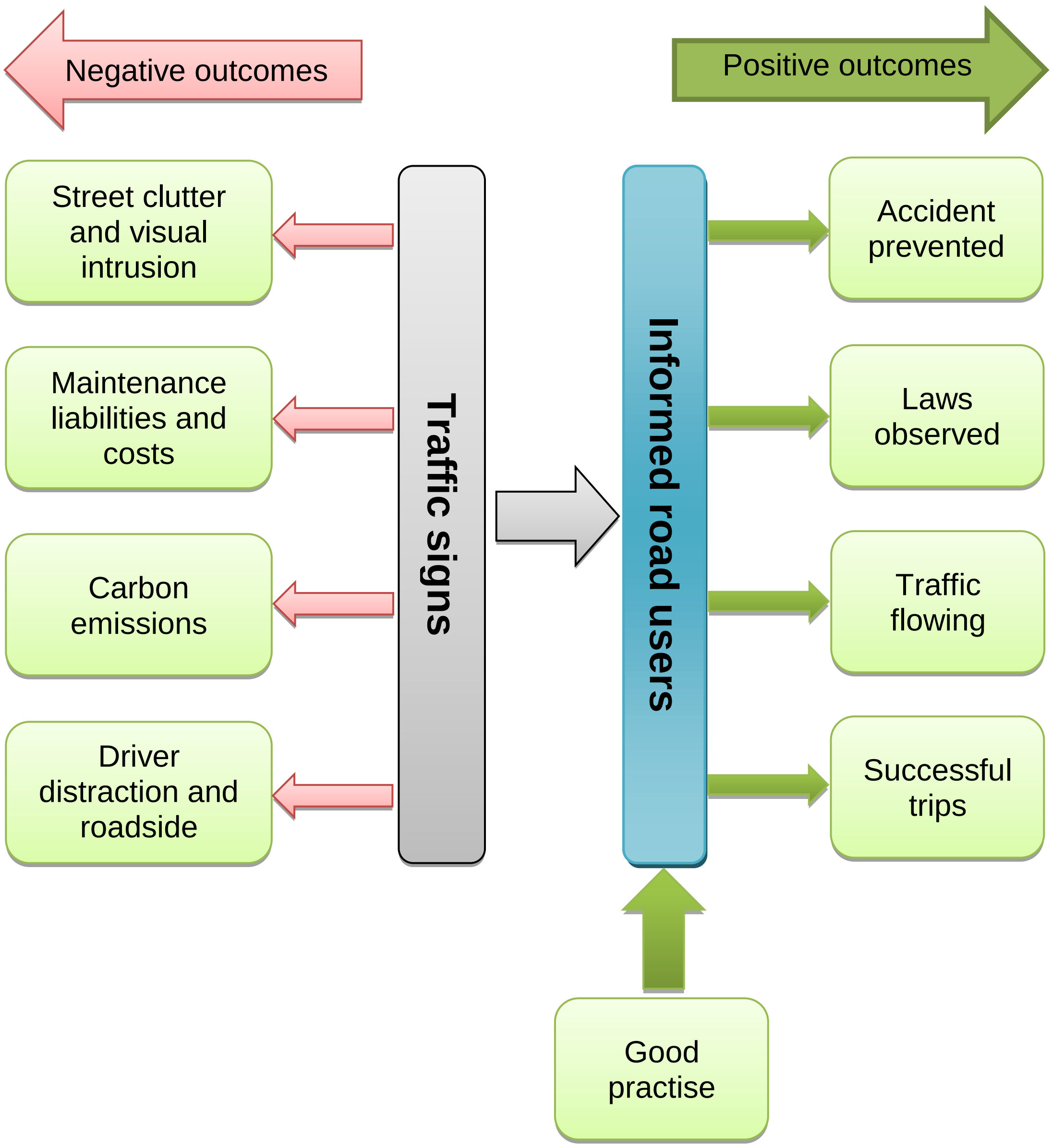


Figure 4-2 The impact of traffic signs (Source: DfT, 2011)

Choices or decisions are important elements when drivers have to decide among two or more different roads. Difficulties in making a quick choice increase workload for drivers, such as time wasting, motivation decrease, no short turns and road accidents. Table 4-1 shows the Choice-clue Model to be applied in driving wayfinding (including traffic signs) scenarios (Raubal and Egenhofer, 1998). The model represents a different level of wayfinding complexity. Raubal and Egenhofer (1998) proposed the wayfinding scenario in six different situations which could be applied into airport road access network.

Kuipers (1978) stated a large-scale space in an environment usually takes place in human wayfinding. It is due to unmoved objects or physical wayfinding (e.g. landscapes and buildings) around airport space, as drivers have to navigate to learn about it. Human wayfinding is based on ‘a consistent use and organization of definite sensory cues from the external environment’ (Lynch, 1960; Raubal and Worboys, 1999). Previous research related to human wayfinding mostly dealt with the exploration of ‘knowledge of the head’ (Norman, 1988, cited in Raubal and Egenhofer, 1998) and less attention has been paid to the ‘knowledge in the world’ (Gluck, 1991, cited in Raubal and Egenhofer, 1998). This is because people do not need to have all knowledge in order to behave accurately (Raubal and Egenhofer, 1998) during navigation to the airport.

Wayfinding issues in airport road access explained in Chapter 1, Section 1.2 were now be revisited. Bristol Airport reported that roadway signage has been improved after frequent comments on ineffective of airport road network signage has been received from travellers (Bristol International Airport, 2006). The ineffective of signage could lead to drivers’ confusion at airport road access network. In order to increase passenger travelling to and from London Luton Airport, a proposed action plan has been highlighted to improve wayfinding and onward travel facilities for passengers as well as increases attractiveness and visibility of road access navigation. On the other hand, Southampton Airport agreed that due to finite capacity of airport road space within the vicinity of the airport there are effects on the operation of all airport road access modes. As a results, Southampton Airport proposed that a clear directional signage and information on airport road access network was necessary (Southampton Airport, 2012).

Table 4-1 Decision-clue wayfinding model of airport road access (Source: Raubal and Egenhofer, 1998)

Clue(s) \ Choice(s)	Choice = 1	Choice > 1
Good	1	4
Poor	2	5
No clue(s)	3	6

1. Choice = 1 and good clue(s): At one direction, a driver at the decision point is forced to keep driving. Good clues lead the drivers' navigation to the right track to the airport. The wayfinding process is easy at this point.
2. Choice = 1 and poor clue(s): Drivers hesitate to proceed with one direction because of poor clues uncertainty about the airport route.
3. Choice = 1 and no clue(s): Drivers are not willing to proceed with one direction because there is no guarantee that they are on the right track to reach the airport.
4. Choice > 1 and good clue(s): Good clues help drivers to choose the alternative airport route. If clues are completed, easy to read and understandable, wayfinding and navigation process to reach the airport are easy at this point.
5. Choice > 1 and poor clue(s): Drivers might have a problem at the decision point if the clues are incomplete or misleading.

6. Choice > 1 and no clue(s): Drivers at this point get easily confused and lost. This is the worst scenario in a wayfinding process in order to navigate to the airport.

In general, drivers (including senior drivers) used spatial and cognitive knowledge to navigate in an airport wayfinding process. Spatial knowledge consists of landmark, route, and survey (Farr et al., 2012; Siegel and White, 1975, cited in Raubal and Worboys, 1999). Farr et al., Raubal and Worboys also agreed that spatial knowledge in wayfinding is necessary, such as following pathways and signage. Landmark knowledge involves significant points of references in the environment; route knowledge places landmarks into a sequence (e.g. navigation paths), and survey knowledge allows drivers to locate landmarks and routes within a general frame of references (Emo et al., 2012) to reach airport.

However, cognitive ability (cognitive maps) is dependent on the navigation task. Drivers (including senior drivers) prefer to use clues within their environment (e.g. past experience) and representations of spatial knowledge about their environment (Farr et al., 2012) to succeed in wayfinding to the airport. Drivers need to create and develop cognitive ability in the wayfinding process to reach airport based on their past experience and information acquired. Complex environmental structures lead to slower development of cognitive ability and also construct inaccuracies in wayfinding (Kuipers, 1978; Raubal and Egenhofer, 1998; Xia et al., 2008).

In psychology, cognitive learning theory (Anderson, 2015) describes three stages of learning in order to provide a useful tool for explaining how drivers' cognitive knowledge is developed within wayfinding task. This theory could be applied to airport road access wayfinding. Drivers are basically in the cognitive stage, which explain that drivers are consciously aware when they are learning something new. For example, drivers (including senior drivers) who are unfamiliar with road access network (Orellana and Sayed, 2013) to an airport may be unsuccessful in navigation without any clues provided. At the second phase, known as the associate stage, drivers begin to perform and progressively become competent at a skill. Any errors in the initial understanding start to be eliminated and new information or knowledge is strengthened. Novice drivers are attentive to airport road signs and adjust their behaviours according to the information received. Finally, at the autonomous stage, performance is becoming more automated and rapid. Drivers understand the relevant information that is included on airport signage design. Drivers are practically more aware on different types of signs; where they are placed and what the sign looks like and respond automatically.

Good wayfinding systems can be measured by considering the effect of driving experience on the airport road access, and how the self-navigation signage information facilitates from a start point to the airport area. Airport road access wayfinding systems should create a welcoming and enjoyable environment, reassure drivers and provide answers before they have to ask for assistance in the airport area (National Passenger Facilitation Committe, 2011). It can be achieved by focussing on the drivers' needs, especially during the planning and design phases, and, encompassing environmental factors (e.g. building design, user expectation and signage information) into airport road access wayfinding design.

4.2.1 Signing the Way

Signage is a tool in wayfinding. Signage delivers directional guidance, reassures drivers' location, indicates sites of local services, states the speed limit, and warns of upcoming changes or hazards. Given the value of such information, it is important for signs to be designed and placed so that drivers can locate, read and understand them within a timeframe appropriate for changing their plans and behaviour (Mitchell, 2010). Signage in other ways provides information for drivers to identify where they are, where they need to go, ensure they can get to their destination and to know when they have arrived. Findlay and Southwell (2004a, 2004b) mentioned a variety of user strategies and information sources afforded by the landscape of which signs of wayfinding are a key component, often supplemented by leaflets, published maps, personal contacts and word of mouth.

Difficulty in finding a destination decreases the functionality of this form of transportation and threatens the mobility of its users (Burns, 1998). The signage information required by drivers is a location awareness that relates to the destination, and to other places. Drivers should have knowledge of the intended destinations and obstacles that should be avoided to arrive at the destination successfully. It is also necessary to have architectural environment (e.g. building) knowledge which will influence the ease of wayfinding.

According to Transport Scotland (2006), the following are the elements to be applied on landside planning (including wayfinding systems):

1. Traffic direction - The traffic regulations suggested that the set of signs should be erected to direct traffic but there might be flexibility to vary the number and size in certain circumstances. Some of the signs are not entirely necessary.
2. Safety issue - There is often pressure to provide optimum road furniture, such as signs or barriers to road users. It is important to evaluate the road furniture to ensure a minimum extra provision is made, if any is necessary at all. Too much wayfinding design on airport road surface access encourages complacency and increases accident rate.
3. Need for the information - There are pressures from businesses, road users and tourism agencies to develop more information signs alongside roads. Road and tourist authorities should consider the effectiveness of existing signs, or whether the information is necessary at the first place.
4. Information needs to be clear and precise - Instead of creating additional signs or other furniture, the airport planner should be thinking about other alternative methods to deliver information, for example, to use road markings on airport road access. Road markings are often seen when a verge-mounted sign is obscured, providing a continuing message, and

improving the safety and efficiency of traffic flows (Department for Transport, 2003).

Previous research findings indicate that drivers attend to signs differently depending on personal variables such as driving experience and route familiarity. Mitchell (2010) confirmed that drivers do not attend to every sign and it is probably not safe for them to do so. However, when a driver does need a sign, it should be available and in a useful form. Most of the drivers navigate by reading the path of the road marking within the landscape, noting objects along the road, and the presence and speed of other vehicles. In this situation, drivers do need signage to help them to tell where they are and how to complete the wayfinding. Thus, a good signage design helps drivers when and where they need it (Borowsky, Shinar and Parmet, 2008). Drivers in general are more likely to recall more personally threatening warning signs than other (Mitchell, 2010). For instance, drivers are more likely to remember signs that indicate a change in speed limit or a police control area, than signs that indicate a general or non-specific warning; (e.g. speed breaker or zebra crossing). Drivers give more attention to signs on unfamiliar routes than to familiar routes because experienced drivers may have expectations about where particular signs should be placed (Burns, 1998; Mitchell, 2010).

In terms of airport road access wayfinding development, there are regular patterns (e.g. straight lines and right angles) that need to be highlighted. Montello and Sas (2006) stated that there are three major environmental factors that could improve the orientation and wayfinding as follows;

1. Differentiation. Variation of size, shape, colour and architectural styles are noticeable in certain area of the environment. Some differentiation of environments may be memorable to wayfinding due to distinctiveness or a disorienting effect.

2. Visual access. Environment space can be seen from various viewpoints. For example, drivers view the route and landmarks as a way of easing navigation to the airport.
3. Layout complexity. The environment offers a mixed impression that is difficult to express in formal terms. More complex layouts of wayfinding design cause difficulties with road navigation.

Airport road access wayfinding is important for the purpose of travelling to all transport users, locally and internationally. Airports play a role by connecting both ground and air transportation systems. Airport landside system offers surface transportation services such as taxi, bus and trains for the passengers. Alhussein (2011) stated that the airport also served as a distribution centre for freight movement by using the surface transportation for physical business, and transferring people and goods from origin to destination. It is an interrelated system between air and road surface transportation systems which affect each other on physical movement (Coogan, MarketSense Consulting LLC and Jacobs Consultancy, 2008).

Liverpool Airport (2011) reported that surface access design is important to ‘ensuring the sustainable airport opportunities are maximised’. The use of public transport, cycling, car sharing, private transport and other innovative transport initiatives in an efficient and viable manner is recommended (Coogan, MarketSense Consulting LLC and Jacobs Consultancy, 2008). Airport road access wayfinding development should indicate the preferences of passenger and airport staff itself. Several options can be applied to complete airport surface access development (Liverpool John Lennon Airport, 2011) as follows:

1. The road infrastructure is linked to the main road and airport is good overall, continuing to make the private car the most attractive travel option for many; and

2. Frequent shuttle bus services have proven to be very successful to increase the numbers of airport passengers arriving by public transport.

In addition, signage information systems are very important in providing various services and functions to the drivers. According to Transport Scotland (2006), a complete street must provide a structure within a road corridor whether the road is a motorway or a country lane. It includes road signs of all descriptions such as variable message and directions signs to tourist destinations (i.e. lighting, safety fences, barriers and bollards). Good airport road access wayfinding ease the decision making process for senior drivers. For instance, airport road access wayfinding information is important for making a quick decision to go to an intermediate destination (Fewings, 2001), such as departure or arrival terminals or intersection and interchange points.

As the signs are meant to be read and aid drivers in getting to the airport, the signage is designed based on the requirement of airport users. The key considerations in ensuring that the information is appropriately included in the signs are ‘why’, ‘who’, ‘when’ and ‘how’ (National Passenger Facilitation Committe, 2011). The next step is to know when is the most appropriate time to display the information signs. Therefore, it is important that signs adhere to basic guiding principles for copy, styles and sizes, uniform colours, consistent terminology and symbols of standard functions. Message content should be easily understood by both the frequent and first time traveller. The following points should be applied to wayfinding (including signs) design in airport area.

1. The wayfinding is positioned to ensure consistency of information. Visual clutter is reduced and drivers are presented with key information at critical decision making points;
2. The content of wayfinding (including signage) to support drivers’ goals is appropriate in the area it is located;

3. The text information is legible and easy to read at realistic viewing distances;
4. Any symbols used are clear and easy to understand;
5. The information is clear, sufficient, unambiguous and easy to read; and
6. The colour should enhance the readability of the signs.

4.3 Characteristics and Principles of Airport Road Access Wayfinding Systems

A good wayfinding (including signage) has its' own characteristics and principles. The principle of wayfinding are split into two different types of route decision-making; (1) the "static choice problem", where people already know the environment they are to navigate and the decision is made knowing the possible results (Raubal and Egenhofer, 1998); and (2) the "dynamic choice", where the decision-making is done in an unfamiliar environment (Mitchell, 2010) by first-time visitors. An example of this might be a choice of routes and transport modes from one's home to an airport. Where the route selection involves searching for or being given information on new routes, it is termed a dynamic choice problem. This is the type of problem faced by first-time travellers on entering an airport terminal (Fewings, 2001). The following are the basic principles of airport road access wayfinding design:

1. The requirement of the signs information in certain areas to make quick decision;
2. Minimise the number of signs in one place;
3. Minimise the signage size;
4. Simplifying colour, font style and the size of signs;
5. Avoid pedestrians obstructing traffic;
6. Consider the signs position (low and high);
7. Provide signs information where necessary;
8. Coordinate the current sign provision;

9. Avoid redundant signs information; and
10. Use double sided signs where possible.

There are three techniques that have been identified to ease wayfinding; recreational, resolute and emergency wayfinding (Fewings, 2001; Harding et al., 2011). Recreational wayfinding offers an individual (e.g. senior drivers) the opportunity to solve problems (i.e. where to go next) that can be a source of satisfaction and enjoyment. Resolute wayfinding applies where the main purpose is to find a way in the most efficient manner. Under emergency wayfinding conditions, the only important factor is reaching the destination as quickly and easily as possible.

As discussed in Chapter 2, Section 2.7, wayfinding performance is an accumulate wayfinding experience (signs information) in space (road). Lynch (1960) stated that the image-ability of large scale space is the ability of the driver to form a coherent-mental image or developing a map of it during wayfinding. Lynch also found that the driver is able to memorise the image in space by using common features such as landmarks, paths, barriers and intersections. The imageable or memorable features of a space are used by the driver to assist in wayfinding.

Wayfinding systems should provide the following information to drivers:

1. Airport location identification;
2. Reinforce when they are travelling in the right direction;
3. Identify the destination on arrival (of each area); and
4. Know where to exit safely in an emergency.

Wayfinding sign information can be delivered through the following:

1. Dynamic information;
2. Static signs;

3. Temporary information;
4. Lighting;
5. Building design;
6. User prior knowledge and experience; and
7. Audible information.

Mitchell (2010) suggested that a better sign offers better guidance to drivers. As shown in Table 2-3 (Chapter 2, Section 2.3), the guidance emphasises the principles of primacy, spreading, coding, and redundancy (Mitchell, 2010; Smiley, Houghton and Philp, 2004). The principle of primacy is defined as signs only being placed where needed and in the order needed. The principle of spreading is defined as the amount of information being kept within cognitive information processing limits. For instance, at some points (i.e. junctions and roundabouts), drivers need more information to make a quick decision before continuing their journey. Therefore, the information should be spread across multiple signs to complete the decision process. This is confirmed by DfT (2011b) that the design and use of traffic signs require a high level of knowledge and experience, particularly for more complex restrictions.

1. Placing traffic signs in a broader policy context with a strong link to other functions, including the impact of signs on the wider environment;
2. Provide flexibility; the local authorities deliver signing that is tailored to meet local needs;
3. Recommending the auditing of traffic signs and including traffic signs in asset management planning;
4. Reducing unnecessary sign clutter to provide the important messages to drivers;
5. Challenging the requirement to place traffic signs; traffic signs enforce restrictions and delivers essential information. For example, where there is a real hazard to road users;

6. Placing the regulatory signs designed at the start of the process of wayfinding;
7. Involving the local community in the placing of signs that meet the needs of road users; and
8. Listening to the feedback from the field for enforcement, setting in place procedures for obtaining intelligence from the field (e.g. civil enforcement officers, police, public complaints, local amenity groups) to identify traffic signing issues that potentially need resolving.

