The Behavioural Validation Of Driving Simulators As Research Tools: A Case Study Based On The Leeds Driving Simulator.

by

Eumorfia Blana

Submitted in accordance with the requirements
for the Degree of Doctor of Philosophy

Institute for Transport Studies
Department of Civil Engineering
The University of Leeds
Leeds, LS2 9JT

February, 2001

The candidate confirms that the work submitted is her own and
that appropriate credit has been given where
reference has been made to the work of others.

Η εργασία αυτή αφιερώνεται
στους συνανθρώπους μας που άφησαν
την τελευταία τους πνοή στην άσφαλτο
και σε όλους αυτούς που έχουν αφιερώσει τη ζωή τους
στην πρόληψη των τροχαίων ατυχημάτων.

This work is dedicated to
all people who have died in road accidents and
to those who have devoted their lives to the prevention
of road accidents.

Abstract

The objectives of this thesis was to provide researchers with a scientifically-based guide for interpreting driver behaviour results obtained on a fixed-base driving simulator and to provide guidance on how the Leeds Advanced Driving Simulator (LADS) could be modified to overcome any deficiencies that were detected. However. objectives of any simulator validation study are directly related to the specific driving task under investigation. our ability to perform a similar task in the field (for the comparison of the results between the two environments) and the existing configuration capabilities of the simulator.

To achieve the objectives of this study, driver behaviour was investigated at the control level under different road geometry and oncoming traffic conditions using the LADS. Speed and lateral displacement in terms of mean and standard deviation were chosen to represent driver behaviour. They were measured under free-flowing conditions on a rural A road. The objectives of the study were fulfilled by comparing observational uncontrolled real road data with experimental simulator data and by evaluating the differences between the two environments using the absolute and relative validity criteria. It was found that LADS is relatively valid in terms of speed and lateral position. It was also found that higher speeds are developed in the simulator where speed in not confined by the road geometry and simulator subjects drive significantly closer to the edge of the road compared to their real road counterparts irrespective of the road geometry and the oncoming traffic conditions.

The face validity of the simulator was examined using subjective data obtained from questionnaires relative to the realism and ease of controlling the simulator. Subjects commented that the least realistic features of the simulator were the braking and steering systems. Subjects were classiffied to "good" and "poor" according to their responses regarding the simulator face validity. It was found that "good" subjects behave slightly better compared to "poor" subjects when driving the simulator.

Acknowledgments

I would like to thank Dr. Oliver Carsten, Institute for Transport Studies. University of Leeds for his supervision and to express my gratitude to Assistant Professor John Golias, Department of Transport Planning and Engineering, National Technical University of Athens for his valuable advice and his continuous support especially during the last phase of this work.

Special thanks to my dearest friend, Dr Paul Firmin for his help. encouragement and technical advice throughout the long course of this thesis.

Finally, many thanks to my colleagues at work for being patient with me, to Lisa Kalaitzi and her big smile and to everybody who helped me to successfully complete this hard and lonely work.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. CHAPTER ONE

INTRODUCTION

1.1. Background

The history of simulators starts before the Second World War. The first simulators that appeared were flight simulators and were used for training purposes (Morrison, 1991). Flight simulators were used as an adjunct to training conducted in flight. Their use was intended principally to effect a reduction in the overall cost of flight training (Valverde, 1973; Caro, 1973).

Highway research simulators were developed in the late 1950's and the first actual highway simulator was operated in the early 1960's (Roberts, 1980). There was a decline in the highway simulator activity in the mid 60's due to insufficient state of the art in visual displays and computer technology but this was overcome in the late 60's. Much of the technology was developed by the National Aeronautics and Space Administration (NASA) to support its space program. These improvements renewed interest in highway simulation techniques; by 1975 several driving simulators were operating through the United States (at least 16 using different techniques for the generation of the visual field). By that time only two driving simulators were operated in Europe (one at SAAB and one at VW using electronically generated imagery) (Allen, Klein and Ziedman, 1979).