The principle of coding is defined as the signs being organised into larger units using colour and shape coding to enhance performance. Smiley et al. (2004) found that signage must be standard in term of colours, shapes, size of font, words providing information and location which allows drivers to easily identify the signs and respond immediately. Airport road access wayfinding (including signs) such as roadways, terminal and parking should be standardised in terms of terminology, lettering size, colour and location (Harding et al., 2011). Short and unambiguous messages are important because of the time-share between vehicle control and the time it takes to read while driving (Harding et al., 2011; Mitchell, 2010). These factors influence drivers to locate sign information easily despite being in a complex environment. Drivers can easily understand signs which display information in more than one way (e.g. signage shape and message). Redundancy could express the same information with two devices (e.g., "no passing" indicated with both sign and pavement markings) to the drivers; with both symbol and words being provided on the signage. For example, international drivers are able to make a good guess about priority actions or decisions to be taken due to their driving experience in different countries (Castro and Horberry, 2004).

4.4 Factors Influence Airport Road Access Wayfinding

According to the Australian International Airports (National Passenger Facilitation Committe, 2011), there are three contributing factors that influence airport road access wayfinding.

4.4.1 The Human Factor

The human factor indicates the individual and their ability to interpret wayfinding information that is being conveyed to them. This is influenced by their experience in the airport landside environment and their familiarity with the type of information they encounter. Inexperienced drivers do not have a good enough understanding on how to navigate and require more information (e.g. signage) to direct them to the airport. Drivers who are unable to locate the information will seek alternatives such as signage and architectural clues. In addition, drivers unable to memorise a lot of information in a short period of time could possibly ignore the important information (AASHTO, 2010).

4.4.2 Information

Wayfinding information types (e.g. visual, audible or physical), interpretation and understanding are the factors that contribute to the navigation to an airport. The drivers are more able to distinguish wayfinding (e.g. including signage information) than other types of information, such as adverts and operational signs (e.g. road work signs) whilst driving to the airport. Wayfinding information which is similar to other airport information may be confusing and should be avoided wherever possible.

4.4.3 Environment

Airport landside and architectural features create successful wayfinding. By providing information and reassurance at decision points, it will help drivers to make decisions. The use of landmarks or other visual clues (e.g. tree, hill and road marking) will also aid navigation (Antonson et al., 2009) to the intended airport.

4.5 Research Methodology: The Questionnaire

As discussed in Chapter 3, Section 3.7, in order to evaluate the airport road access wayfinding, an adoption of a specific method of research to achieve the study objectives was reviewed. In this section, the descriptive approach continued to be applied to understand airport road access wayfinding. A problem or situation was evaluated using a descriptive analysis after extensive previous knowledge was defined (Robson and McCartan, 2016). This research needed extensive preliminary work to be done to gain familiarity with the phenomenon in the airport road access wayfinding situation and understanding the research scope, before a theoretical model was developed for further investigation. For instance, emails have been sent to academic and professional experts in order to have a better understanding of airport road access wayfinding systems. Theories (e.g. theoretical frameworks), hypotheses and theoretical model were designed after airport road access wayfinding data and patterns were gathered.

In order to increase the validity of the research on airport road access wayfinding, the quantitative approach was applied. Items and concepts were tested through a questionnaire. Bryman (1984, 2006) stated that the questionnaire can be carried out by employing the same research instrument in another context with the problem of causality being eased by the emergence of path analysis to which surveys are well suited. It conveys a sense of solid and objective research using numbers and is also capable of presenting the findings in the form of graphs and tables to contribute to theoretical model development.

4.5.1 Ethical Considerations

The questionnaire was approved by the Science and Engineering Research Ethics Committee (SEREC) (Appendix A). Written consent is compulsory throughout the process and confidentiality of records were maintained (Appendix C). The simulation assessment and procedure were explained to each participant prior to formal testing. The questionnaire was distributed after each simulation assessment and procedure. The following is the procedure for conducting the questionnaire:

1. The researcher suggested respondents take a few minutes to complete the questionnaire (i.e. 5 minutes short break after questionnaire sessions) before continuing with the next simulated drive.
2. Respondents were able to answer the questionnaire more accurately after each driving simulation test ended. The pilot study revealed that participants were not remembering the whole experience during simulated driving. This is because of participants can only absorb a limited amount of information while driving, thus, overload can lead to confusion. Thus, the questionnaire distribution after each simulation ended to gather more meaningful data from the participants was recommended.
3. Participants were informed that they were free to terminate the study at any time without any negative consequences.

4.5.2 Developing the Questionnaire

A questionnaire was designed as the primary measuring instrument of the study. The questionnaire acted as a way of providing supporting information for the simulator study to increase the validity and reliability of the research.

Research objectives and research questions are revisited as follows:

To assess the effects on drivers' wayfinding of alternative airport road access design solutions.

1. Does road access design have an effect on wayfinding?
2. How should the effects of airport road access design on wayfinding be measured?
3. How does the receipt of wayfinding information affect driver navigation?

A questionnaire may be divided into two types, open-ended or closed. The open-ended questionnaire allows respondents to answer in any way they choose (Sekaran, 2003). The closed questionnaire is designed to permit only one form of response and allow the respondents to make a choice from a set of alternative responses (Frankfort-Nachmias and Nachmias, 1996; Robson and McCartan, 2016; Sekaran, 2003). The questionnaires were developed in order to explore, probe and acquire new knowledge or information in a systematic way. The participating respondents (i.e. senior drivers) were expected to answer the pre-arranged questions which were presented in a specific order. The questionnaires were designed to be effective, approachable and easy to understand. Feedback and comments were acquired from senior drivers who volunteered to take part in the driving simulation test, and this was refined before the pilot test has been conducted on senior drivers.

A draft of the questionnaire was constructed at the beginning of January 2014. The questionnaire was designed based on the literature review, research objectives, research questions and improvement of questions from pilot study. It was divided into three sections as shown in Table 4-2. The first section indicates respondent demographic profiles. General information is useful in obtaining data on the background of the respondents which might have a direct correlation with the responses to the questionnaire statement (Frankfort-Nachmias and Nachmias, 1996; Sekaran, 2003).

Section 2 evaluates the impact of simulated airport road access wayfinding on senior drivers' driving performance. The questions in this section were based on the simulated driving scenario experiment as well as previous experiences of driving to the airport. The questions were developed based on research questions; *does road access design have an effect on wayfinding?,* and *how should the effects of airport road access design on wayfinding be measured?.*

Table 4-2 The questionnaire design framework

Question	Survey	Rating
Section A (Demographic background)		
1 to 5	To identify the demographic background of the respondents to the wayfinding survey. The responses indicated respondents' age, gender, frequency of travelling to the airport in a 12 month period, travelling purpose, and travelling time spent to and from the airport.	Multiple choice (nominal/categorical data)
Section B (Based on simulated driving experience – Chapter 3)		
1 to 20	To evaluate the impact of simulated airport road access wayfinding design on senior driver behaviour.	Rank 1 to 5 (interval data)
Section C (Based on participants' general experience to drive to the airport)		
1 to 21	To evaluate the significant effect that exists between wayfinding provisions and driving behaviour in airport road access wayfinding design.	Yes or No (nominal data)

The Likert scale[19] is a method designed to measure attitudes (Frankfort-Nachmias and Nachmias, 1996). The Likert scale was used in this research to examine how strong senior drivers' agreed or disagreed with the statements (Sekaran, 2003) on a 5-point scales; *1 (strongly disagree), 2 (disagree), 3 (neutral), 4 (agreed, and 5 (strongly agreed).* These values expressed the

[19] Likert scale is an interval scale used to summate rating scale designed to assist in excluding questionable items (Frankfort-Nachmias and Nachmias, 1996; Sekaran, 2003).

relative weights and direction of the research objective and questions, which were determined by the favourableness or unfavourableness of the questions. The responses were analysed and presented in frequency analysis and graphs (Section 4.6).

Section 3 examines the impact of wayfinding information and drivers' navigation to the airport. The questions were developed based on research questions; *how does the receipt of wayfinding information affect drivers' navigation?*. The dichotomous scale[20] was used to elicit a *Yes* or *No* answer. Simple questions were asked based on the drivers' general and past experience of driving to the airport. The responses were analysed and presented in frequency analysis and graph (Section 4.6).

All questions in Section A, B and C were analysed based on senior drivers' experience on three simulated scenarios ('Less Complex', 'Complex' and 'More Complex' scenario) (Chapter 3, Section 3.8.4) and general experiences of driving (Appendix E). The results were compared and presented in frequency analyses and graphs.

A continuous effort of contact through e-mails was used to encourage better responses from respondents. In order to increase the response rate, the following techniques were adopted:

1. A cover letter of self-introduction, questionnaire purpose, assurance of confidentiality or privacy and expression of gratitude for their responses was provided (Kanuk and Berenson, 1975);
2. Instructions on completion of questionnaires were provided and explained;
3. A consent statement or form;
4. A direct and clear questionnaire was developed; and

[20] Dichotomous scale allows respondents to choose one of two values or an answer to two different aspects of a concept (Beins and McCarthy, 2012).

5. Questionnaire was distributed to senior drivers after driving simulation tests were conducted. A verbal explanation was conveyed to senior drivers that the questionnaire was part of the research and their volunteering as a respondent was appreciated.

The following are the reasons to include the questionnaire into research:

1. The questionnaire is used as a supporting study to increase the reliability and validity of the research;
2. The research focuses on the easing wayfinding solutions into airport planning and development;
3. Quick access to the potential respondents; and
4. Various demographic backgrounds of the respondents and purpose of travel were acquired.

A combination of open and closed questions was developed which led to a quantifiable measurement of the research technique. Table 4-3 shows mapping of survey questions to research questions.

Table 4-3 Mapping of questionnaire to research questions

Research Question	Survey Question	Section
1. Does road access design have an effect on wayfinding? 2. How should the effects of airport road access design on wayfinding be measured?	It was easy to drive on the road	Section B (driving simulation)
	I noticed that the trees were blocking some of the road signs	
	There were too many traffic lights	
	Poor visibility along road because of terrain	
	At the junction on the road to the airport, I was able to make a fast decision	
	The bend on the road did not affect my feeling of safety	
	The level of traffic did not make any difference to my driving	
	I felt nauseous when driving on the simulator	
	I felt safe to perform the simulated driving exercise	
	I feel anxious while driving to the airport	Section C (general experience)
	I am not aware of street lighting	
	I plan the route before drive to the airport	
	I look for landmarks (e.g. buildings) to help me find my way	
	I feel safe to drive at night with the street lights	
	Missing highway exits make me confused	
	The more complex to access to the airport, the less likely to drive to the airport	
	I less likely to drive to airport if the traffic is heavy	
3. How does the receipt of wayfinding information affect drivers' navigation?	The signs were easily noticeable	Section B (driving simulation)
	I could not read the text on the signs	
	I was looking for the word "airport" on the sign	
	Type of warning signs were adequate	
	The font of the road signs were clear and readable	

	The signage helped me navigate easily	
	There were too many road-side adverts	
	I could not read the adverts	
	I was distracted by the adverts	
	The frequency of warning signs were adequate	
	The variable speed limit signs were noticeable	
	Airport signs should have the same style as normal road signs	Section C (general experience)
	I would prefer signs to be larger	
	Additional information in signage design is relevance	
	Speed limit signs should be displayed frequently	
	Adverts on the road are distracting	
	The directional arrow sign is useful	
	I do not like the symbol sign	
	The airport text on the signs is too small	
	The types of road signage does not help drivers	
	A variable speed limit affects my driving behaviour	
	Too many signs are confusing to drivers	
	Signs indicating directions to the airport should be displayed as far as possible from the airport	

4.5.3 Pilot Study Validation

The content validity of the questionnaire was checked by asking experts in airport road access systems. For instance, a formal meeting with Birmingham Airport Transport Specialist was conducted on 3rd April 2014. The highlights outcomes of meeting as follows:

1. No specific measurement was considered on airport road access wayfinding design. The signs are placed based on its requirement (such as junction, roundabout and pedestrian crossing) to ease traveller to make a decision on airport road network;
2. Types of signs (e.g. direction, information, warning and advertisement) are important as similar as conventional road;
3. No specific equation or measurement was considered on the number of signs. The signs are placed based on its requirement to ease traveller navigation on airport road network; and
4. The signs (e.g. font and size) are similar to national traffic signs design. The airport directional signs colour is proposed to be pink in order to be identical and unique.

Content validity is considered as an important procedure to ascertain that the instruments (e.g. driving simulation and questionnaire) are measuring what they are designed to measure (Sekaran, 2003). The pilot study is vital because the combination of airport road access wayfinding simulation and questionnaires has never been tested before in the field, and original (self-designed by researcher) research enables researcher to make a contribution to the knowledge (novelty of the research).

To evaluate the driving scenarios, a pilot study was conducted with the aim of determining whether the outcome measures of simulated driving were sensitive to differences in the detection performances on driving behaviour during the airport road access wayfinding process. A full simulated driving scenario was tested (Chapter 3) and subsequently followed up with the questionnaire. Participant data from the pilot study was interpreted and analysed after the driving scenario simulations and the questionnaire had been completed. The respondents' feedback was kept strictly confidential and used for research purposes only.

4.5.4 Research Validation and Reliability

In order to improve the research quality, the research needs to be validated and reliable for use in the further study. Validity refers to the correctness or credibility of a description, explanation, conclusion or other sort of account (Beins and McCarthy, 2012). Validity is primarily important in a research context as it deals with the integrity of the research. The validity and reliability of the results were controlled by adequate research techniques or approaches (Chapter 3, Section 3.7). The validation and reliability tests were synchronised from the research approach including aims, objectives, sampling techniques, data collection and data analysis.

In order to increase the research validity and reliability, the following are the appropriate measures related to the intended research.

1. The research aim and objectives were designed to answer the research questions;
2. The research methodology was tested to evaluate the research variables and satisfies the aims and objectives. An appropriate research technique was adopted to reduce research constraints (Chapter 3, Section 3.7); and
3. Combinations of research methods, sampling design, data collection methods and data analysis techniques were employed.

The reliability of the assessment method was enhanced through the following measures:

1. Adequate clarity in the definition of the purpose and process of questionnaire assessment;
2. Scales within the questions were uniformly set in order to reduce information processing by respondents; and
3. Continuous attention was given to the working environment to ensure the information given was adequate.

4.5.5 Target Population and Sample Size

As discussed in Chapter 3, Section 3.8.5, the same respondents (senior drivers) that participated in the driving simulation were selected as an element of population in order to answer the research questionnaire. Respondents who volunteered for the simulated driving test were encouraged complete the questionnaire. The questionnaire was answered after each simulation test was completed. Forty respondents volunteered for the driving simulation tests.

4.5.6 Sampling Design (Sampling Frame and Methods)

As discussed in Chapter 3, Section 3.8.5, the convenience sampling was selected in order to collect adequate data from the population. Convenience sampling is a nonprobability sampling design in which information or data for the research are gathered from members of the population conveniently accessible to the researcher (Sekaran, 2003). Convenience sampling is a non-random (nonprobability) sampling technique that involves using whatever participants can conveniently be studied. Convenience sampling is the best sampling design for this research because the collection of information is gathered from members of the population (senior drivers) who are conveniently available to provide it (Beins and McCarthy, 2012).

Based on the previous studies (Table 3-8, Chapter 3, Section 3.8.5.1) and recommendations from experts, 40 respondents were selected and considered an appropriate sampling size for the research.

4.5.7 Data Analysis and Interpretation: Frequency Analysis

A frequency distribution, known as a univariate frequency distribution, is the number of times various subcategories of a certain phenomenon occur; from which the percentage and the cumulative percentage of their occurrence can be easily calculated (Frankfort-Nachmias and Nachmias, 1996; Sekaran, 2003). The researcher constructed frequency distributions to examine the pattern of senior drivers' responses to each of the questions. Frequency analysis indicates the drivers' age, gender, frequency of travelling to the airport, purpose of travelling and time spent travelling to the airport. The data was categorised into group of variables and extracted using SPSS[21]. The data extracted from the questionnaires were coded and prepared for analysis. The variables were analysed and presented in frequency analysis in the next section.

As discussed in Chapter 3 (Section 3.9.1), analyses were described by a comparison of Mean and Standard Deviation (SD). In airport road access wayfinding research, the calculation of the mean (or the average) and the standard deviation were rendered possible since the data pertained to values measured on a ratio scale. As the questionnaire data is in the interval scale, thus, the mean (i.e. measure of central tendency) and the standard deviation (i.e. measure of dispersion) were appropriate (Sekaran, 2003).

[21] Statistical Package for Social Science (SPSS).

4.6 Results: The Effects of Airport Road Access Design on Wayfinding

4.6.1 Reliability and Validity Test

A reliability test is an indication of the stability and consistency with which the questionnaire results were analysed. This process avoids bias (error free) of the measured variables. IBM SPSS Statistics Version 22.0 is a comprehensive statistical system used to performed reliability test due to handling large amounts of questionnaire data which need to be entered and analysed. Reliability is necessary to ensure the number of errors occurred during variables are measured and errors that may be greater than physical variables are measured. For instance, the respondent momentary distractions[22] during the simulated driving test could affect the questionnaire completing process and cause the introduction of variable measurement errors.

Validity is an important procedure that was used to ascertain that the instrument (questionnaire) was designed to measure the research variables (Beins and McCarthy, 2012; Frankfort-Nachmias and Nachmias, 1996; Sekaran, 2003). The draft of the pilot study is important to indicate participants' responses, comments and questions' applicability, validity, relevancy and length. The research (indicates the airport road design simulation and questionnaire) has never been tested before.

4.6.2 Results 1 (a): Frequency of Travelling to the Airport in 12 Month

There were a total of 40 respondents who volunteered to participate in this research as a convenience sampling design was applied. In total, 24 male drivers (60 per cent) and 16 female drivers (40 per cent) successfully completed the driving simulation test as well as the questionnaire session. The selection of

[22] Respondents momentarily divert their eyes and attention away from the road scene during simulated driving tests (Regan, Hallett and Gordon, 2011).

senior drivers' gender was based on convenience sampling (Chapter 3, Section 3.8.5.1) and volunteered feedback during invitation timeframe (e.g. 6 months).

Figure 4-3 shows the proportion of frequency of travelling by age group. Drivers aged 55 to 59 years make up the majority airport road access users (45 per cent), followed by drivers aged over 60 years (30 per cent) and drivers aged 50 to 54 years (25 per cent). The survey shows that 10 respondents aged 55 to 59 years travelled 3 to 5 times a year to the airport, followed by 8 respondents drove less than 3 times a year. The result also shows that 9 drivers aged over 60 years travelled less than 3 times a year. 7 drivers aged 50 to 54 years travelled less than 3 times a year, followed by 2 respondents travelled 3 to 5 times a year and 1 respondent, drive more than 5 times a year to the airport.