In the last decade, there has been a strong increase in the use of driving simulators for both research and training purposes in the field of driving behaviour. The main reason has been the development of very powerful computer systems and graphics display at a reduced cost. There was also the need to improve our understanding of driver behaviour and therefore improve traffic safety but under controlled experimental conditions specified by the researcher. In the past, such controlled environments have often been unrealistic and their relationship to real-world driving conditions rather tenuous. Advanced driving simulators combine the advantage of full control for the experimenter with a relatively high degree of realism as regard to the driving environment. This means that results obtained are much more likely to be relevant and transferable to the real world.

1.2. Validation of driving simulators

While a driving simulator may have a number of advantages, a central problem is the extent to which driver behaviour in a simulator will be similar to driver behaviour in a "real life" situation. For instance, the advantage of a simulator that subjects are not exposed to any real risk may mean that the subjects in a simulator do not drive exactly as they would drive in a similar real life situation where risk is present. One assumption behind the design of driving simulators is that the more realistic the sensations that a simulator can produce, the higher is the ability to generate behaviour close to real life behaviour. Thus, the optimal driving simulator should be able to reproduce all the information a driver receives through the different senses.

In this context, one important question is if all sensory inputs are of equal importance, or, if some input is more important than others are. Driving is often characterised as a task, which is 90% visual in nature (Mourant, Rockwell and Rackoff, 1970; Charman, 1986; Rockwell, 1988; Rumar, 1988; Dewar and Ellis, 1994). Spare visual capacity when driving has been investigated by several researchers (e.g. Hughes and Cole, 1986a,b; Rockwell, 1988; Wierwille, Hulse, Aritin and Dingus, 1988). It has been established that under many scenarios the visual demands of the driving task remain within the capabilities of the driver (Rockwell, 1988; Wierwille, Hulse, Fischer and Dingus, 1988). Brown (1965) pointed out that driving is a task, which does not require a driver's full attention and that drivers can have spare visual display. Various other studies demonstrate this. For instance on low density roads drivers often look at irrelevant driving-related objects (Rockwell, 1972) and in simulated driving task, subjects spent some time looking at the sky (Hughes and Cole, 1988). However, other sources of information may also be of importance during driving like the auditory information and the kinaesthetic feedback. Auditory information may include the engine, side-wind and tyres sounds whereas kinaesthetic feedback may include the nature of the road surface, accelerations, decelerations and forces experienced during curve negotiations. To date, there are limited number of studies investigating the effect of visual, auditory and kinaesthetic information on subject behaviour when driving the simulator.

Another limitation in driving simulators behavioural validity is that simulators vary in a number of dimensions. One dimension has to do with the number of real car driving sensory impressions that a simulator is capable of presenting. In a real driving situation, a driver will receive information through sensory channels (e.g. visual, auditory, tactile) and gravitational forces. There is not yet any simulator in the world capable of simulating all these sensations, where most can only simulate the visual and auditory feedback experienced during the driving of a real car. Other dimensions have to do with the realism with which different simulators can recreate the information sent to the different senses. Realism is usually measured by the degree to which objects (e.g. houses and other vehicles) in a simulator look and behave like objects in the real world as well as by the degree to which other types of sensations (e.g. sound and tactile information) are perceived compared to a similar real life situation.

To get an indication of the possibility to generalise the results found in driving simulators to real life, it is necessary to have some index on simulators' ability to replicate different aspects of real life behaviour. On the other hand, there has been comparatively little investigation of how drivers behave in a simulator environment compared to the real world. It is therefore not possible to predict with any degree of certainty, that behaviours and responses observed in a simulator accurately represent those that occur on real roads.

1.3. Objectives

The primary objective of this study was to provide researchers with a scientifically-based guide for interpreting driver behaviour results obtained on a fixed-base driving simulator and to provide guidance on how the Leeds Advanced Driving Simulator (LADS) could be modified to overcome any deficiencies that were detected. However, objectives of any simulator validation study are directly related to the specific driving task under investigation, our ability to perform a similar task in the field (for the comparison of the results between the two environments) and the existing configuration/capabilities of the simulator.

To succeed the primary objective, it was decided to investigate driver behaviour at the control level under different road geometry and oncoming traffic conditions using the LADS. The control level was chosen as at this level the most automated action patterns of driving behaviour occur. Longitudinal and lateral control of the vehicle are the characteristics of this level. Therefore, speed and lateral displacement in terms of mean and standard deviation (variation) were chosen to represent driver behaviour. Since, at the time of the experiment, LADS did not have the ability to replicate vertical road alignment and accelerations due to curvature the road environment had to be completely flat. Only free-flowing vehicles were observed to enable measuring driver behaviour at the control level (in any other case, driving manoeuvres like overtaking, car-following, turning would imply investigation of driving behaviour at a higher level). The real road oncoming conditions were also recorded and replicated in the simulator environment in order to investigate the effect of oncoming traffic on driver behaviour at the control level on a rural road environment. A rural A road with moderate traffic flow was chosen as the most suitable road to observe driver behaviour under different road geometry and oncoming traffic conditions.

The objectives of the study were fulfilled by comparing observational uncontrolled real road data with experimental simulator data and by evaluating the differences between the two environments. No such study has been performed before. It is the first time where observational data of genuine road users are compared with simulator subjects' data and road environment (including road geometry, roadside environment and oncoming traffic) is simulated as closely as possible to the real road environment.

1.4. Thesis structure

This chapter sets out the background to the research by introducing driving simulators, their limitation relative to the issue of validity and the objectives of this study. Chapter 2 starts by describing the subsystems of a simulator, its advantages and disadvantages and ends with a classification of driving simulators according to their use and their acquisition cost. Chapter 3 defines the behavioural validation of a driving simulator, describes various methodologies and criteria used by researchers to approach the problem of the behavioural validity of a driving simulator and finishes with a thorough critical literature review of early and recent behavioural validation studies.

Chapter 4 details the methodology followed to validate the Leeds Advanced Driving Simulator in terms of driving behaviour (namely speed and lateral position). Chapter 5 details the field study by describing the methods for collecting data of genuine road users and assesses the best method to be used for the study, the final selection of the road and the data points. It also details the simulator experiment in terms of subject acquisition and recruitment, design of the simulator road environment, description of the Leeds Advanced Driving Simulator, and the experimental design followed for the statistical analysis of the simulator data.

Chapter 6 reports on the descriptive and qualitative analyses of the subjective data obtained from the pre- and post-experiment questionnaires.

Chapter 7 accomplishes the objectives of this thesis through the comparison of the real road and simulator data. It discusses the major findings relative to the absolute and relative validity criteria of LADS and the implications on the design of simulator behavioural validation studies. The final chapter gives a critical appraisal of the experimental techniques utilised to obtain these findings; puts forward recommendations for improving the existing configuration of LADS and includes suggestions proposed for further work.

2. CHAPTER TWO

AN INTRODUCTION TO DRIVING SIMULATORS

2.1. The development of driving simulators

The development of driving simulation techniques is a direct derivative of established technology used in aircraft flight simulation, which was initially developed during the Second World War as a means for safely training pilots (Caro, 1973). The main components of driving simulators consist of a real vehicle cab connected to computers and electronic equipment arranged to provide interactive steering and speed control for the driver as well as the visual scenery. Generally the simulation is controlled by a host computer that monitors the simulation operation, controls the scenario and traffic event sequences and measures and records driver performance in the driving task. For a review of technical characteristics of the most known driving simulators around the world see Allen et al, 1979; Weir and Clark, 1995 and Blana, 1996a. The main subsystems of a simulator are described in detail in the following subsections.