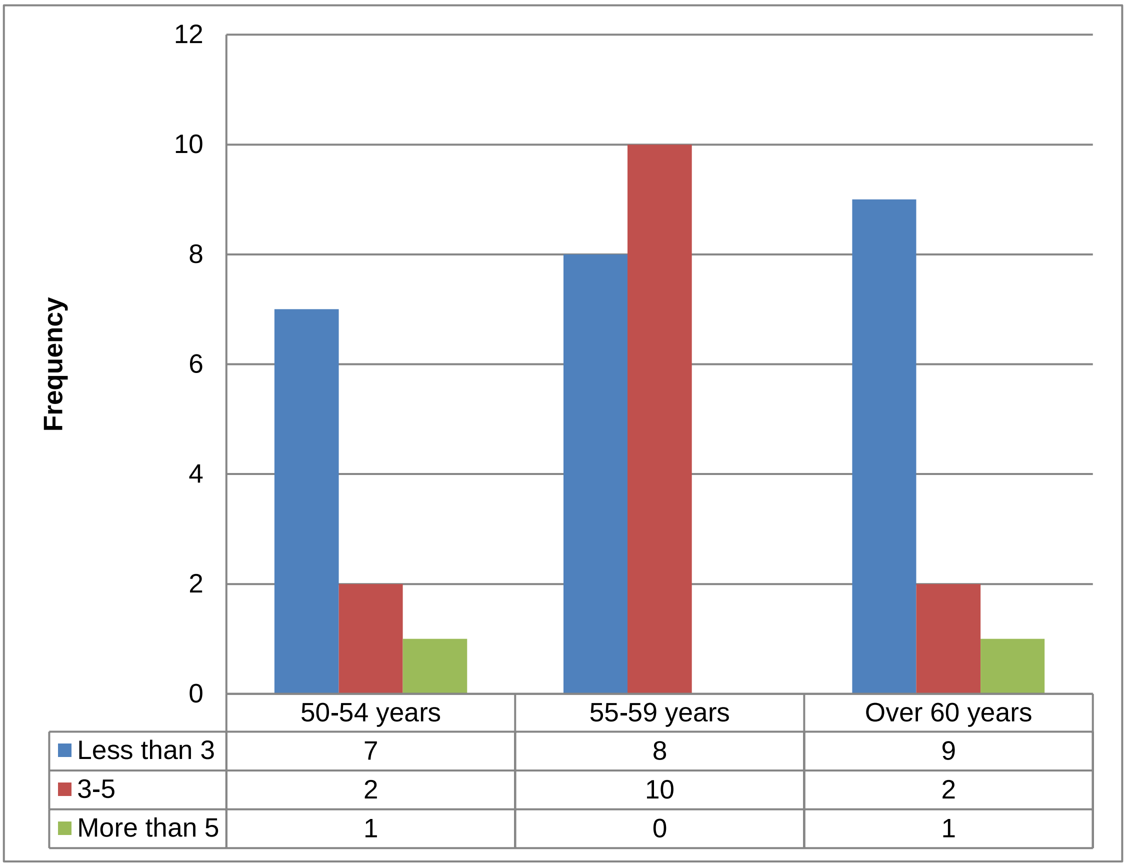


Figure 4-3 Proportion of drivers by age and frequency of travelling in 12 month

In total, 60 per cent of senior drivers travelled to the airport less than 3 times a year, followed by 35 per cent of senior drivers who travelled between 3 to 5 times, and only 5 per cent of senior drivers who travelled more than 5 times a year to the airport. Chang (2013) found that senior drivers preferred a safe and comfortable journey to the airport. Improving the quality of road access and services of access mode could attract more senior travellers to access the airport. The contributing factors, such as an increase of frequent travellers to the airport, better airport road access to ease driving option to senior drivers, an increase in the well-being of senior drivers and the growing reluctance of individuals to change their modal behaviour once they enter retirement (Alsnih and Hensher, 2003; Marottoli et al., 2000) are highly considered.

4.6.3 Results 1 (b): Travelling Purpose

Figure 4-4 shows the percentage, by travel purpose, for business, leisure and business and leisure passengers based on driving simulation test. Based on survey results, the purpose of travelling to the airport are mainly for leisure rather than business purposes. From the survey, 77.5% of respondents drove to the airport for leisure purpose, followed by 20% of respondents who drove to the airport for both business and leisure purpose, and 2.5% of respondents drove to the airport for only business purposes.

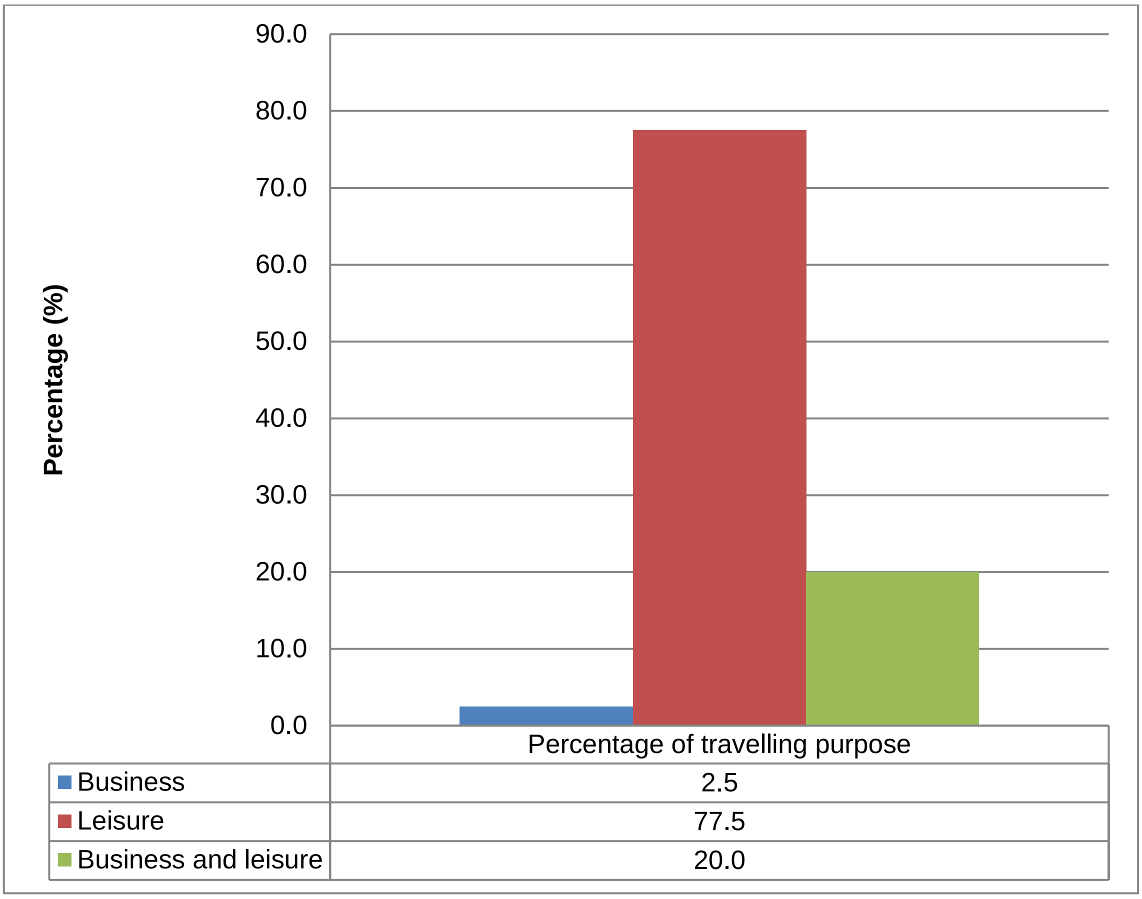
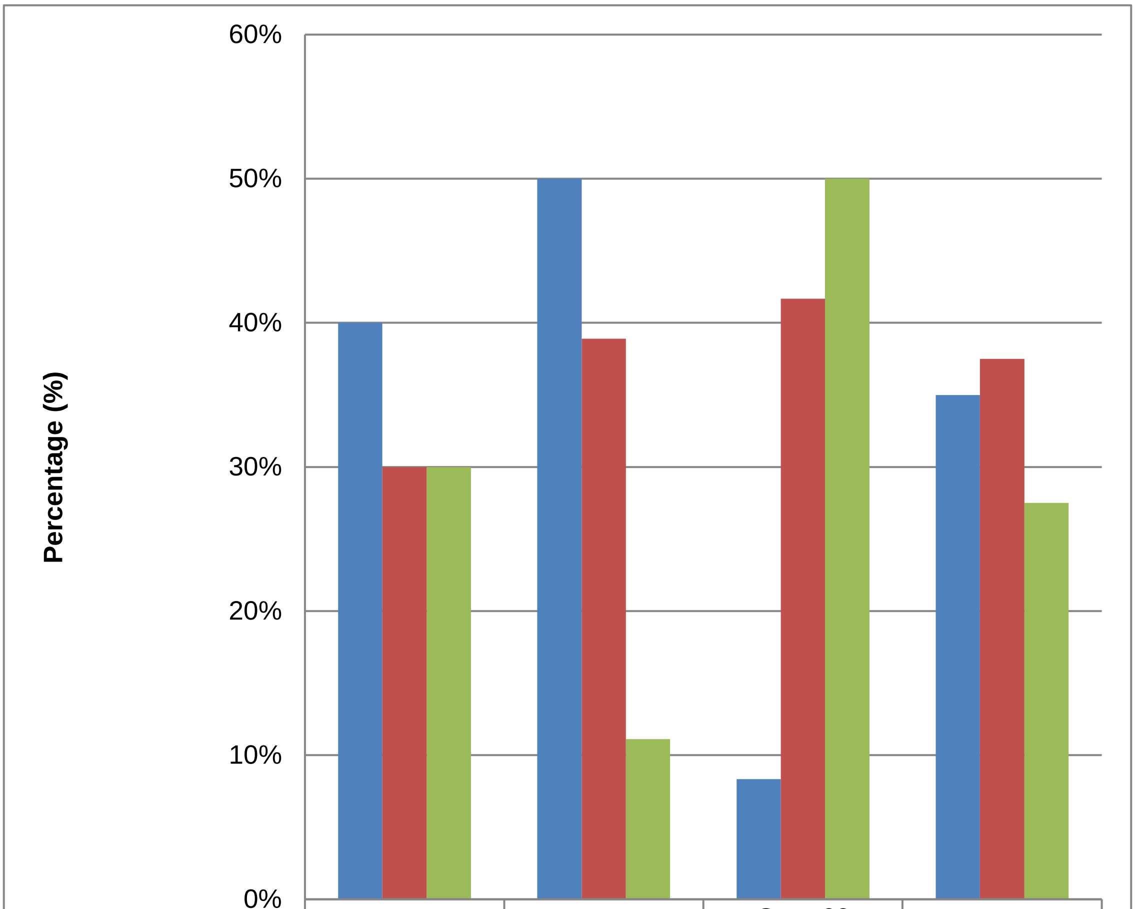


Figure 4-4 Percentage of drivers by travelling purpose in driving simulation

Based on the results, senior leisure passengers are the major users of airport road access services. They seem interested in using their own car to drive to the airport instead of other modes of transport. However, business travellers prefer to use public ground transportation services rather than drive to the airport.

4.6.4 Results 1 (c): Time Spent from Departure Point to the Airport

Figure 4-5 shows the proportion of time spent from the departure point (e.g. residential area) to the airport. The following are the results of time spent by senior drivers: 38 per cent (15 respondents) spent 41 to 60 minutes on the road before arriving at the airport, followed by 35 per cent (14 respondents); 21 to 40 minutes, and 28 per cent (11 respondents); more than 60 minutes. Based on the proportion of the drivers' age group, 50 per cent and 39 per cent of respondents aged 55 to 59 years spent 21 to 40 minutes and 41 to 60 minutes to the airport, respectively. Figure 4-5 also shows that 50 per cent and 42 per cent of respondents aged 60 years and over spent more than 60 minutes and 41 to 60 minutes to arrive at the airport, respectively.



	50-54 years	55-59 years	Over 60 years	Total
21-40 mins	40%	50%	8%	35%
41-60 mins	30%	39%	42%	38%
More than 60 mins	30%	11%	50%	28%

Figure 4-5 Proportion of drivers by time spent from departure point to the airport

Based on observation during the driving simulation study, senior drivers took an early turn at the roundabout and interchange. They are also not able to judge the exact distance in meters and occasionally took a wrong turn (Department for Transport, 2015c; Shahid, Omar and Abdullah, 2009). Senior drivers also required a longer period of time to read and process the wayfinding and traffic signs information (Leversen, Hopkins and Sigmundsson, 2013). Senior drivers read the information displayed on traffic signs, potentially glance frequently in their rear view mirror, detect the image of traffic signs information and understand the meaning and recalling of its content to relate it with the current environment (A. Pauzié and D. Letisserand, 1992; Charles and Haddad, 2008; Head and Isom, 2010). This process influenced decision making and increased the travelling time of senior drivers when driving to the airport.

4.6.5 Results 2: Impact on Wayfinding of Road Design

Research objective:

To assess the effects on drivers' wayfinding of alternative airport road access design solutions.

Research question:

1. *Does road access design have an effect on wayfinding?*
2. *How should the effects of airport road access design on wayfinding be measured?*

Figure 4-6 shows the respondent feedback based on simulated driving in Simulation 1 (Less Complex), Simulation 2 (Complex) and Simulation 3 (More Complex) scenarios. The results were analysed and linked to research question; *does road access design have an effect on wayfinding and how should the effects of airport road access design on wayfinding be measured*. In general, participants felt safe while driving in all three simulated scenarios. The results show that 9 respondents, 18.36% (Simulation 1), 8 respondents, 16.67%

(Simulation 2 and 3) felt nauseous after completed the simulated driving study, respectively. These participant's data were excluded in the final analysis. The results also show that complexity of road design not affected wayfinding process on senior driving behaviour.

Simulation 1: Less Complex Scenario. All respondents agreed that the driving simulation test was safe and convenient to complete (mean=4.43, SD=0.93). In term of road access wayfinding design, respondents found it easy and "less complex" to drive on the road (mean=4.40, SD=0.90). Figure 4-6 also shows that the respondents were able to make a fast decision at the decision point (mean=4.33, SD=0.89) on their journey to the airport. Car movement on the opposite lane were also considered in simulated driving. Adding more to that, the results show that respondents were not distracted by road traffic movement (mean=3.13, SD=1.34). The road traffic is created in the driving simulation due to measuring the driving manoeuvre and behaviour of senior drivers whilst in the traffic situation.

Although, the airport road access design indicates a simple and convenient wayfinding in a 'Less Complex' scenario, a road bend and terrain has been developed in a simulated road. It allowed the researcher to assess respondents' visibility and decision making (i.e. based on questionnaire). Respondents believed that this terrain (mean=2.50, SD=1.18) reduced their driving control and visibility towards the upcoming road. Bends on the road did not affect the driving behaviour of the senior drivers (mean=3.48, SD=1.11). Senior drivers did not pay attention to trees blocking traffic signs (mean=1.75, SD=0.90). The frequency of traffic lights (mean=1.68, SD=0.94) was acceptable in Simulation scenario 1. Surprisingly, only 9 respondents were feeling nauseous after completed the driving simulation study (mean =1.83, SD=1.34). Senior drivers were exposed to the sickness (e.g. nauseous and dizziness) due to the high resolution of simulator screen. The researcher suggested the respondents take a short break of five minutes after each of simulation test (i.e. respondents have total fifteen minutes rest in total during the simulated driving test process). Brooks et al. (Brooks et al., 2010) confirmed that senior participants of driving simulation studies have more difficulty with simulator sickness and are more likely to be unable to complete the driving simulation study. It is because of this aging factor that senior drivers experienced dizziness and nausea during or after the driving simulation exercise.

Simulation 2: Complex Scenario. All respondents felt safe (mean=4.53, SD=0.72) while driving in the simulated scenario. The ‘Complex’ road design was easy to drive along as respondents were able to make a fast decision at the junction of the road (mean=4.20, SD=0.85). The results showed that from 40 respondents, the road traffic movement (mean=2.95, SD=1.40) are distracted while they are driving to the airport. Poor visibility on the road due to the terrain, and frequency of traffic lights on the road (mean=2.38, SD=1.05 and mean=1.78, SD=0.89), respectively, did not affect their focus when driving to the airport. The colour and high resolution of the simulator screen affected 8 respondents (mean=1.75, SD=1.21) who felt nauseous after they completed the driving simulation study.

Simulation 3: More Complex Scenario. All respondents felt safe (mean=4.58, SD=0.71) whilst driving in the simulated scenario. Unlike ‘Less Complex’ and ‘Complex’ road designs, senior respondents found more difficulty in driving in the ‘More Complex’ road design (mean=3.45, SD=1.18). Respondents were able to make a fast decision at the junction of the road to the airport (mean=3.53, SD=1.06).

Senior respondents agreed that road bend (mean=2.40, SD=1.41), road traffic movement (mean=2.71, SD=1.49) and poor visibility on the road due to the terrain (mean=2.83, SD=1.32) affects drivers’ behaviour. Trees blocking some of the road signs were not noticeable (mean=1.83, SD=0.96) and the frequency of the traffic lights were acceptable in Simulation 3 (mean=1.85, SD=0.95). The colour and high resolution of simulator screen affected 8 respondents which made them feel nauseous after completing the driving simulation (mean =1.98, SD=1.17).

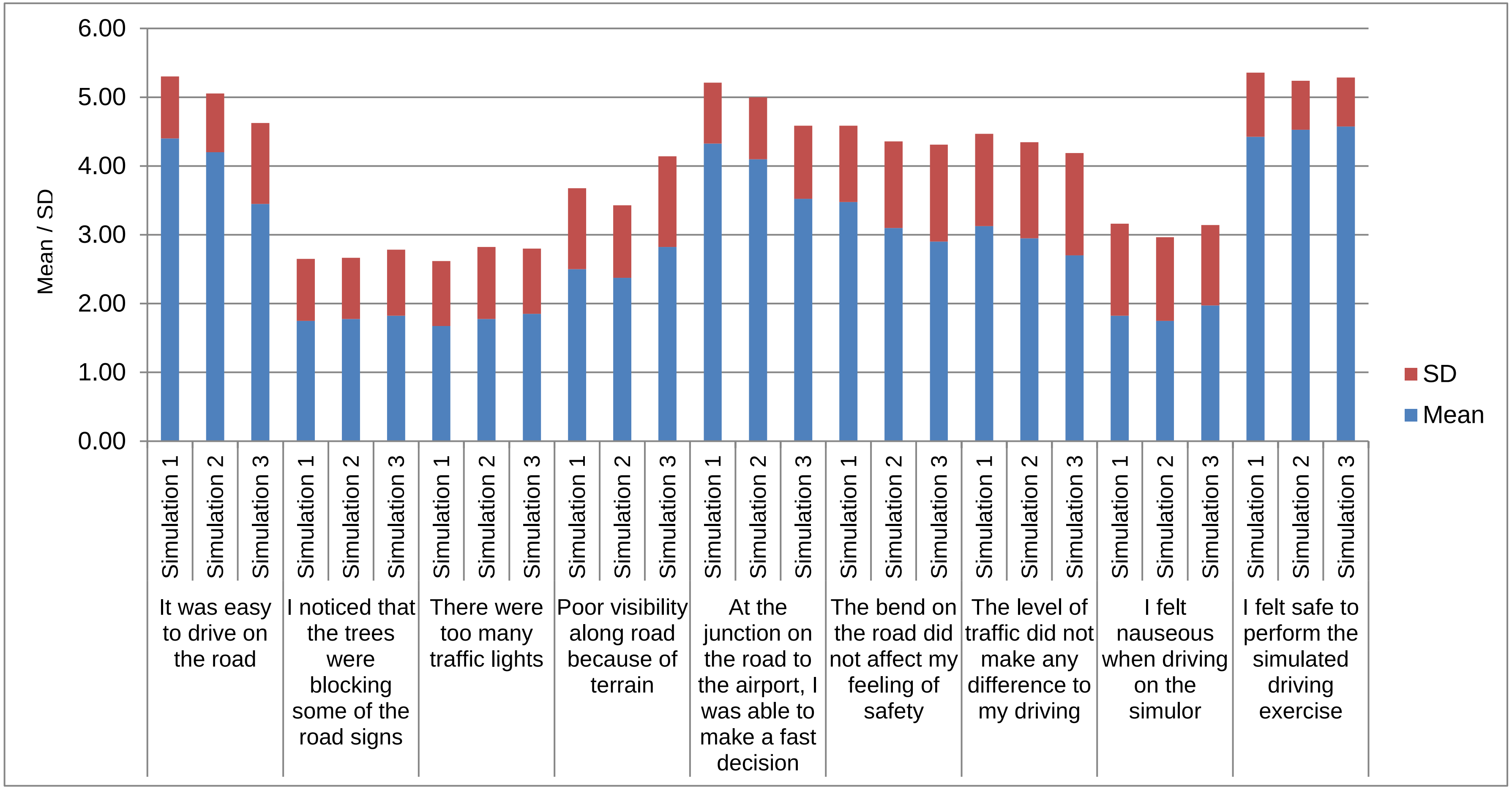


Figure 4-6 Respondent feedback in mean and SD based on ‘Less Complex’, ‘Complex’ and ‘More Complex’ Scenarios

Figure 4-7 shows the respondent feedback based on their general experiences. These feedbacks were not based on simulated driving scenarios. The results show that 95 per cent of respondents agreed that heavy airport road traffic affected their decision to drive to the airport. The complexity of the airport road access design influenced senior drivers' decision to drive to the airport. 90 per cent of respondents agreed that if it were 'more complex' to access the airport, it would be less likely that they would drive to the airport.