2.2. Key elements of a driving simulator

2.2.1. Modified car

Most of the simulators use an actual vehicle that has been modified. In some cases part of the car (e.g. rear or front) has been removed, for example the TNO and VTI driving simulators (Hogema, and Hoekstra, 1998; Nilsson, 1989). Some driving simulators have the ability of exchangeable simulator cabins (cars, trucks, tractor cabs), for example the Daimler-Benz driving simulator (Käding, 1995) and the National Advanced Driving Simulator (NADS) (Papelis, 1998a) –see Figure 2-1 below. The brake, accelerator pedal, gear selector and other controls need to have feel-characteristics consistent with task requirements. Secondary vehicle controls such as radio, climate control, turn signal etc. are only instrumented if the study requires them. The interior compartment and driver workspace needs to be relatively complete, with details depending on the task. The steering wheel needs to have a "feel system" (or control loader) to simulate the kinaesthetic and force displacement properties of the subject vehicle (a torque motor can be connected into the steering wheel).

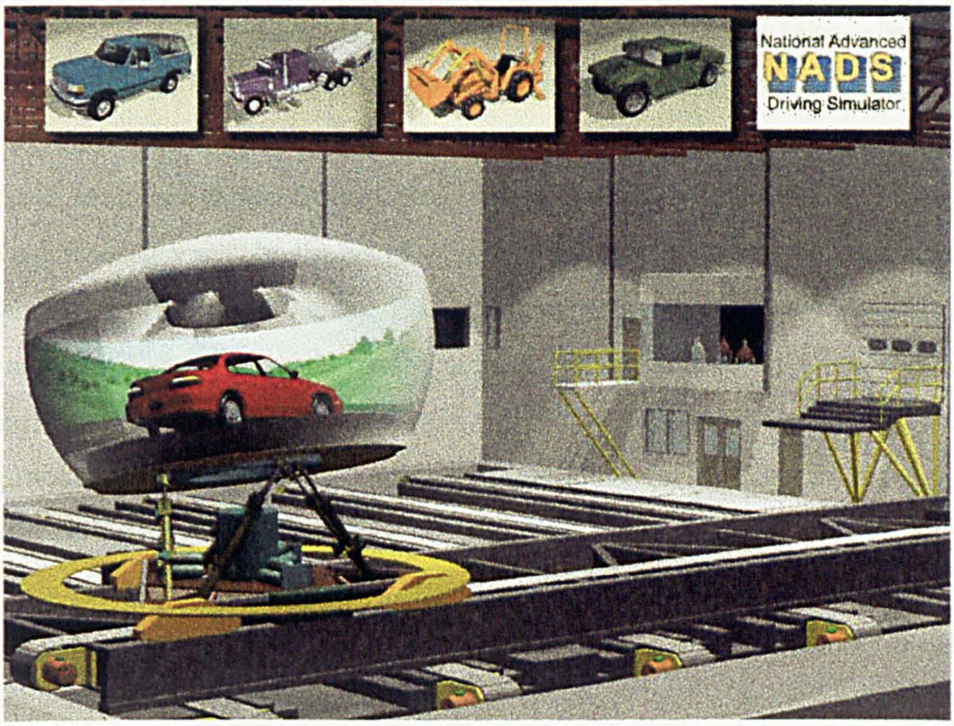


Figure 2-1 NADS driving simulator different cabs – artist's view

2.2.2. Visual system

Various visual display systems have been used since the development of the first driving simulators. In terms of increasing capability for presenting image complexity the simplest technique is the Cathode Ray Tubes (CRT) line drawings. They can be generated rapidly by means of electronic circuit, and intensity control can be used to obtain the desired image brightness. Projection screens can be used to present large-sized displays (Wierwille, 1973; Lincke, Richter and Schmidt, 1973; Donges, 1975). Point-light source techniques provided an alternate approach to simple display generation but tended to be limited in their capability to reproduce photometric conditions (Shuttel, Shumacher and Gatewood, 1971). In motion picture display simulators, film taken on a roadway was projected in some way for viewing by the subject (Hulbert and Mathewson, 1958; Beinke and Williams, 1968). Speed could vary by changing projector speed. The display image of the scale model simulators was achieved by means of a closed-circuit television and a movable camera (Weir and Wojcik, 1971; TNO, 1978). To date digital computer graphics imagery (CGI) systems are used mostly. They typically consist of a graphics/animation model and a projection system The first digital CGI for driving simulators was used by Southern California Research Institute (Allen et al, 1979).