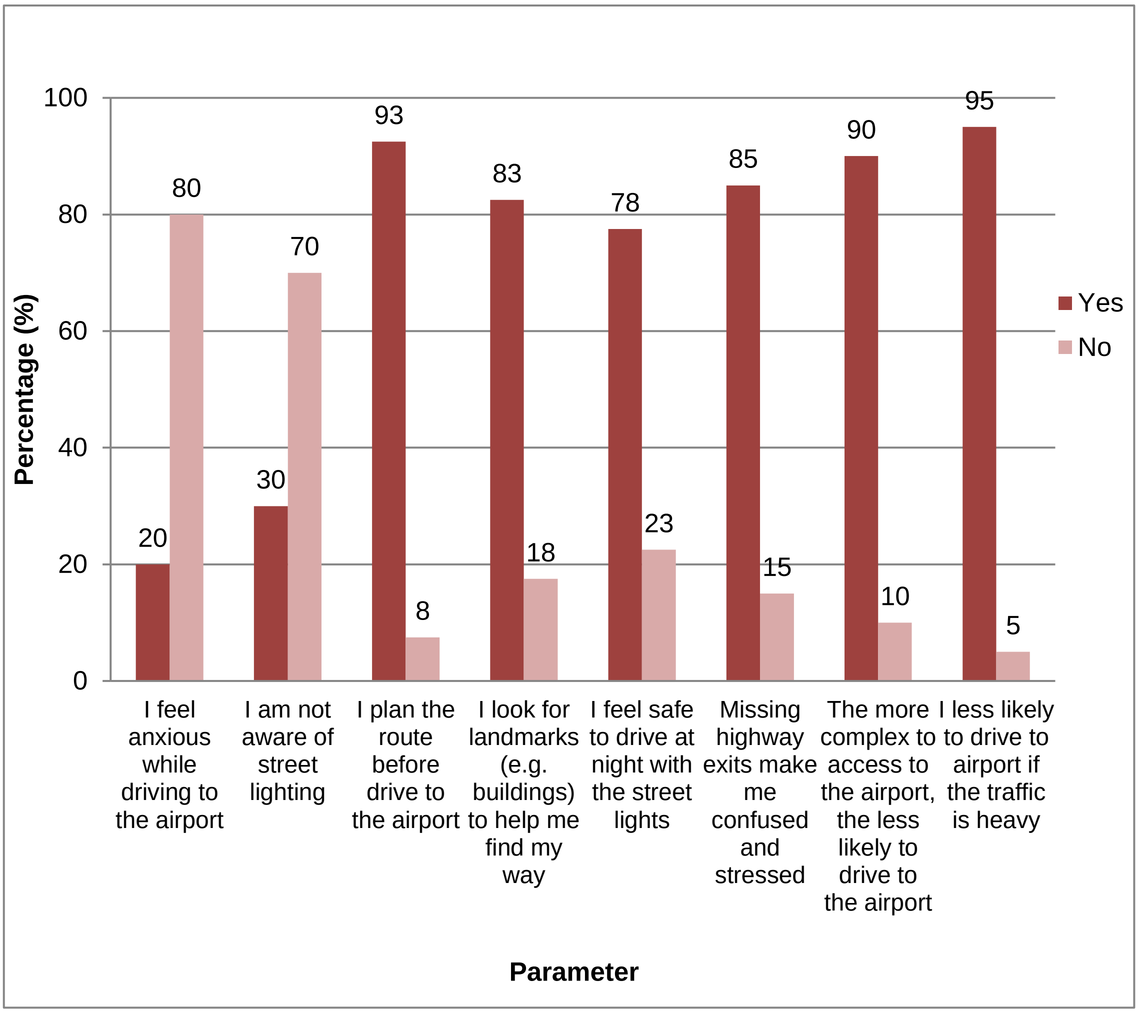


Figure 4-7 Respondents' general experience on real road

The results confirmed the previous research findings as discussed in Section 4.2; as making a journey with a proper plan improves road navigation. In addition, 93 per cent of respondents decided which routes to use before they made a journey to the airport. These results confirmed the importance of sign information; they need to be accurate, designed and placed to assists drivers to locate, easily read and understood, if there is possibility that drivers need to change their plans and behaviour (Mitchell, 2010). 85 per cent of respondents agreed that missing exits at junctions make them confused and stressed while driving to the airport.

Figure 4-7 also shows respondents were looking for landmarks to find the way (83 per cent agreed) while navigating to the airport. Respondents felt safe driving at night with the aid of street lights (78 per cent agreed). However, even though street lights play an important role in wayfinding process, 70 per cent of respondents were not aware of street lights while driving to the airport. Based on observation and informal interviews, the complexity of airport road access and limited travelling time influenced senior drivers driving performance. In addition, 80 per cent of respondents did not agree that driving to the airport would increase their anxiety. Senior drivers used travelling knowledge and skills gathered from past driving experience and expectations about roadway and traffic control when driving in simulated driving scenarios.

4.6.6 Results 3: Impact of Wayfinding (Including Signage) on Simulated Driving

Research objective:

To assess the effects on drivers' wayfinding of alternative airport road access design solutions.

Research question:

1. *How should the effects of airport road access design on wayfinding be measured?*
2. *How does the receipt of wayfinding information affect drivers' navigation?*

Figure 4-8 shows the questionnaire outcomes based on Simulation 1 (Less Complex), Simulation 2 (Complex) and Simulation 3 (More Complex) scenarios. The results were analysed in response to the research questions; *how should the effects of airport road access design on wayfinding be measured and how does the receipt of wayfinding information affect drivers' navigation?*. Respondents agreed that the traffics signs were easily noticeable on all three simulated scenarios. Respondents also revealed that the signage were able to help them to perform wayfinding to the airport. The results confirmed that wayfinding information (including signage) did not affect senior drivers' navigation.

Simulation 1: Less Complex Scenario. The results show that the signs font were clear and readable (mean=4.53, SD=0.68). The results also show that (1) the signs were easily noticeable (mean=4.28, SD=0.85), (2) the type of warning signs were adequate (mean=4.45, SD=0.71), (3) the frequency of warning signs were adequate (mean=4.20, SD=0.82) and (4) the variable speed limit signs were acknowledge (mean=4.38, SD=0.84), respectively.

Participants were also looking for the word 'airport' on the signs (mean=3.95, SD=1.06) to continue their journey to the airport. However, the senior drivers found that the road advertising signs were not distracting; (1) could not be read (mean=1.65, SD=0.80) and (2) distracted by the advert signs (mean=1.93, SD=1.05). 14 of respondents agreed that there were too many advertising signs on the roadside (mean=2.65, SD=1.25) which could have distracted their driving performance when driving to the airport. However, airport road advertising (including advert sign) is important to generate extra airport income (Chapter 2, Section 2.6). Therefore, airport planners should find the balance between the safety and commercial provision in order to develop an ideal road access wayfinding design.

Simulation 2: Complex Scenario. The traffic signs clearly assisted road navigation to the airport (mean=4.68, SD=0.66). A traffic sign is important to direct, inform and control senior drivers' behaviour in order to make the roads as safe as possible. As discussed in an earlier chapter (Chapter 2, Section 2.4) the necessity of signs is not just for new drivers that have passed their driving test, but for all road users, including experienced professional drivers.

Figure 4-8 also shows that the respondents agreed the wayfinding information affect drivers’ navigation as follows; (1) the signs were easily noticeable (mean=4.25, SD=0.87), (2) type of warning signs is adequate (mean=4.38, SD=0.90), (3) the font on signs were clear and readable (mean=4.33, SD=0.73), (4) the frequency of warning signs were adequate (4.03, SD=1.00) and (5) the variable speed limit signs were noticeable (mean=4.28, SD=0.72), respectively. 15 respondents claimed that there were too many road-side adverts (mean=2.73, SD=1.34) which could distract and affect driving performance. Majority of the respondents have no difficulties in reading the road advertising (mean=1.80, SD=0.91) and were not distracted by the road advertising whilst driving to the airport (mean=2.20, SD=1.16).

The complexity of road scenario and various speed limits led to senior drivers not being able to read the text on the signs when necessary (mean=1.78, SD=0.80). Bazire and Tijus (2009) suggested that road signs should not be ambiguous as they were designed to assist drivers in complying with traffic law whilst driving. However, the ambiguity of traffic signs led to misunderstandings or to the simple omission of the signs’ information. Similar to the ‘Less Complex’ scenario, respondents were looking for the word ‘airport’ on signs to continue their journey to the airport (mean=4.10, SD=0.93).

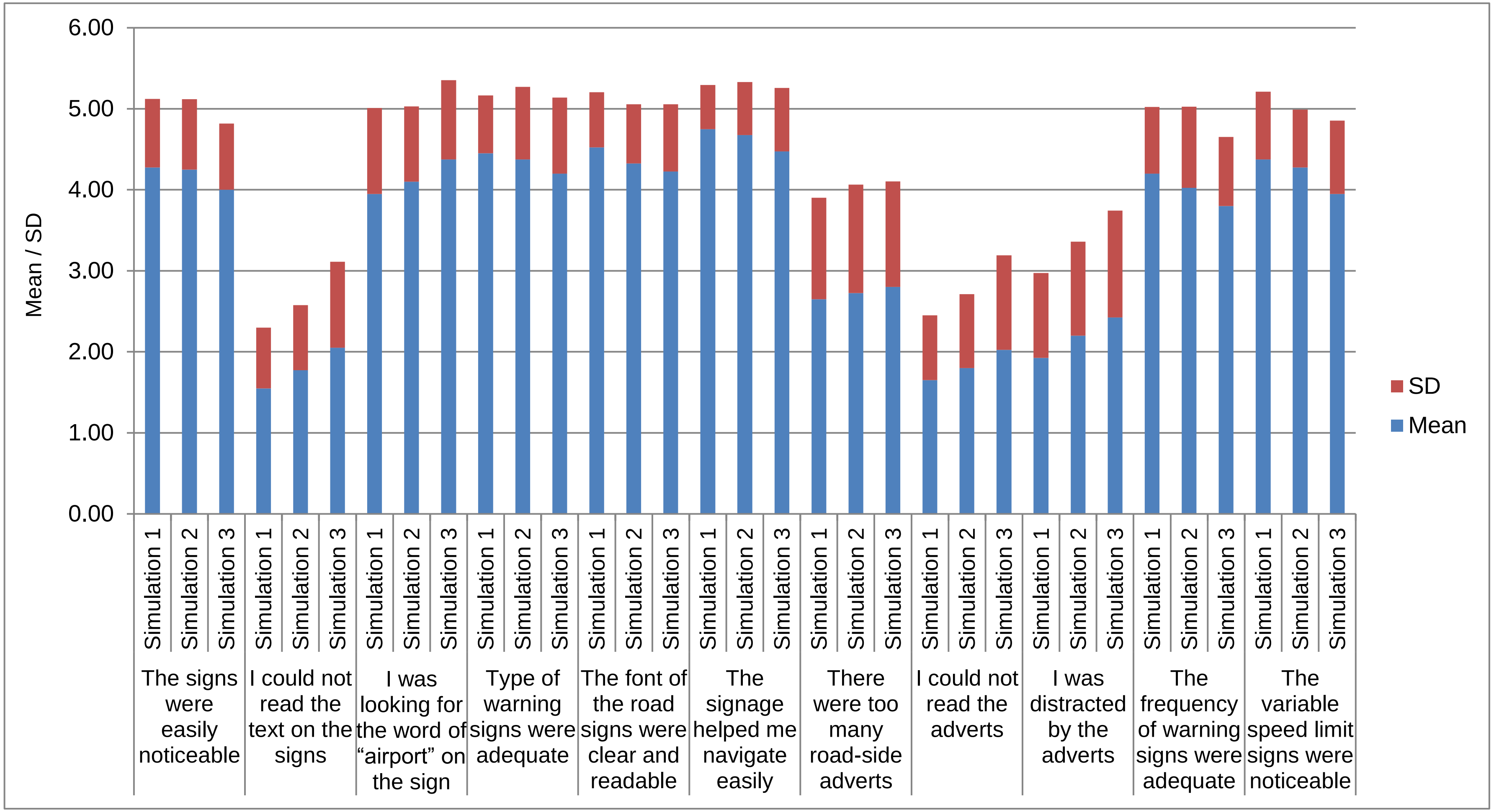


Figure 4-8 Respondent feedback in mean and SD based on ‘Less Complex’, ‘Complex’ and ‘More Complex’ Scenarios

Simulation 3: More Complex Scenario. The complexity of the airport road access design affected respondents driving performance in Simulation 3. Based on the results (Figure 4-8), (1) the respondents navigate easily (mean=4.48, SD=0.78), (2) the signs were easily noticeable (mean=4.00, SD=0.82), (3) type of warning signs is adequate (mean=4.20, SD=0.94), (4) the font on signs were clear and readable (4.23, SD=0.83), (5) the frequency of warning signs were adequate (mean=3.80, SD=0.85), (6) and the variable speed limit signs were noticeable (mean=3.95, SD=0.90), respectively. These results confirmed that respondents pay more attention on wayfinding tools to navigate to the airport.

As for road advertising signs, respondents found that (1) the road advertising (mean=2.80, SD=1.30) was adequate, (2) the adverts could not be read (mean=2.03, SD=1.17) by 5 respondents, and (3) 11 respondents became distracted while driving to the airport (mean=2.43, SD=1.32), respectively. Due to the complexity of road scenario and various speed limits, respondents were not able to read the text on the signs when necessary (mean=2.05, SD=1.06). However, respondents agreed that they looked for the word ‘airport’ on signs to continue their journey to the airport (mean=3.95, SD=0.90). Psychologically, drivers are more aware of different types of signs and what the signs look like, so that they can respond automatically (Section 4.2).

Figure 4-9 shows the respondent feedback based on general experiences with the driving simulation process. This feedback was not based on simulated driving scenarios. All respondents agreed that the traffic signs indicating directions to the airport should be displayed as far as possible from the airport. Respondents expected the road planner to develop the direction signs effectively as soon as senior drivers exit the motorway and approach the airport road. 98 per cent of respondents agreed that the directional signs (with arrow) were useful to navigate to the airport. Too many signs led to drivers becoming confused (95 per cent agreed) and missing the exit at the junction to the airport. As discussed on Chapter 2, Section 2.4, having many signs in one place can be ineffective, creates ambiguity and confusion and looks visually intrusive to senior drivers. Speed limit signs should be frequently displayed to monitor driving behaviour as 90 per cent of senior respondents agreed with this statement. Senior drivers are not able to process too much information at one time and are not able to make fast manoeuvres to change their speed when required. Senior drivers can only determine acceptable information loads that they can manage while driving. When drivers' acceptable incoming information load is exceeded, they may neglect the information based on level of importance (for example if the senior driver was looking for the word 'airport' on the sign, they may neglect the speed limit signs).

As proposed by Harding et al. in ACRP Report 52 (2011), the airport signs should have the same style as normal road signs as 75 per cent of respondents supported the study. 68 per cent of respondents agreed that the type of traffic signs did not affect the wayfinding process which confirmed that the traffic sign design on airport road access should be similar to the standard roadway signage. 78 per cent of respondents preferred larger signs as well as larger text on the signs on the road. However, 78 per cent of respondents were not agreed that the signs should be displayed as a symbol (e.g. airplane symbol). 68 per cent of respondents stated that the additional information in signage is relevant. Traffic signs' information corresponds with drivers' limitations (Chapter 3, Section 3.3) and expectations increasing the likelihood of drivers responding to situations and information correctly and quickly.

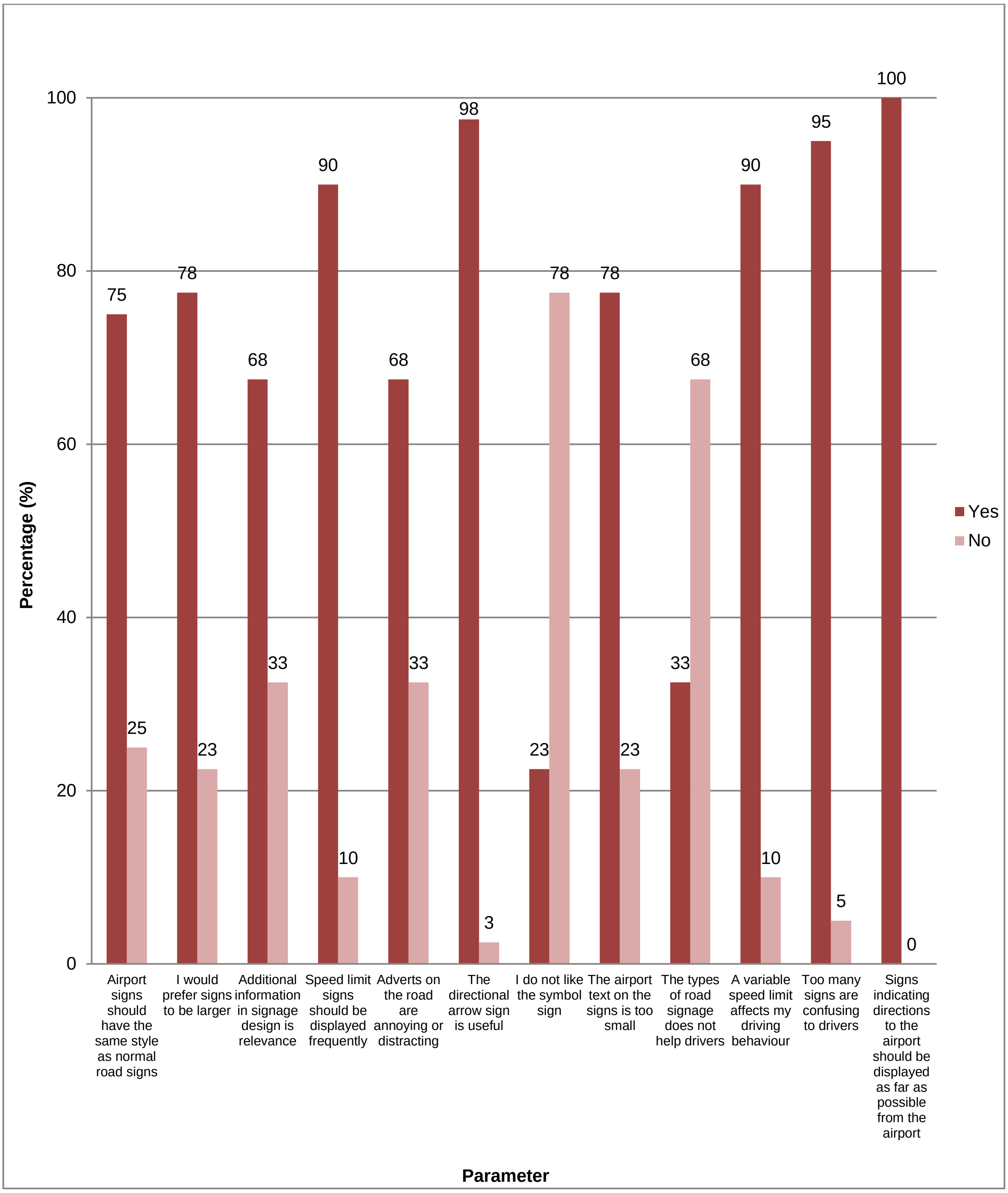


Figure 4-9 Respondents' general experience on real road

4.7 Recommendation based on the Questionnaire

The most important factor in airport road design is to improve sight distance of an upcoming road conditions. Perception-reaction time improves by appropriate time available to react to airport road access condition. Table 4-4 shows the highlights of effective wayfinding, signage and road design based on this study.

Table 4-4 Recommendation of wayfinding design based on the questionnaire data

Signage	1. Airport directional signs with bigger size, larger font and identical than roadway signs are suggested.
	2. Advance distance notification is required to navigate to airport.
	3. Clearer and less complex signage are suggested.
	4. Larger lettering on signs and pavement markings are recommended.
	5. Better street lighting, particularly at intersections.
	6. The symbol should be used on the advance warning sign.
	7. The word “airport” on the signage would be helpful to avoid confusion to senior drivers.
Road design	1. Bright, luminous lane markings and directional signals are recommended.
	2. Adding or widening the bend and turn lanes.
	3. Wider lanes (e.g. roundabout and bend) and shoulders reduce the consequences of driving mistakes.
	4. Longer acceleration lanes (e.g. junction) assist senior drivers who drive more slowly on merging.
	5. Reduce the number of senior driver fatalities and severe injuries by addressing specific roadway features known to be most difficult for senior drivers.

4.8 Chapter Conclusion

There are three major environmental factors that ease driving orientation and airport road access wayfinding design. Firstly, the traffic sign of the driving scenario should be distinctive, unique and different. The airport 'directional arrow' sign should be bigger, have bolder text, be a different colour and different symbol than the other traffic signs. The airport road access wayfinding (including traffic signs) should be identical in term of size, colour and style to motorway signs. Message content should be easily understood so the senior drivers can differentiate and it should signify the navigation to the airport. Therefore, it is very important that airport signs adhere to copy, styles and sizes, consistent terminology, symbols and uniform colours of the basic guiding principles standard functions.

Secondly, the attributes of driving simulation can be seen from various perspectives. For example, the 'less complex' scenario was developed with a 'comfort' driving environment, which allows drivers to view the routes and landmarks more easily. However, in the "More Complex" driving scenario, senior drivers required sign direction to be displayed as far as possible along the route to the airport. AASHTO (2010) and Australian International Airports (National Passenger Facilitation Committe, 2011) suggested that the element of 'primary' as a justification of signs placement is important to the driver.

Finally, as age increases, it is certain that general health and fitness will begin to deteriorate as senior drivers felt that their driving experience skills and driving abilities may not be as good as they once were. As a result, senior drivers developed more defensive and cautious driving behaviours as they grow older. The senior drivers are commonly involved in collisions often because they have misjudged the speed or distance of other vehicles or fail to see a hazard (Chevalier et al., 2016; Cuenen et al., 2016; Department for Transport, 2015c; Devlin and McGillivray, 2016; National Institute on Aging, National Institutes of Health and U.S. Department of Health and Human Service, 2011).

The study confirmed that the attention and ability of senior drivers to process signage and wayfinding information in airport road access wayfinding designs is limited. These limitations create difficulties because driving requires the division of attention between control, guidance and navigational tasks by the senior drivers. Drivers' attention can be switched frequently from one wayfinding information source to another. This means that senior drivers only attend well to one source at a time. For instance, while driving to the airport, they may only be able to extract a small proportion of the available information from the road scene (i.e. airport directional signs). Therefore, given a limited information processing capacity while driving, senior drivers can only determine acceptable information loads that they can manage. When senior drivers' acceptable incoming information load is exceeded, they may neglect other information based on the level of importance (i.e. if a senior driver was looking for the word 'airport' on the sign, they tend to neglect the speed limit signs) (Mårdh, 2016). As with decision making of any sort, error is possible during this process (Casutt et al., 2014).

In addition to information processing limitations, senior drivers' attention is not fully within their conscious control. For senior drivers with some degree of experience, driving is a highly automated task. Driving can be performed while the driver is engaged in thinking about other matters. Most senior drivers, especially a frequent traveller to the airport or one who is familiar with the airport route, have experienced the phenomenon of becoming aware that they have not been paying attention during the last few miles of driving (e.g. airport staff).

5 CONCLUSIONS

Chapter 5 revisits the research aim and objectives, with the conclusions drawn from the work undertaken throughout this research being discussed in respect of these. It will begin by returning to the thesis structure presented in Chapter 1 to address the aims and the wider research objectives. Section 5.1 focusses on the association of the research aim and objectives with the conclusion. Contribution to the knowledge relating to the research aim is discussed in Section 5.2, followed with airport road access wayfinding policy recommendation in Section 5.3. All limitations during the research process have been highlighted in Section 5.4, with recommendations for future work described in Section 5.5. It is hoped that this research will be beneficial to airport management, road sign design professionals, road authorities, senior drivers and airport users as discussed in Section 5.6. This chapter then closes the thesis with concluding remarks.

5.1 Relating the Research Aim and Objectives with the Conclusions

This research began by extensively reviewing, describing and discussing the literature review to identify the problem in hand and to justify the need to alleviate this problem. This was followed by proposed ways to address this problem. The research aim was defined to set the direction together with two objectives to guide the research flow, employing driving simulation test and quantitative methodologies. The works undertaken to achieve the aim and objectives are briefly presented, with the conclusions drawn from these works being discussed under each objective.

The aim of the research was:

"to evaluate senior drivers' behaviour of alternative airport road access designs".

The specific objectives of the research were:

1. To measure the impacts of alternative airport road systems on driving behaviour.
   Objective one included an exploration of those behavioural adaptations which have the potential to degrade safe driving and paying attention to reduce road accident. The findings from the driving simulation experiment were discussed focussing on potential strategies to remediate or mitigate senior driving behaviour.
2. To assess the effects on drivers' wayfinding of alternative airport road access design solutions.
   Objective two was mainly to assess the effects on drivers' wayfinding of alternative airport road access design. It included those which have positive, negative and neutral impacts on driving behaviour, wayfinding and navigational efficiency.

The following are the highlights of driving simulation results (Chapter 3):

1. The Two-Way ANOVA results showed that there were no significant effect of airport road access wayfinding (in terms of age group) on the research parameters of; (1) risk of collisions [Simulation 1 (F=0.928, p=0.405), Simulation 2 (F=0.727, p=0.490), and Simulation 3 (F=0.158, p=0.855)] (2) exceeding the speed limit [Simulation 1 (F=0.216, p=0.807), Simulation 2 (F=0.523, p=0.597), and Simulation 3 (F=1.725, p=0.192)], (3) traffic light tickets [Simulation 1 (F=0.849, p=0.436), Simulation 2 (F=1.177, p=0.319), and Simulation 3 (F=0.720, p=0.493)], (4) centreline crossings [Simulation 1 (F=0.742, p=0.483), Simulation 2 (0.416, p=0.865), and Simulation 3 (F=0.826, p=0.446)] and (5) road edge excursions [Simulation 1 (F=0.564, p=0.574), Simulation 2 (F=1.262, p=0.295), and Simulation 3 (F=1.228, p=0.305)] (Chapter 3, Table 3-25).

2. The research outcomes indicate the significant implication on the complexity of airport road access design for senior drivers (Chapter 3, Section 3.11, 3.12 and 3.13). The complexity of road design clearly raises the risk of accidents for elderly drivers. For example, the results confirmed that the senior drivers required great awareness of the speed limit (i.e. bigger font than conventional signs) as they drove faster in lower speed limit areas (Chapter 3, Section 3.12.2).
3. The study also confirmed that there is no significant impact between navigation systems of airport road access and the age group of senior drivers. The results show that the age group has no impact on the research parameters of; (1) lane position, (2) steering wheel rate, (3) acceleration and (4) speed.
4. The study suggested that driving simulation is useful to test drivers' wayfinding process in virtual environments and validated selected research variables (i.e. wayfinding obstacles and contributing factors to wayfinding difficulties).

The following are the highlights of questionnaire measure (Chapter 4):

1. The results show that 9 respondents (Simulation 1) and 8 respondents (Simulation 2 and 3) felt nauseous after completed the simulated driving test, respectively. The results also show that complexity of road design affected senior driving behaviour.
2. Respondents agreed that the traffics signs were easily noticeable on all three simulated scenarios. Respondents also revealed that the signage was able to help them to perform wayfinding to the airport. The results confirmed that wayfinding information (including signage) did affect senior drivers' navigation.

Previous research shows that driving abilities decline as people get older. By reducing risk factors and incorporating safe driving practices, senior drivers are able to continue driving safely. However, they have to pay attention to wayfinding tools (e.g. including traffic signs) to make an appropriate adjustment. Age could be interfering with their driving ability even for a quick choice at the decision point. Senior drivers need consistent, concise, accurate and timely information to navigate to the airport. They are able to deal with only limited amounts of information at any one time. Prioritisation of information is critical to avoid cognitive overloading, which results in confusion, stress and frustration.

Good wayfinding strategy offers a number of benefits, including:

1. Navigating. Senior drivers use wayfinding as a strategy to solve problems during the journey to and from the airport. Effective wayfinding design reduces traveling time, improves safe driving behaviour and increases drivers' satisfaction while navigating to the airport.
2. Reduce clutter and unnecessary information in the airport road landside environment. ACRP Report 52 (Harding et al., 2011) suggested a simple and consistent signing throughout an airport roadway network is essential to good airport wayfinding.
3. Senior drivers bring with them experience and expectations about roadways and traffic control when entering an airport landside system. This experience is gained by driving on conventional roads and motorways. ACRP Report 52 (Harding et al., 2011) suggested that the more an airport road can be made to look and function like a regular road, the more it will conform to driver expectations which will lead to a safer and less stressful driving experience.
4. Drivers (or passengers) are able to get to their flights on time. The travelling purpose to the airport will usually affect senior drivers' decision to drive to the airport. Several factors such as frequency of trips, duration of trips and sensitivity to time affected senior drivers' decisions. For instance, senior drivers who are travelling for business purposes may

have more information available on access options at specific airports because they make more trips to the airport than senior drivers who are travelling for leisure purposes and only occasionally drive.

5. Allow drivers to reach their destination easily and quickly, to give them time to explore their environment (e.g. shopping, eating and relaxing). This in turn, may increase airports and retailers' revenue.
6. Accident reduction. The contributory factors that lead to road accidents during navigation to the airport have been discussed in Chapter 3, Section 3.11 (Table 3-12) and Section 3.14. Traffic accidents on airport roads are influenced by human, vehicle and environment (Mamais, 2009). Good wayfinding (including signage systems) are able to reduce the risk of crashes at airport road access. Montello and Sas (2006) agreed that the wayfinding occurs when people need to move from one place to another without having accidents or getting delayed.
7. Environmental impact. The establishment of wayfinding design has direct and indirect impact on airport road development. While the benefits in terms of safe driving behaviour is well known, the environmental impact is underestimated. The focus of airport road access design is to minimise ecological disturbance, reviewing the resources required to build and maintain road access wayfinding system in future. The emission from the transportation, construction works and maintenance associated with the road access wayfinding design, makes it one of the greatest contributors to climate change.

Wayfinding at the airport entrance or points where drivers enter the airport area should be signified in a special and recognisable way that is consistent and conveys a sense of welcome. For instance, a lower speed limit is required in the airport area. By placing speed limit signs at the entrance to the airport terminal where they may be transitioning from a typical roadway requires road design changes to support the requested reduction in speed.

Recommendations to enhance wayfinding with good signage at entrance points are as follows:

1. Clarity of airport area entrance from a distance is importance;
2. Clarity of signage from a distance is needed;
3. Effective use of font, colour and light;
4. Visibility of next signage from entrance;
5. Use of architectural features to highlight entry, such as airport welcoming signage;
6. Sense of familiarity may be achieved through a consistent approach to the design of all signage; and
7. Signage should have generic elements and consistency of information.

The processing point is the area from the airport entrance to the terminal. Within the airport environment, consistent signage and appropriate road furniture should aid drivers in the processing point. Recommendations to enhance processing points are as follows:

1. Signage information and road furniture can be used to define the wayfinding and navigation;
2. Airports should make the road access wayfinding process a comfortable and pleasant experience to the senior drivers. This may be achieved with variable message signs, or by providing sign information that will draw drivers' attention. Road furniture (e.g. traffic signs, landscaping and colour of signs) will also improve their experience; and
3. The processing point is itself a significant landmark.

The leaving point is the point where driver leaves an airport terminal or exits the processing point. The leaving point should be signified in a reassuring way that is consistent and conveys a sense of completion. Recommendations to enhance leaving points are as follows:

1. Signage information and road furniture can be used to define the airport road access wayfinding and navigation;
2. The wayfinding experience is different between leaving and arriving at the airport;
3. Drivers are aware of the options ahead through use of signs;
4. Make the leaving process as effortless as possible to ensure no obstacles are in the way and that the driver is confident of their onward travel once exiting; and
5. Leaving routes should be clearly distinctive to help drivers easily find the way out.

Chapters 3 and 4 discussed driving behaviour which have significant impact on the airport road access wayfinding design. Results show that age does not affect drivers' performance; however, driving attitude impact on road navigation. The results do not indicate that there was a certain age group in which senior drivers become unable to drive safely. Thus, setting an arbitrary age limit beyond which there is considered a risk of unsafe driving would inevitably be unfair to some drivers.

Statistics showed that the senior drivers are more likely to be involved in accidents due to the influence of age (Chapter 3, Sections 3.11, 3.12 and 3.13). In fact, fatal crash rates rise sharply after a driver has reached the age of 70 (Chapter 1, Section 1.3). Research found that factors such as decreased vision, impaired hearing, or slowed motor reflexes may become a problem. They may have a chronic condition that gradually worsens with time. Aging tends to result in a reduction of strength, coordination, and flexibility, which can have a major impact on senior drivers' ability to control a car safely.

Senior drivers have a slower reaction to spot vehicles emerging from side streets and driveways, or to realize that the vehicle ahead of them has slowed or stopped. Keeping track of so many road signs, signals, and markings, as well as all the other traffic also becomes more difficult as they ineffectively divide attention between multiple activities such as focusing on the road as well as processing signage information.

In addition, the results in the above-mentioned sections of Chapter 3 strongly showed that drivers' age was not related to loss of driving ability. Senior drivers may consider continuing driving safely by taking care in the way they drive and understanding or rectifying physical issues that may interfere with their driving. Senior drivers who do have health issues (Cuenen et al., 2016; Leversen, Hopkins and Sigmundsson, 2013; National Institute on Aging, National Institutes of Health and U.S. Department of Health and Human Service, 2011) that might interfere with their driving ability should have a regular check-up or ask for medical advice and keep in the best possible driving shape. For instance, in talking with a doctor about the effects that medications may have on driving ability, such as glaucoma, they may find tinted eyeglass lenses useful to reduce glare. Drivers may also keep the car's mirrors, windshield, and headlights clean and turn the brightness up on the instrument panel on the dashboard.

Research using simulation shows that senior drivers are easily distracted by the moving car closest to them (Harding et al., 2011). In these days, for instance, GPS devices or music players are one of the contributory tools to distract drivers. AASHTO (2010) suggested that instead of concentrating on traffic signs and the road, senior drivers could take extra caution such as leaving adequate space to the car in front, paying extra attention at intersections and making sure to use appropriate speed with the flow of traffic. They should avoid trying to puzzle out a map while the car is moving; by pull over instead. Sufficient braking distances in unfamiliar environments or during the very first time to the airport are suggested. If drivers double up their speed (e.g. from 30mph to 60mph), the braking distance does not become twice as long but four times as far, particularly if the road is wet or icy.

The lack of an assessment of wayfinding navigation system within an airport area which takes into account drivers' perception and linking them with safe driving behaviour has been revealed. The research provides worthwhile concepts for the design of efficient wayfinding provision. Three simulated scenarios of airport road design were compared to one another to investigate the senior driving behaviour. Each scenario has some significant based on its complexity (i.e. 'Less Complex' scenario, 'Complex' scenario, and 'More Complex' scenario) such as being a better wayfinding system, safer driving environment and travel time saving.

Harding et.al (2011) in ACRP Report 52 suggests the factors to evaluate the best possible route of the airport road access as follows:

1. *Safety*. It is a priority to keep road safe with good road design for drivers. However, there may be other routes that are equally as safe but can offer a simpler or shorter path without sacrificing safety;
2. *Length*. The shortest route may expose drivers to conflict with other road users and therefore could create a major safety hazard. The shortest route does not mean it is the safest, especially in environments shared by moving vehicles and pedestrians; and
3. *Simplicity*. In complex wayfinding environments like an airport, it is important to keep the wayfinding as simple as possible. For instance, if time is the most critical factor for a passenger making a connecting flight and they are faced with a choice to walk or drive, the simplest route may not be the quickest and a passenger risks missing their flight.

By incorporating these three factors as part of the process for developing the wayfinding logic, the best overall route for any given airport can be identified.

5.2 Relating the Research Aim to the Contribution to Knowledge

The aim of the research is "to evaluate senior drivers' behaviour of alternative airport road access designs". This section details the contributions to knowledge that have been made in achieving this aim.

5.2.1 The Use of Simulated Driving to Examine Senior Driver Behaviour and Wayfinding Provision

The findings highlight the important concept of airport road access wayfinding and senior driving behaviour (Chapter 3 and 4). The concept suggests airport road access wayfinding principles which derive from the study of senior drivers using a simulated driving environment and the literature search of wayfinding or navigation in the actual environment.

The use of driving simulations to investigate driver perception and driving behaviour is expanding rapidly as such simulations save engineering time and costs (Kemeny and Panerai, 2003). Driving simulators have become an essential means to improve knowledge in the field of driving behaviour. It allows investigation concerning in particular drivers' behaviour, vehicles and road infrastructures conception (Espié, Gauriat and Duraz, 2005).

The simulator has several advantages over comparable vehicle testing: safe driving behaviour, ease of data acquisition, the convenience to change vehicle models and simulated surroundings in software rather than testing hardware (Gruening et al., 1998).