Critical issues for a computer generated image system are update frequency and refresh rate, aliasing and delay in the displaying system. Update frequency is the frequency with which a totally new image content is generated (AGARD, 1981). Refresh rate (also called frame rate) is the frequency with which a whole frame of the display is written (Rolfe and Staples, 1986). A low update frequency causes shaky moving images or distortion of contours; a low refresh rate causes luminance flicker. Generally the refresh rate is kept at a fixed frequency, whereas the update frequency may be the refresh rate divided by a whole number, depending on the scene complexity (Rolfe and Staples, 1986). Maximum update frequency in a CGI system of given computing speed depends on the number of polygons to be processed. For many applications, an update frequency of 30 Hz will suffice. However, for simulation of critical driving tasks (e.g. hard braking) update frequencies of 60Hz or higher may be required (Riemersma, 1987; van der Horst, 1990).

The term aliasing means the distortion of contours as a consequence of the image representation in discrete pixels (Padmos and Mildres, 1992). It causes flickering of far objects when their apparent size approaches pixel definition. Image anti-aliasing techniques can be used to avoid this problem (Magnenat-Thalmann and Thalmann, 1987). Total image delay (or dead time) in the display system consists of a combination of the sampling time of the cabin controls, the time for calculating a change in viewpoint in the vehicle dynamics model, and the net image delay (Padmos and Mildres, 1992). The net image delay is the time between a new viewpoint position input from the host computer to the CGI system and the writing of the full corresponding image frame. A large image delay may cause instability of vehicle control and also may promote simulator sickness (Frank, Casali and Wierwille, 1988). Most of simulator computer engineers seem to agree that delay may vary between 40-100 milliseconds in order not to disturb driver-vehicle performance (Allen and Jex, 1980; Drosdol and Panik, 1985; Ashkenas, 1986; Haug, 1990). Hogema (1992) studied the effectiveness of a compensation technique as a measure to counterbalance delay and showed that the technique reduced the effect of delay to an insignificant level.

The appearance of surfaces depends on level of detail (LOD) and texture. LOD is a feature that minimises polygons to be calculated while keeping the number of visible details on objects sufficiently high. The LOD feature is important for simulator driving since it is often desirable to display many details at a short distance. Texture means all structures that may be depicted on a flat surface (polygon). For example texture may include text on a traffic sign or the façade of a house. The advantage of texture is that it makes it possible to provide many details in a scene with a restricted use of polygons. Texture mapped polygons can also be used as a depth reference to describe object details, but their intensive use may result in false visual cues and simulation sickness.

According to Olson (1993), most of the information used by the automobile driver comes from close field of view and concerns sharp details (signs, lights and objects). Thus the need for required (limiting) resolution for driving simulators should be high. Resolution is the power of a system to make small details visible. Required resolution is determined by the size and distance of objects or details that are critical for the subject's performance (e.g. timely reading of text on signs, overtaking cars on road ahead). Ideally the limiting resolution should be at least equivalent to the subject's acuity (Padmos and Mildres, 1992). For a fixed pixel capacity of an image generating system, it follows that a high resolution can be obtained only at a small field size. For large field size, a solution for this problem is to have a higher resolution screen in the central image field that decreases toward the edges (Geltmacher, 1988). This technique is followed, in the TRL (Duncan, 1995) and UMTRI (Reed and Green, 1995) driving simulators. A resolution of about 1000x1000 pixels per channel is suitable for the representation of traffic and road network details in simulator driving (Kemeny and Reymond, 1994).