Driving simulation scenarios were developed based on senior drivers' behaviour, risk of accidents and contributory factors such as intersections, interchanges, tailgating, speeding and poor turn or manoeuvre. Driving simulation scenarios does not replicate any current airports road access such as Luton Airport as its geography layout and road design might be identical to other airports. ACRP Report 52 highlighted that each airport environment is different and the wayfinding logic used at one airport may not necessarily work at another airport (Harding et al., 2011). Blana (1996) agreed that driving simulators will never replicate real world environment in all its complexity into virtual driving scenarios. There will always be the issue of validity, for instance, to what extent behaviour in a simulator corresponds to that in the real life. Thus, driving simulation in this research, hopefully, could be used to any airport road access design.

5.2.2 Extending the Wayfinding Research to the Airport Road Access Network and Senior Driver

According to Phillips and Pugh (2007), the originality of the research is dependent on a research principle that applies something in a region that has previously only been done in another country or region, by taking a particular technique and applying it in a new field. This research has performed an original study on the evaluation of airport road access wayfinding design, taking into account driving behaviour. The study has never been conducted in the region; the established methodology, analysis and results will add useful information to the knowledge base.

As discussed in Section 1.1 (Chapter 1), senior drivers are a large and increasing proportion of the population (National Institute on Aging, National Institutes of Health and U.S. Department of Health and Human Service, 2011; RoSPA, 2010). Senior drivers also are likely to drive to the airport due to carrying extra luggage and preferring more time spent in the vehicle (Ashford, Mumayiz and Wright, 2011; Chang, 2013). With a current ageing population throughout much of the developed world, there is an imminent need to understand the current transportation requirements (Alsnih and Hensher, 2003; O’Hern and Oxley, 2015) of senior drivers, and to ensure sustained safe mobility and comfort on airport road access (Chang, 2013; Chebli and Mahmassani, 2002; O’Hern and Oxley, 2015). The results confirmed that wayfinding design has importance for the promotion of good behaviour of senior drivers.

5.2.3 The Use of a Combined Simulated Driving and Questionnaire

The combination of simulated driving (Chapter 3, Section 3.7) and questionnaire method (Chapter 4, Section 4.5) to investigate effects of airport road access wayfinding on senior drivers' driving behaviour has not been extensively explored and tested before in the field.

A complete simulated driving scenario was tested and subsequently followed by questionnaire distribution. Simulation data was interpreted and analysed after the driving scenario simulations ended. The questionnaire responses were gathered and interpreted. The questionnaires were designed to be effective, approachable and easy to understand. Feedback and comments were acquired from senior drivers who volunteered to take part in the simulated driving.

5.2.4 The Importance of Wayfinding Guidelines

As discussed in Section 4.3 (Chapter 4), the set of wayfinding design principles is concerned with making information spaces to the airport effectively navigable by senior drivers.

A key finding of this research was the ability to successfully perform wayfinding tasks by senior drivers. Successful wayfinding occurs when the senior drivers could make correct navigation decisions especially at decision points to the airport. For instance, the use of the landmarks as a memorable location that help senior driver navigate to the airport. Since the senior driver uses these features to record their past route-following experiences, a designed space that employs them should be more effectively navigable.

5.3 Validity of Conclusion in Relation to Statistical Output

The validity of research conclusion indicates the significant implication of complexity of airport road access design for senior drivers. Although, the age group of senior drivers had no significant linked with driving performance in all simulated driving scenarios, the Two-Way ANOVA test shows that the results of the research parameters tested as Tables 3-25 and 3-26 (revisited from Section 3.12, 3.13 and 3.15). The research confirms no correlation of simulated driving performance, which were limited to the over 60 years old as the age group did not include the health and medication use domain. The research suggests that further research to 75 years and over age group which indicates the health and medication use domain is highly considered.

5.4 Relating Conclusion to the Literature Review

There are three major environmental factors that ease driving orientation and airport road access wayfinding design; (1) the traffic sign of the driving scenario should be distinctive, unique and different, (2) the attributes of driving environment can be seen from various perspectives, and (3) as age increases, it is certain that general health and fitness will begin to deteriorate as senior drivers felt that their driving experience skills and driving abilities may not be as good as they once were. As a result, senior drivers developed more defensive and cautious driving behaviours as they grow older (Chevalier et al., 2016; Cuenen et al., 2016; Department for Transport, 2015c; Devlin and McGillivray, 2016; National Institute on Aging, National Institutes of Health and U.S. Department of Health and Human Service, 2011).

Complexity of road design or increased traffic congestion contributes to a distracted driver’s ability (Taylor and Dorn, 2006). Inattention results in diverse movements out of the lane, exceeding the speed limit (Chevalier et al., 2016) and failure to detect a vehicle on a conflicting path at an intersection (Dukic and Broberg, 2012; Mårdh, 2016; Oxley et al., 2006) that exposes drivers to the risk of collisions.

A complete airport road access wayfinding allows senior drivers and airport users to find their direction to the airport intuitively. Senior drivers instinctively search the road and cues as to where to go next on their journey. If a journey unfolds in an understandable way, senior drivers are able to read the environment and make a quick decision to continue their journey. In order to develop airport road access wayfinding which is accessible to senior drivers, several functions of road transport should be considered as follows; (1) *linkage,* (2) *transportation,* (3) a*ccess*, (4) *Public right-of-way,* and (5) *Sense of place* (Chapter 2). The traffic signs (element of wayfinding) for car drivers (including senior drivers) should be considered differently than to the terminal interiors design (Harding et al., 2011). The traffic signs' users are in moving vehicles at much higher speeds. The focus should primarily be directed at road lanes and safe driving manoeuvres, including interaction with other objects such as pedestrian crossings and warning signs. Therefore, senior drivers will be safer and find it easier to navigate by using their previous experience of the airport roadway signs. Harding et al. (2011) also highlighted that by making airport roadway wayfinding (i.e. traffic signs) look, feel and operate like other roadway signs, the needs of the drivers (including senior drivers) are better served.

5.5 Relating Airport Road Access Wayfinding Recommendation for the Improvement of Safe Driving Behaviour

The research contributes to the area which introduces a better understanding and improvement of airport road access wayfinding systems. In addition, the research findings empirically propose a drivers' wayfinding definition which should enhance the academic discourse in airport road access wayfinding and driving behaviour.

Information, education and publicity are needed to increase awareness of the effects of ageing, and of the possible effects of health on driving performance. Transport planners should be catering for senior road users who may be considering driving to the airport. This is because senior drivers will not consider driving to the airport if there are suitable, safe, clean, attractive, convenient and affordable alternatives. This research helps to develop a better understanding of the link between airport wayfinding and safe driving to the airport. Based on research findings, an airport road access wayfinding model taking into consideration senior driving behaviour has been developed as shown in Figure 5-1.

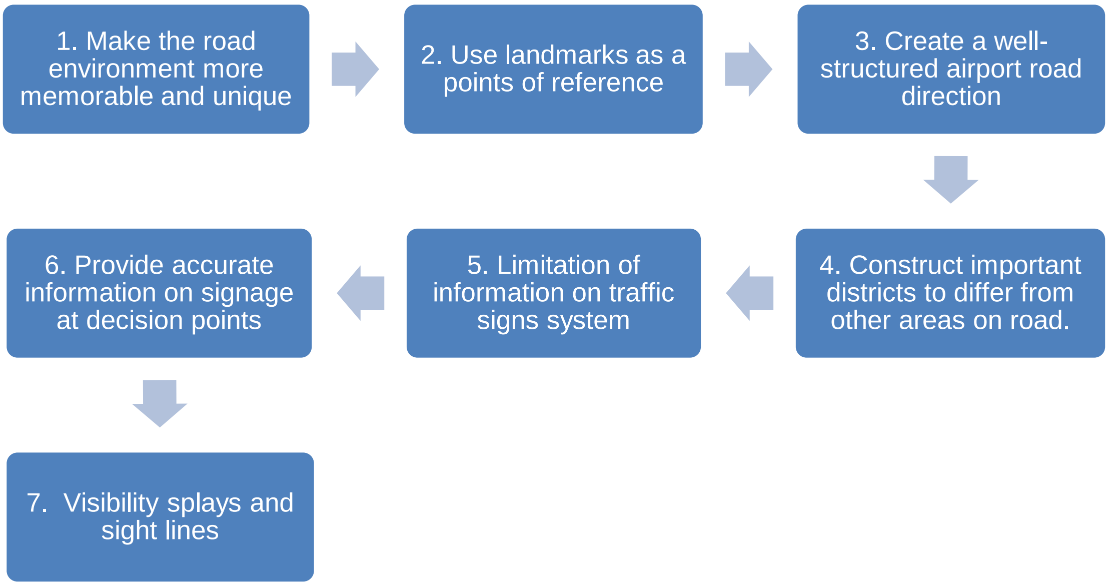


Figure 5-1 Proposal of an airport road access wayfinding model

1. Make the road environment more memorable and unique

The driving environment to and from the airport area should have its own uniqueness for the senior drivers. Airport authorities should offer every location in the airport road access space a unique perceptual identity to stimulate safe driving behaviour and quick decision making at decision points. It is the first rule in wayfinding; the ability to use conceptual and spatial knowledge to recover position or orientation. It means that senior drivers should be able to access their travelling knowledge gathered from past driving experience to recover their location when they are off track from their desired route. In some cases, senior driver may use wayfinding cues to accomplish wayfinding tasks to the airport. The wayfinding process indicates that every environment should function, to some extent, as a landmark to recognise a point of reference in a large environment or space. Identity of the location was reported in the literature search (Anderson, 2015; Lynch, 1960; Montello and Sas, 2006; Woollett and Maguire, 2010), as the uniqueness of location makes the area or space vary from other road environments. It allows the environment to be grouped by their common characteristics such as speed limit and road complexity. This idea may help the senior drivers to make a quick decision when wayfinding.

2. **Use landmarks as a point of reference**

   Landmarks are systems to organise and define an information space. Based on previous literature, landmarks can be used not only as a memorable point which helps senior drivers to perform wayfinding to the airport, but they are also useful as head paths emanating from junctions and indicating what is down the road. It means that landmarks could be used to assist airport road access wayfinding and helps to define and organise information in the road environment (Baskaya, Wilson and Özcan, 2004). Senior drivers could use architectural items (e.g. buildings and road furniture) around them in the environment or space as a landmark for their next visit in the future. For instance, they are able to recognise their current location and which way they are facing in the environment that they identify with the landmark (Lynch, 1960). It is important to state that a desired landmark should be visible and can be seen clearly from a large airport's surrounding area. Landmarks assist senior drivers to make a quick decision within a wide airport area. In addition, a landmark is useful as a memorable reference point which acknowledges the basic tool of location or route to aid senior drivers in the wide environment to accomplish their driving plan to the airport.

3. **Create a well-structured airport road direction**

   Airport road access should possess a set of well-structured features. It is proposed that airport road access wayfinding is continuous and have a clear beginning, middle and end when viewed in each direction. This would help senior drivers make assumptions on the progress and distance of their journey to the airport. It will help them to easily follow the traffic signs and drive along the road by its directionality. This step helps senior drivers associate with the relevant content in the space. It will inform how the connection to a pre-considered route will appear to the drivers.

The beginning and end of the road will form an ‘introduction’ and ‘conclusion’ as the wayfinding progress is marked by moving from a single piece of information (e.g. traffic signs) to the next. A continuous route should have both shared features that are defined as distinct from its context and connect one part to a subsequent part. For instance, the entrances and exits along the highway are clearly marked by signs, and mile markers indicate progress and relative distance to destinations (Harding et al., 2011). In this case, the path is structured not so much by diversity of appearance or meaning, but by a system of signs arranged along its length.

4. **Construct important districts to differ from other areas on road**

A partition of the environment can be created through a distinctive set of road attributes that can be seen in a large space to aid airport road access wayfinding. For instance, airport authorities encourage using different colours on traffic signs (AASHTO, 2010; Harding et al., 2011; Transport Scotland, 2006). The colour on the signs contrast with their background, which means they are easily detected from the sign’s surroundings. The district of the road environment could aid airport road access wayfinding by providing a set of clues to recovering location. They connect a set of defining features within the airport environment scenario or area and give a way of recognising a location along the road. It occurs during a movement from one point of an area to another by informing senior drivers of their current location along the boundary of the two areas along the road. In addition, districts allow distinguishing the road environment from each other. Districts correspond to some features shared by the content within, such as supporting the same information and relating the same experience. Airport road access could use this concept by making a variation in the colour of traffic signs from one area to another.

5. Limitation of information on traffic signs system

Specific and important information on traffic signs assist senior drivers to perform airport road access wayfinding. As discussed in Chapter 3

(Section 3.8), senior drivers were provided with different information on every simulation study (Simulation 1, Simulation 2 and Simulation 3). It was shown that senior drivers were confused when more information was given in Simulation 3. The complexity of airport road access wayfinding requires senior drivers to drive carefully and more time was needed to make a quick decision using a given airport road access wayfinding simulation. Repeated traffic signs were suggested on every alternative route in a same design so as to test senior drivers' conceptual knowledge and past experience after a decision has been made on certain road points.

In this wayfinding process, senior drivers are able to find a correct way even if they missed the exit to the terminal or airport area. This concept could be applied throughout the airport entrance to the terminal to ensure drivers encountered the main points no matter which alternative route they chose. In other words, this concept is used when there are few alternative routes of the airport road access but with the same goal of arriving at the airport. The information on every route communicates the same message to the drivers.

6. **Provide accurate information on signage at decision points**

A traffic sign at the decision point such as a roundabout is necessary. Decision points are where a driver must make a decision regarding which path they should take on their onward journey, either to continue driving on the current road or to change to an alternative route (Raubal and Egenhofer, 1998). The purpose of traffic signs at the airport road access is to give direction to senior drivers and help them reach their wayfinding, which is to arrive at the airport successfully. As discussed in Chapter 4, the senior drivers start their journey to the airport with high hopes and acquiring information from the environment or from their experiences.

7. **Visibility splays and sight lines**

   It is an important feature of an access or junction to provide a wide and extensive view in a particular direction for the senior drivers. First time drivers to the airport area may have uncertain expectations as to its extent and purpose, and therefore visibility splays and sight lines are valuable means of giving enough information about the road environment ahead (Baskaya, Wilson and Özcan, 2004). It would help senior drivers to move farther by providing selective views into a larger space. Visibility splays and sight lines are alternatives to traffic signs by showing the actual environment and thereby making a decision point. As an essential feature of an access and junction, sight lines assist senior drivers to see other vehicles on the main road. An unobstructed visibility splay or sight line allows a motorist to see and be seen. With appropriate visibility splays or sight lines, the road users have time to see and react to any potential incident.

5.6 Limitations for the Research

The research applied a well-established method and utilised a verified arrangement for encoding the driving simulation. It involved collecting primary and secondary data as well as carrying out the required analysis as the availability of research material was limited. The airport road access wayfinding design simulation is new to the aviation industry. Difficulties were encountered in obtaining participants to run the airport road access wayfinding simulation. The barriers in coding of simulation reduce the quality of the data, therefore, assistance from academic and professional experts was highly appreciated.

Driving simulators have a few disadvantages. For instance, simulator sickness (a type of motion sickness) was experienced by senior drivers whilst “driving” in the simulator room; it included dizziness, headache, nausea and vomiting (Mourant and Thattacherry, 2000). Apparently, senior drivers would be compromised when experiencing these symptoms as not appropriate for all senior drivers involved in a simulated driving test. Another limitation when developing simulated driving scenario is its ability to mimic the real life environment. For instance, problems regarding speed and distance perception are difficult to address (Haperen et al., 2015).

Gruening et al. (1998) agreed that the information gained through driving simulations may be misleading if the simulator does not provide an appropriate analogue to the simulated scenario, and that high reliability driving simulations are sometimes far more expensive than vehicle testing. The researcher has experienced a few limitations during a specific scenario development such as:

1. **Limited traffic and advertising signs provided in STISIM Version 2**

   The STISIM Version 2 simulator is limited in the warning signage of road design, with no directional and information signage provided. Airport advertising signs also are not provided in the simulator database. Much time has been spent in order to obtain an accurate Scenario Definition Language (SDL) code and objects. For example, more than 2,000 objects (road furniture) were coded in order to develop the driving scenario simulation. The static objects (SOBJ) (i.e. signage and street lights) must be formatted in a .3ds file due to the limitation of supporting software.

2. **Roundabout design**

   There were difficulties to coding of a roundabout because of the road design scenario being based on the United States' driving environment. As the study is mirrored to the United Kingdom's driving environment, a lot of time and effort were spent in order to obtain and accurate Scenario Definition Language (SDL) code (Chapter 3, Section 3.8.1).

3. **Age of participants**

   As the study investigated the impact on the driving behaviour of senior drivers (more than 50 years old) of different wayfinding and signage provisions, the Two-Way ANOVA results showed that there were no significant effects of airport road access wayfinding (in terms of age group) on research parameters of; (1) risk of collisions, (2) exceeding the speed limit (3) traffic light tickets, (4) centreline crossings and (5) road edge excursions.

Referring to Chapter 1; Section 1.3, Figure 1-4 shows the trends in road accidents and casualties involving senior drivers. The trends of seriously injured and killed on roads are constant each year. The number of all severities fluctuated between 1,000 accidents a year from 2010 and 2013 before rising to 28,798 in 2014. The contributory factor of loss of control was reported as 32 per cent of fatal accidents in 2014. The pair of contributory factors relating to poor wayfinding that were most frequently recorded are (1) failing to look properly and (2) judging other person’s path or speed. Drivers’ mistakes or reaction was the most frequently reported, as 73 per cent of all accidents in 2014. These contributory factors were also the most frequent category reported for each severity of accident. Behaviour or inexperience and injudicious actions (which include travelling too fast for conditions, following too close and exceeding speed limit) were the next most frequently reported categories, involving of 25 and 23 per cent of all accidents, respectively. The equivalent figures of fatal accidents, for both contributory factors, were higher at 27 and 29 per cent, respectively.

The differentiation between young driver (below than 50 years old) and senior driver (above than 50 years old) not showed in the study. Based on the findings, the researcher suggested that the young driver might contribute and more effective in future study.

4. Role of experience

Drivers aged over than 75 years old was exposed to the accident risks as age increases, it is certain that general health and fitness will begin to deteriorate. Senior drivers felt that their driving experience skills and driving abilities may not be as good as they once were (Leversen, Hopkins and Sigmundsson, 2013). As a result, senior drivers likely to control their driving experience and develop a more defensive and cautious driving behaviour as they grow older. The senior drivers are commonly involved in collisions, occurring often because they misjudge the speed or distance of other vehicles or fail to see a hazard (National Institute on Aging, National Institutes of Health and U.S. Department of Health and Human Service, 2011).

The peak ages for nervous senior drivers are learner drivers or people without much experience, and drivers aged 70 or over. The senior drivers may have more experience behind the wheel, but could be more likely to be nervous and concerned about their own reaction times and eyesight.

For example, the complexity of road scenario and various speed limits led to senior drivers not being able to read the text on the signs when necessary (mean=1.78, SD=0.80). Bazire and Tijus (2009) suggested that road signs should not be ambiguous as they were designed to assist drivers in complying with the law prescriptions whilst driving. However, the ambiguity of traffic signs led to misunderstandings or to the simple omission of the signs' information. Similar to the 'Less Complex' scenario, respondents were looking for the word 'airport' on signs to continue their journey to the airport (mean=4.10, SD=0.93).

Greater complexity in road design clearly raises the risk of accidents for elderly drivers. For example, the results confirmed that the senior drivers required great awareness of the speed limit (i.e. bigger font than conventional signs) as they drove faster in lower speed limit areas.

5. Simulator Sickness

The senior drivers faced the severity and type of simulation sickness while conducting the test. 25 of participants (17.24%) were discontinued as they experienced nauseous and dizzy in the beginning and middle of the simulation study (Chapter 3, Section 3.7). Common symptoms are generally grouped into nausea, oculomotor discomfort, and disorientation (Blana, 1996). The research found in most of symptoms reported was in the oculomotor discomfort category. This included eye strain, headaches, difficulty focusing and blurred vision. Simulator sickness can vary widely among individuals who experience it and among simulators that induce it. The most critical variables are the visual horizontal field-of-view and the level of moving scene detail. Adding more to that, room environment factors such as temperature regulation and humidity control when the simulator room is considered.

6. **Transferability of findings for elderly drivers**

   The issue of transferability of elderly drivers from the real environment to the simulated has always been of critical importance in this research. The attitude, ability and motivation of the senior drivers signifies to the validity of the research as it allows at least the transfer of basic driving skills of senior drivers from a real driving environment to a simulated and at the same time it should present the subject with realistic visual, auditory cues and traffic scenario.

The number of participants for the airport road access wayfinding simulation study were increased as the senior drivers were allocated ample time to respond to the tasks and questionnaire. Simulation scenarios, data collection and processing were completed in 16 months. In order to improve the research quality, the simulation needs to be validated and reliable for further research. Validity refers to the correctness or credibility of a description, conclusion, explanation or other sort of account (Robson and McCartan, 2016; Sekaran, 2003). Validity is primarily important in a research context as it deals with the integrity of the research.

5.7 Recommendations for Future Work

This research addressed the gaps in the literature on the airport road access wayfinding and the relationship between senior driving behaviour and airport road access wayfinding design. A driving simulator has been used as a tool to measure the relationship between these variables. In this section, further directions for future research are suggested.

1. In the beginning stage of the research, the use of Satellite Navigation (Sat Nav) was suggested as one of the objectives to assess its impact on senior driving behaviour towards airport road access wayfinding. However, the Sat Nav was not built-in in the STISIM driving simulator Version 2. The idea of the insertion of Sat Nav as a tool to aid senior drivers to perform airport wayfinding hopefully would extend the current research, with additional variables on the impact of airport road access design using a simulated driving scenario.
2. Senior drivers aged 50 years and over were chosen to participate in this research. Results from the simulated driving test were analysed and findings were measured only focusing on senior drivers' attributes. It is suggested that this research could be extended to the younger drivers and with a consideration of gender to assess any effects on driving behaviour on the complexity of road design.
3. This research using a driving simulator was mainly focused on airport road access wayfinding. The research could be extended to other areas such as the hospital and school environments. The impact of road access complexity to senior drivers in these areas is perhaps an interesting topic for future research.
4. This research may fill the gap on the choice of typeface in signage systems, for example senior drivers may experience vision problems. Thus, it is important to understand that certain signage could be improved according to their need.

5.8 Research Implications

The continuous improvement of airport road access wayfinding would give huge beneficial impact to senior drivers and increase the airport road access efficiency.

Better airport road access wayfinding systems reduce accidents and incidents on the airport road access or landside areas.

5.8.1 Implications for the Airport Industry

The research will be beneficial for developing an adequate airport road access wayfinding provision which is able to increase the quality of drivers' navigation in airport areas. The research contributes to the aim of a safe navigational system being adopted by the parties involved (e.g. drivers, airport authorities and road planners). The findings revealed that there are different views on wayfinding between airport management and road sign design professionals as summarised in Chapter 2 (Section 2.5).

The following are the viewpoints of airport management regarding road access wayfinding:

1. Airport signs are used as an identity or branding of the airport (i.e. use of similar colour and style of signs throughout), providing a sense of arrival and the beginning of the airport user's experience;
2. Airport signs should look different to road signs, as a means to slow down traffic, confirm entry into a different environment and essentially to remind senior drivers that they have arrived at the airport area; and
3. Airport operators view wayfinding systems as consisting only of signs which are installed and subsequently ignored.

In contrast, the viewpoints of road sign design professionals are as follows:

1. Airport signs should comply with all roads (e.g. motorway), traffic signage regulations and design criteria;

2. The more an airport road can be made to look and function like a regular road, the more it will conform to a safer and less frustrating driving experience; and
3. Road navigational spaces consist of important tools; maps for drivers with good targeting skills, and landmarks for drivers with strong memorization skills.

If the research is accepted, under an ideal albeit perhaps hypothetical situation, the airport road access wayfinding would be self-sufficient in terms of ideal road access design provided for the airport road users.

These limitations were observed to make the airport road access facilities inadequate, causing low convenience and willingness to travel, especially during peak times. The application of this research which incorporated the preferences of senior drivers and airport users may help to provide a design concept of airport road access wayfinding guidelines for senior drivers and airport users in the future.

5.8.2 Implications for Senior Drivers and Airport Users

From a senior driver's and airport user's point of view, the journey is just as important as the destination. Three situations that affects senior drivers' wayfinding have been identified; recreational, resolute and emergency wayfinding (Harding et al., 2011). They are summarised as the following (Chapters 3 and 4):

1. Recreational wayfinding offers a senior driver the opportunity to solve problems (where to go next, for example) that can be a source of satisfaction and enjoyment. An example is driving for pleasure, where the senior driver is not in a hurry to reach a destination and, therefore, the

experience of wayfinding takes priority over the functional aspect of getting to and from the airport.

2. Resolute wayfinding is used where the main purpose is to find one's way in the most efficient manner. The complexity of the environment may have positive or negative aspects depending on the type of wayfinding being undertaken.
3. Under emergency wayfinding conditions, the only important factor is reaching the destination as quickly and easily as possible. Due to pressures (Naveteur et al., 2013) of time, and possible human factor elements such as stress and panic (Matthews et al., 1998; Taylor and Dorn, 2006), the wayfinding design should be as simple as possible.

As discussed in Chapter 2, Section 2.9, five functions of road transport is revisited to develop airport road access wayfinding which is accessible to senior drivers; (1) *Linkage*; Airport road access connects cities to the airport area, an airport building to another, and to activities and places (e.g. roadway, traffic signs, pavement, information board and wayfinding); (2) *Transportation;* Airport road access provides the surface and structure for a variety of road transport modes (e.g. private car, taxis and buses). Airport road access for motor vehicles, emergency services, and maintenance services for airport purposes should be developed; (3) *Access*; Airport road access provides public access to the airport terminal, car parking space or other airport buildings; (4) *Public right-of-way*; Space for utilities and other infrastructure is usually a hidden function of the street. Airport users have the right to access some roadway in the airport ground's area; and (5) *Sense of place;* The street is a definable place which is a place for people to interact; it is the heart of a community.

Good wayfinding (Section 5.1) creates a welcoming and enjoyable environment to senior drivers. It can be achieved by focussing on the senior drivers' needs, especially during the planning and design phases, and, encompassing environmental factors (e.g. building design, user expectation and signage information) into airport road access wayfinding design.

5.9 Closing Remarks

Driving to an airport is a basic transportation mode that has frequently been overlooked in the quest to build sophisticated transportation systems. For instance, senior drivers require welcoming, safe and enjoyable road spaces. Creating an airport road access for better wayfinding involves more than laying down road lanes or installing traffic signs. A truly viable airport road access system involves both the big picture and the smallest details; from how an airport environment is built to what materials are chosen for the users' convenience. Airport road access wayfinding should be accessible to all users, including those who are elderly or with disabilities. Accessibility is the foundation for all road design and facilities need to be planned, designed, operated and maintained so as to be usable by all people.

The study shows that a safe and ideal airport road access wayfinding for senior drivers is important to airport authorities. Safety is not merely installing closed-circuit television (CCTV) or placing a security booth along the airport road access, but also includes all road facilities (e.g. street lighting, traffic signs and bollards). Traditionally, safety problems have been addressed by analysing road accident statistics and improvements have been made only after they are warranted due to the number of accidents and incidents. Airport and road planners and engineers should consider problem identification methods such as interactive public workshops, surveying drivers' manoeuvres in airport areas or working closely with the police to identify safety problems in an area before the accidents occur. This may help proactively identify locations for safety improvements and will involve airport users in the process of improving safety and mobility in the airport landside area.

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APPENDICES

Appendix A Research Ethics Approval

Ethics Proposal 138-2014

SEREC

Fri 05/09/2014 11:09 AM

To: Anuar, Nur Khairiel <n.anuar@cranfield.ac.uk>;

Dear Nur

Your proposed research activity "A Wayfinding, Road Safety and Cost-benefit Analysis of Alternative Airport Road Access Design Solutions" has been reviewed by SEREC and confirmed as posing a low risk in terms of research ethics. This approval is subject to one amendment – the consent form should state that participants can ask to have their data withdrawn from the study, up to one week from completing the survey (or whatever timeframe you think is appropriate), by contacting the researcher and quoting their participant number. You can now proceed with the research activities you have sought approval for and we wish you a successful project.

Please remember that SEREC occasionally conducts audits of low risk projects and we may therefore contact you during or following execution of your fieldwork to verify that you are following good practice.

Guidance on good practice in research ethics is available at:
https://intranet.cranfield.ac.uk/researchethics/Pages/SEREC.aspx

With best regards

Sue Garrod
School of Aerospace, Transport & Manufacturing

Appendix B Participation Instruction

Centre for Air Transport Management
Cranfield University
Cranfield, Bedford, MK43 0AL

Participant Instructions

Please adjust the seat position to the pedals and as comfortable as possible. The car controls work in the same manner as any normal car and it operates with a manual gearbox.

You need to make sure the car is in neutral when you start it and it needs plenty of revs, otherwise it has a tendency to stall.

It is important that you drive as you would normally. We don't want you to drive as if you are on a driving test nor as if the simulation is a computer game. We are not here to judge your driving skills, so please do not feel anxious.

The Task Scenario:

You are almost late for counter check-in at the airport. In order to arrive to the airport on-time, you have to drive a car by your own. However, this is your first time drive to the desire airport. The road and driving environment is totally new to you. ***To complete the task, you are given 10 minutes to drive to the airport before check-in time closed.***

The drive will start on the dual carriageway with normal traffic. Three simulated driving will be tested from *less complex*, *complex*, and *more complex* road design. Each driving simulation is taken approximately 5-10 minutes (based on your driving manoeuvres). The road speed limits are varied. Please be aware of the speed limits signs and drive according to the speed limit signs.

By the aids of the road signage, make your own decisions while driving and complete the wayfinding process to get to the airport on time. You should try to keep to given speed limit and able to keep to the centre of your lane.

You will see a vehicle in front of you as well as on opposite lane. Please do your best to keep at a safe and constant distance behind it. A voice instruction will let you know when the simulated driving task has finished.

To start the car driving, please follow the voice instructions and drive as you would normally.

Thanks for your participation!

Appendix C Consent Form

Centre for Air Transport Management
Cranfield University
Cranfield, Bedford, MK43 0AL

Participant Consent Statement

Purpose:
The purpose of this study is to investigate ways in which airport road access design can be improved, through an assessment of both the cost and benefits of different solutions. The study is part of the PhD research and thesis, under the supervision of Dr Pagliari and Mr. Moxon.

Procedure:
If you agree to be in this study, you will be asked to do the following:

1. Taking part in driving simulation to approximately 20 minutes.
2. Complete a questionnaire.

The total time required to complete the study should be approximately 40 minutes.

Benefits/Risks to Participant:

1. Better understanding and improvement of airport road access wayfinding design.

Voluntary Nature of the Study/Confidentiality:
Your participation in this study is entirely voluntary. You may refuse to complete the study at any point during the experiment, or refuse to answer any questions with which you are uncomfortable. You may also stop at any time and ask the researcher any questions you may have. Your name will never be connected to your results or to your responses on the questionnaires; instead, a number will be used for identification purposes. Information that would make it possible to identify you or any other participant will never be included in any sort of report. The data will be accessible only to those working on the project.

Contacts and Questions:
At this time you may ask any questions that you may have regarding this study. If you have any questions later, you may contact Khairiel Anuar at n.anuar@cranfield.ac.uk or his supervisors, Dr. Pagliari at R.Pagliari@cranfield.ac.uk or Mr. Moxon at r.moxon@cranfield.ac.uk

Statement of Consent:
I have read the above information. I have asked any questions I had regarding the experimental procedure and they have been answered to my satisfaction. I consent to participate in this study.

Name of Participant: ____

Age: ______________ (Optional) Gender: ______________

Signature of Participant: ______________________________ Date: ______________

(Note: You must be 18 years old or older and hold a valid UK driving license or equivalent to UK driving license to participate in this study).

Thanks for your participation!

Appendix D Personal Comfort Questionnaire

Personal Comfort Questionnaire

Please read the following list of symptoms carefully.

Using a cross anywhere along the scale, please rate your current feelings of each symptom.

Symptoms:

- Headache

0 1 2 3 4 5 6 7 8 9 10

No symptom at all — Unbearable level of symptom

- Eyestrain

0 1 2 3 4 5 6 7 8 9 10

No symptom at all — Unbearable level of symptom

- Blurred vision

0 1 2 3 4 5 6 7 8 9 10

No symptom at all — Unbearable level of symptom

- Dizziness

0 1 2 3 4 5 6 7 8 9 10

No symptom at all — Unbearable level of symptom

- Sickness

0 1 2 3 4 5 6 7 8 9 10

No symptom at all — Unbearable level of symptom

Appendix E Self-designed Questionnaire

QUESTIONNAIRE

A SURVEY ON A WAYFINDING DESIGN AND ROAD SAFETY OF ALTERNATIVE AIRPORT ROAD ACCESS DESIGN SOLUTIONS

This survey will take about 10 minutes to complete and participation in this research is completely voluntary. The aim of the survey is to understand drivers' views on the simulation and driving behaviour while perform navigation to the airport.

You have the right to withdraw at any time or refuse to participate entirely. Please note that all information will be treated in a strictly confidential. Thank you.

PART A : DEMOGRAPHIC BACKGROUND

Q1: Age		√
1.	50 to 54 years	
2.	55 to 59 years	
3.	Over 60 years	
4.	Prefer not to say	

Q2: Frequency of Travelling to the Airport in 12 Month		√
1.	Less than 3	
2.	3-5	
3.	More than 5	

Q3: Travelling Purpose		√
1.	Business	
2.	Leisure	
3.	Business and leisure	

Q4: Time Spent from the Road to the Airport (minutes)		√
1.	Less than 20 minutes	
2.	21 to 40 minutes	
3.	41 to 60 minutes	
4.	More than 60 minutes	

Q5 Which airport have you visited for the last six month or you may have visited often? Please write.

....

PART B : IMPACT OF SIGNAGE AND WAYFINDING ON SIMULATED DRIVING

Please answer the following statements based on your experience in the driving simulator exercises. Please ensure your answers accurately reflect your own experience. Please rank (1 to 5) of each simulation.

1	=	Strongly disagreed
2	=	Disagreed
3	=	Neutral
4	=	Agreed
5	=	Strongly agreed

		Simulation 1	**Simulation 2**	**Simulation 3**
Q1	It was easy to drive on the road			

		Simulation 1	**Simulation 2**	**Simulation 3**
Q2	The signs were easily noticeable			

		Simulation 1	**Simulation 2**	**Simulation 3**
Q3	I could not read the text on the signs			

		Simulation 1	**Simulation 2**	**Simulation 3**
Q4	I was looking for the word of "airport" on the sign			

		Simulation 1	**Simulation 2**	**Simulation 3**
Q5	Type of warning signs were adequate  			

		Simulation 1	Simulation 2	Simulation 3
Q6	The font of the road signs were clear and readable			

		Simulation 1	Simulation 2	Simulation 3
Q7	The signage helped me navigate easily			

		Simulation 1	Simulation 2	Simulation 3
Q8	There were too many road-side adverts			

		Simulation 1	Simulation 2	Simulation 3
Q9	I could not read the adverts			

		Simulation 1	Simulation 2	Simulation 3
Q10	I was distracted by the adverts			

		Simulation 1	Simulation 2	Simulation 3
Q11	I noticed that the trees were blocking some of the road signs			

		Simulation 1	Simulation 2	Simulation 3
Q12	There were too many traffic lights			

		Simulation 1	Simulation 2	Simulation 3
Q13	Poor visibility along road because of terrain			

		Simulation 1	Simulation 2	Simulation 3
Q14	At the junction on the road to the airport, I was able to make a fast decision			

		Simulation 1	Simulation 2	Simulation 3
Q15	The frequency of warning signs were adequate			

		Simulation 1	Simulation 2	Simulation 3
Q16	The variable speed limit signs were noticeable			

		Simulation 1	Simulation 2	Simulation 3
Q17	The bend on the road did not affect my feeling of safety			

		Simulation 1	Simulation 2	Simulation 3
Q18	The level of traffic did not make any difference to my driving			

		Simulation 1	Simulation 2	Simulation 3
Q19	I felt nauseous when driving on the simulator			

		Simulation 1	Simulation 2	Simulation 3
Q20	I felt safe to perform the simulated driving exercise			

PART C : IMPACT OF SIGNAGE INFORMATION ON WAYFINDING AND AIRPORT ROAD ACCESS

Please answer the following questions based on your general experience on the road. If you 'Agreed' with the statement, please tick (✓) 'Yes' and if you 'Disagreed' with the statement, please tick (✓) 'No'.

		Yes	No
Q1	I feel anxious while driving to the airport		

		Yes	No
Q2	I am not aware of street lighting		

		Yes	No
Q3	Airport signs should have the same style as normal road signs		

		Yes	No
Q4	I would prefer signs to be larger		

		Yes	No
Q5	Additional information in signage design is relevance		

		Yes	No
Q6	Speed limit signs should be displayed frequently		

		Yes	No
Q7	Adverts on the road are annoying or distracting		

		Yes	No
Q8	I plan the route before drive to the airport		

		Yes	No
Q9	I look for landmarks (e.g. buildings) to help me find my way		

		Yes	No
Q10	I feel safe to drive at night with the street lights		

		Yes	No
Q11	The directional arrow sign is useful 		

		Yes	No
Q12	I do not like symbol sign (e.g. aeroplane) 		

		Yes	No
Q13	Missing highway exits make me confused and stressed		

		Yes	No
Q14	The airport text on the signs is too small		

		Yes	No
Q15	The types of road signage does not help drivers		

		Yes	No
Q16	A variable speed limit affects my driving behaviour		

		Yes	No
Q17	Too many signs are confusing to drivers		

		Yes	No
Q18	Signs indicating directions to the airport should be displayed as far as possible from the airport		

		Yes	No
Q19	The more complex to access to the airport, the less likely to drive to the airport		

		Yes	No
Q20	I less likely to drive to airport if the traffic is heavy		

Q21 Are there any changes that you would make to improve airport road signs? Please specify.

……

…….

THANK YOU.

7

Appendix F Driving Simulation: Examples of Scenario Definition Language (SDL)

F.1 Simulation 1 - Less Complex Scenario

Scenario:
```
0, BSAV, 0, 50, Khairiel data, 1,2,3,4,5,7,12,13,23,32,50
0, V,  0, 580{7}, -200{2}, 0, 45L,  580{7}, -650, 0, 20
0, V,  0, 580{7}, -400{2}, 0, 53L,  580{7}, -650, 0, 20
0, V,  0, 580{7}, -550{2}, 0, 35L,  580{7}, -650, 0, 20
0, V,  0, 1485{7}, -100{2}, 0, 31L,  1485{7}, -650, 0, 20
0, V,  0, 1485{7}, -400{2}, 0, 33L,  1485{7}, -650, 0, 20
0, V,  0, 580{7}, 700{2}, 0, 31L,  580{7}, -600, 0, 25
0, V,  0, 580{7}, 800{2}, 0, 44L,  580{7}, -650, 0, 25
0, V,  0, 615{7}, 300{2}, 0, 35R,  615{7}, 650, 0, 20
0, V,  0, 615{7}, 500{2}, 0, 33R,  615{7}, 650, 0, 20
0, V,  0, 615{7}, 800{2}, 0, 26R,  615{7}, 650, 0, 20
0, V,  0, 615{7}, 1000{2}, 0, 31R,  615{7}, 650, 0, 20
0, V,  0, 615{7}, 1500{2}, 0, 35R,  615{7}, 650, 0, 20
0, V,  0, 615{7}, 1800{2}, 0, 33R,  615{7}, 650, 0, 20
0, V,  0, 615{7}, 2000{2}, 0, 26R,  615{7}, 650, 0, 20
0, SOBJ, 6984, 0, 0,0,0,0, C:\ARRIVA\Arrivasigns\ChevronW.3DS,
C:\STISIM\Data\Textures\roundabout.bmp
0, SOBJ, 7000, 0{0}, 0,180,0,0, C:\EXTRA\Roundabout\rotonde.3ds,
0, SOBJ, 18968, 0, 0,0,0,0, C:\ARRIVA\Arrivasigns\ChevronW.3DS,
C:\STISIM\Data\Textures\roundabout.bmp
0, SOBJ, 19000, 0{0}, 0,180,0,0, C:\EXTRA\Roundabout\trafcirc.3DS,
0, CT, 13920, 5, 60, 0, L, *21~23;1;2;30;31, 1
0, CT, 13940, 5, 60, 0, L, *21~23;1;2;30;31, 1
0, CT, 13800, 5, -120, 0, R, *21~23;1;2;30;31, 1
0, CT, 13820, 5, -120, 0, R, *21~23;1;2;30;31, 1
0, CT, 13840, 5, -120, 0, R, *21~23;1;2;30;31, 1
0, CT, 13860, 5, -120, 0, R, *21~23;1;2;30;31, 1
0, CT, 13880, 5, -120, 0, R, *21~23;1;2;30;31, 1
0, CT, 19900, 5, 80, 0, R, *21~23;1;2;30;31, 1
0, CT, 19920, 5, 80, 0, R, *21~23;1;2;30;31, 1
0, CT, 19940, 5, 80, 0, R, *21~23;1;2;30;31, 1
0, CT, 19960, 5, 80, 0, R, 18, 1
0, CT, 19980, 5, 80, 0, R, *21~23;1;2;30;31, 1
0, CT, 20000, 5, 80, 0, R, *21~23;1;2;30;31, 1
0, CT, 20020, 5, 80, 0, R, *21~23;1;2;30;31, 1
0, CT, 20040, 5, 80, 0, R, 18, 1
0, CT, 20060, 5, 80, 0, R, *21~23;1;2;30;31, 1
0, CT, 20080, 5, 80, 0, R, *21~23;1;2;30;31, 1
0, CT, 20100, 5, 80, 0, R, 18, 1
0, CT, 20120, 5, 80, 0, R, *21~23;1;2;30;31, 1
0, CT, 20140, 5, 80, 0, R, *21~23;1;2;30;31, 1
0, CT, 20160, 5, 80, 0, R, *21~23;1;2;30;31, 1
0, CT, 20180, 5, 80, 0, R, 18, 1
0, CT, 20200, 5, 80, 0, R, *21~23;1;2;30;31, 1
100, SOBJ, 700,-30, 0,0,0,0, C:\ARRIVA\Arrivasigns\KillSpeed.3DS,
1000, BLDG, 20000, 200, G35, -90
1000, BLDG, 20000, -400, G34, 90
1000, BLDG, 20000, 400, G34, -90
1000, BLDG, 12100, -100, B17, 0
```

F.2 Simulation 2 - Complex Scenario

Scenario:
1000, SOBJ, 14960, 380, 0,-90,0,0, C:\Khairiel_signs\AptsignW7.3DS,
1000, SOBJ, 15030,-100, 0,-90,0,0, C:\Khairiel_signs\AptsignW6.3DS,
1000, SOBJ, 15030,-380, 0,-90,0,0, C:\Khairiel_signs\AptsignW6.3DS,
1000, SOBJ, 15030, 100, 0,-180,0,0, C:\Khairiel_signs\Roundaboutsign1W.3DS,
1000, SOBJ, 15030, 380, 0,-180,0,0, C:\Khairiel_signs\Roundaboutsign1W.3DS,
1000, SOBJ, 6800, 25, 0,90,0,0, C:\STISIM\EXTRA\ARRIVA\Arrivasigns\keepleft.3ds,
1000, SOBJ, 4700,-30, 0,0,0,0, C:\STISIM\EXTRA\UK_Signs\WarningSigns\CrosRd.3DS,
1000, SOBJ, 13800,-30, 0,180,0,0, C:\Khairiel_signs\Billbrd6.3DS,
1000, SOBJ, 13900, 30, 0,-160,0,0, C:\ARRIVA\Arrivasigns\Billboard6.3ds,
1000, SOBJ, 7900,-30, 0,0,0,0, C:\STISIM\Data\Signs\SIGAHEAD.3DS,
1000, SOBJ, 14800,-30, 0,0,0,0, C:\STISIM\Data\Signs\SIGAHEAD.3DS,
1000, TREE, 80, 0, *1;3;14, 70{0}, 300{0}, 0
1000, SL, -8000, 10 {0}, 3, 10, 0, 24, 4, 2
1000, SL, -15000, 10 {0}, 3, 10, 0, 24, 4, 2
1000, SIGN, 100, 15500, C:\STISIM\EXTRA\UK_Signs\WarningSigns\DoubBnd.3DS, 1
1000, SIGN, 100, 15500, C:\STISIM\EXTRA\UK_Signs\WarningSigns\DoubBnd.3DS, 1, 1
1000, SOBJ, 5920,-30, 0,0,0,0,C:\STISIM\EXTRA\UK_Signs\WarningSigns\RndBout.3DS,
1000, SOBJ, 17890,-30, 0,0,0,0,C:\STISIM\EXTRA\UK_Signs\WarningSigns\RndBout.3DS,
1000, SOBJ, 18750,-30, 0,-180,0,0, C:\ARRIVA\Arrivasigns\AptsignW5.3DS,
1000, SOBJ, 19300,-30, 0,0,0,0, C:\ARRIVA\Arrivasigns\AptsignW9.3DS,
1000, SOBJ, 18910, 40, 0,90,0,0, C:\ARRIVA\Arrivasigns\ParkingW.3DS,
1000, SOBJ, 19000, 40, 0,90,0,0, C:\ARRIVA\Arrivasigns\DisableparkW.3DS,
1000, SOBJ, 15800,-40, 0,180,0,0, C:\Khairiel_signs\Billbrd4.3DS,
1000, SOBJ, 16000,-40, 0,180,0,0, C:\Khairiel_signs\Billbrd3.3DS,
1000, SOBJ, 16300,-40, 0,0,0,0, C:\Khairiel_signs\Billbrd8.3DS,
1000, SOBJ, 16500,-40, 0,0,0,0, C:\Khairiel_signs\Billbrd1.3DS,
1000, SOBJ, 16700,-40, 0,180,0,0, C:\Khairiel_signs\Billbrd3.3DS,
1000, SOBJ, 16900,-40, 0,180,0,0, C:\Khairiel_signs\Billbrd4.3DS,
1000, SOBJ, 18200,-40, 0,0,0,0, C:\Khairiel_signs\Billbrd8.3DS,
1000, SOBJ, 18400,-40, 0,180,0,0, C:\Khairiel_signs\Billbrd4.3DS,
1000, SOBJ, 18600,-40, 0,0,0,0, C:\Khairiel_signs\Billbrd1.3DS,
1000, SOBJ, 18800,-40, 0,180,0,0, C:\Khairiel_signs\Billbrd3.3DS,
1000, SOBJ, 19000,-40, 0,180,0,0, C:\Khairiel_signs\Billbrd4.3DS,
1000, SOBJ, 15900, 40, 0,0,0,0, C:\Khairiel_signs\Billbrd5.3DS,
1000, SOBJ, 16100, 40, 0,180,0,0, C:\Khairiel_signs\Billbrd2.3DS,
1000, SOBJ, 16400, 40, 0,0,0,0, C:\Khairiel_signs\Billbrd5.3DS,
1000, SOBJ, 16600, 40, 0,180,0,0, C:\Khairiel_signs\Billbrd2.3DS,
1000, SOBJ, 18100, 40, 0,0,0,0, C:\Khairiel_signs\Billbrd5.3DS,
1000, SOBJ, 18300, 40, 0,180,0,0, C:\Khairiel_signs\Billbrd2.3DS,
1000, SOBJ, 18400, 40, 0,0,0,0, C:\Khairiel_signs\Billbrd5.3DS,
1000, SOBJ, 18600, 40, 0,180,0,0, C:\Khairiel_signs\Billbrd2.3DS,
1000, SOBJ, 12800,-30, 0,0,0,0, C:\ARRIVA\Arrivasigns\Bollard7.3ds,
1000, SOBJ, 12800,-40, 0,0,0,0, C:\ARRIVA\Arrivasigns\Bollard7.3ds,
1000, SOBJ, 12820,-30, 0,0,0,0, C:\ARRIVA\Arrivasigns\Bollard7.3ds,
1000, SOBJ, 12820,-40, 0,0,0,0, C:\ARRIVA\Arrivasigns\Bollard7.3ds,
1000, SOBJ, 18719,-25, 0,0,0,0, C:\STISIM\EXTRA\UK_Signs\objects\signs\beacon.3ds,
1000, SOBJ, 18734, 25, 0,0,0,0, C:\STISIM\EXTRA\UK_Signs\objects\signs\beacon.3ds,
1000, SOBJ, 18700,-30, 0,0,0,0, C:\STISIM\Data\EuroSigns\E_PedXing.3ds,
1000, SOBJ, 18700, 30, 0,0,0,0, C:\STISIM\Data\EuroSigns\E_PedXing.3ds,
1000, SOBJ, 17980, 0, 0,0,0,0, C:\Khairiel_signs\Welcome.3DS,
1000, SOBJ, 19920,-50, 0,90,0,0, C:\Khairiel_signs\RNRIntAptWORD.3ds,
1000, SOBJ, 19980, 0, 33,90,0,0, C:\Khairiel_signs\RNRIntAirport.3DS,
1000, BLDG, 20000, 0, G35, -90
1000, BLDG, 20000, -200, G35, 90

F.3 Simulation 3 - More Complex Scenario

Scenario:
1000, SIGN, 100, 15500, C:\STISIM\EXTRA\UK_Signs\WarningSigns\DoubBnd.3DS, 1
1000, SIGN, 100, 15500, C:\STISIM\EXTRA\UK_Signs\WarningSigns\DoubBnd.3DS, 1, 1
1000, SOBJ, 5920,-30, 0,0,0,0,C:\STISIM\EXTRA\UK_Signs\WarningSigns\RndBout.3DS,
1000, SOBJ, 17890,-30, 0,0,0,0,C:\STISIM\EXTRA\UK_Signs\WarningSigns\RndBout.3DS,
1000, SOBJ, 18750,-30, 0,-180,0,0, C:\ARRIVA\Arrivasigns\AptsignW5.3DS,
1000, SOBJ, 19300,-30, 0,0,0,0, C:\ARRIVA\Arrivasigns\AptsignW9.3DS,
1000, SOBJ, 18910, 40, 0,90,0,0, C:\ARRIVA\Arrivasigns\ParkingW.3DS,
1000, SOBJ, 19000, 40, 0,90,0,0, C:\ARRIVA\Arrivasigns\DisableparkW.3DS,
1000, SOBJ, 1700,-40, 0,180,0,0, C:\Khairiel_signs\Billbrd4.3DS,
1000, SOBJ, 3000,-40, 0,180,0,0, C:\Khairiel_signs\Billbrd3.3DS,
1000, SOBJ, 3500,-40, 0,0,0,0, C:\Khairiel_signs\Billbrd8.3DS,
1000, SOBJ, 15800,-40, 0,180,0,0, C:\Khairiel_signs\Billbrd4.3DS,
1000, SOBJ, 16000,-40, 0,180,0,0, C:\Khairiel_signs\Billbrd3.3DS,
1000, SOBJ, 16300,-40, 0,0,0,0, C:\Khairiel_signs\Billbrd8.3DS,
1000, SOBJ, 16500,-40, 0,0,0,0, C:\Khairiel_signs\Billbrd1.3DS,
1000, SOBJ, 16700,-40, 0,180,0,0, C:\Khairiel_signs\Billbrd3.3DS,
1000, SOBJ, 16900,-40, 0,180,0,0, C:\Khairiel_signs\Billbrd4.3DS,
1000, SOBJ, 18200,-40, 0,0,0,0, C:\Khairiel_signs\Billbrd8.3DS,
1000, SOBJ, 18400,-40, 0,180,0,0, C:\Khairiel_signs\Billbrd4.3DS,
1000, SOBJ, 18600,-40, 0,0,0,0, C:\Khairiel_signs\Billbrd1.3DS,
1000, SOBJ, 18800,-40, 0,180,0,0, C:\Khairiel_signs\Billbrd3.3DS,
1000, SOBJ, 19000,-40, 0,180,0,0, C:\Khairiel_signs\Billbrd4.3DS,
1000, SOBJ, 15900, 40, 0,0,0,0, C:\Khairiel_signs\Billbrd5.3DS,
1000, SOBJ, 16100, 40, 0,180,0,0, C:\Khairiel_signs\Billbrd2.3DS,
1000, SOBJ, 16400, 40, 0,0,0,0, C:\Khairiel_signs\Billbrd5.3DS,
1000, SOBJ, 16600, 40, 0,180,0,0, C:\Khairiel_signs\Billbrd2.3DS,
1000, SOBJ, 18100, 40, 0,0,0,0, C:\Khairiel_signs\Billbrd5.3DS,
1000, SOBJ, 18300, 40, 0,180,0,0, C:\Khairiel_signs\Billbrd2.3DS,
1000, SOBJ, 18400, 40, 0,0,0,0, C:\Khairiel_signs\Billbrd5.3DS,
1000, SOBJ, 18600, 40, 0,180,0,0, C:\Khairiel_signs\Billbrd2.3DS,
1000, SOBJ, 18719,-25, 0,0,0,0, C:\STISIM\EXTRA\UK_Signs\objects\signs\beacon.3ds,
1000, SOBJ, 18734, 25, 0,0,0,0, C:\STISIM\EXTRA\UK_Signs\objects\signs\beacon.3ds,
1000, SOBJ, 18700,-30, 0,0,0,0, C:\STISIM\Data\EuroSigns\E_PedXing.3ds,
1000, SOBJ, 18700, 30, 0,0,0,0, C:\STISIM\Data\EuroSigns\E_PedXing.3ds,
1000, SOBJ, 17980, 0, 0,0,0,0, C:\Khairiel_signs\Welcome.3DS,
1000, SOBJ, 19920,-50, 0,90,0,0, C:\Khairiel_signs\RNRIntAptWORD.3ds,
1000, SOBJ, 19980, 0, 33,90,0,0, C:\Khairiel_signs\RNRIntAirport.3DS,
1000, BLDG, 20000, 0, G35, -90
1000, BLDG, 20000, -200, G35, 90
1000, BLDG, 20000, 200, G35, -90
1000, BLDG, 20000, -400, G34, 90
1000, BLDG, 20000, 400, G34, -90
15099, Bus lane
15099, 2 lane road
15099, Change to 3 lane Road for layby
15099, Change back to 2 lane road
C:\STISIM\Data\Textures\Road15.Jpg, 18, C:\STISIM\Data\Textures\Dirt15.Jpg, 6,
C:\STISIM\Data\Textures\Dirt15.Jpg, 6, C:\STISIM\Data\Textures\Grass05.Jpg, 6,
C:\STISIM\Data\Textures\Grass05.Jpg, 6
12600, A, 50, 1500, 5 {0}, *37~59
12800, A, 60, 1500, 5 {0}, *1~35
13000, TREE, 250, 0, *1;3;14, 500{0}, 700{0}, 0

Appendix G Convenient Sampling and Open Invitation

G.1 Example of Email 1

Phillips, Amanda
Mon 15/06/2015 4:14 PM

Mark as unread

To: Anuar, Nur Khairiel;

You replied on 16/06/2015 1:40 PM.

Hi Nur

The Wednesday session at 11.00am would be my preference.

Kind regards
Amanda

From: Anuar, Nur Khairiel
Sent: 15 June 2015 15:15
To: Phillips, Amanda
Subject: Re: Volunteer for Cranfield Research

Dear Amanda,

Thank you for your interest to particpate in this research.

Here is the session for this week:

Wednesday, 17th June - 9.30am , 11.00am , 4.00pm
Friday, 19th June - 9.30am , 11.00am

Next week session:

Tuesday, 23rd June - 9.30am , 11.00am , 2.30pm , 4.00pm
Wednesday, 24th June - 9.30am , 11.00am , 2.30pm , 4.00pm

Please let me know which day/time you are available.
Please let me know if you couldn't make it so I can resechedule.
It is much appreciates if you can bring your colleague, friends or family who meet the requirement to participate in this research. Further information will be informed during the session.

Best regards,

Nur Khairiel Anuar
Researcher (Transport Systems)
Centre for Air Transport Management
Cranfield University
Martell House, University Way
Cranfield, Bedfordshire MK43 0TR

G.2 Example of Social Media

Nur Khairiel Anuar
Researcher at Cranfield University
1yr

Volunteer sought for academic research

I am a Researcher at Centre for Air Transport Management. I am working on research that mainly to investigate ways in which airport road access design can be improved, through an assessment of both the cost and benefits of different solutions.
I am looking for a respondent to participate in my research and willing to drive a driving simulator. The research / driving simulator is located at Cranfield University, Bedford, UK.

Volunteer will be asked to do the following:
Taking part in 3 different driving simulations to approximately 20 minutes.
Complete a questionnaire.
Total time required to complete the study should be approximately 40 minutes.

Volunteer must:
Age 50 years old and above.
Have a valid UK driving license.
Meet the DVLA minimum eyesight requirement.

Please email to Khairiel Anuar at
n.anuar@cranfield.ac.uk for details if you are

G.3 Example of Website

General announcements : Volunteer sought for Cranfield research

PhD student Khairiel Anuar in the Centre for Air Transport is working on research to investigate ways in which airport road access design can be improved through an assessment of both the cost and benefits of different solutions.

He is looking for a volunteer to participate in his research who is willing to drive a driving simulator and will be asked to do the following:

1. taking part in three different driving simulations for approximately 20 minutes
2. complete a questionnaire

The total time required to complete the study will be approximately 40 minutes.

The volunteer must be:

1. Aged 50 years old or above.
2. Have a valid UK driving license.
3. Meet the DVLA minimum eyesight requirement.

The study will take place in the simulator room in Building 83, between 10am-4pm Monday to Thursday.

Please email Khairiel Anuar - n.anuar@cranfield.ac.uk if you are interested in taking part in the research.

Thank you