A review of the existing visual display systems both for car and truck simulator is given by Blackham (1999). The key factors for designing such systems are: cost v. performance; resolution, luminance and contrast; scene continuity; image distance and its variability. Maximum desirable field size is dependent on the field size available in the real vehicle and on the task to be performed. A minimum acceptable degree of realism is obtained at a field size of 50x40 degrees (Haug, 1990). For tasks such as lane-changing, merging, seeing traffic approaching from the side, or making a right turn at a crossing (left in England), fields up to 180 degrees horizontally are required (Haug, 1990; Körteling, 1991). Problems related to the projection system include the soft-blending of the different projected images and the illumination of the screen. One of the principal shortcomings of projection-based visual systems is that they are dim. Although state of the art projectors may specify light output as 1000 lumens, whole scene illumination for a typical computer generated image may yield closer to 300 lumens (Greenberg and Park, 1994). Absolute light levels in the simulator are low, optical resolution is well below the human detection threshold, and the image focal plane is at a fixed distance. These limitations are significant in constraining the experimental design. Signs must be simplified or adjusted in size for readability and recognition distance.

Other limitations relate to the perception of depth and motion. For adequate control of a vehicle, perception of depth, self-motion, and motion of other vehicles is generally required (for more information readers are referred to publications of Graham, 1965; Hochberg, 1971; Wickens, Todd and Seidler, 1989 and Warren and Wertheim, 1990). The visual software does not allow the driver to perceive absolute distances (Boff and Lincoln, 1998).

2.2.3. Motion system

The motion system is usually ruled in or out depending on a cost-benefit point of view for the research topics of primary interest and can be classified either as high-cost or low-cost. High cost motion systems consist of a dome (where the car cab is situated) and typically have six degrees of freedom like the Iowa Driving Simulator and the Daimler-Benz driving simulator (Stoner, 1994; Käding, 1995 respectively) (see Figure 2-2 below). Low-cost motion systems consist of a platform (hydraulic rams or pneumatic are fitted into the four corners of the car cab) and usually simulate roll, pitch and heave (e.g. TRL driving simulator, Duncan, 1995).

The critical question is whether the research application areas of driving simulators can justify the investment in moving-base systems. The effects of motion cues on driver performance are not exactly known yet. Most early research on the effects of motion cues was performed with flight simulators. Generally in flight simulation, favourable results were found with moving bases (Stapleford, 1968). Brown (1975), showed that the simulator became much more realistic with the addition of a physical vibration that was absolutely uncorrelated with vibrations observable in the visual display. On the other hand, there have been questions concerning the efficacy of motion cues in military simulators (Caro, 1973; Semple, 1981). Alm (1995), showed that when the moving system was "on" drivers behaved more realistically (especially driving on curves) and they were better able to keep a steady course on the road compared to when the system was "off". Casali & Frank (1986) and Casali & Wierwille (1986) found that high fidelity simulators seem to induce simulator sickness whereas Alm (1995) and Soma, Hiramatsu, Satoh and Uno (1996) found that they decrease simulator sickness.

Figure 2-2 The motion system of the Daimler-Benz driving simulator

2.2.4. Auditory System

McLane and Wierwille (1975) investigated the effects of the presence of speed-related sounds. No statistically significant effects of the presence of audio cues were found, but they suggested that an advantage of sound information might be that irrelevant noises generated by the simulator system are masked. Davis and Green (1995), twenty years later verified the above results since they found that there were no differences in the ratings of realism of the simulation between sound conditions and the provision of sound may lead to small ("marginally significant") improvement in driving performance. In addition, there were several situations where driver performance was worse when all sounds (namely engine sounds at different levels of rpm; wind sound; normal road/tyre sound; tyre squeal; and a shoulder sound used to indicate that the vehicle was past the road edge) were present as opposed to when only speed-related sounds (all sounds besides tire squeal and shoulder sound) were provided.

2.3. Usefulness of driving simulators

Driving simulators are valuable tools both for research and training. They can be easily and economically configured to simulate a variety of human factors research problems. They allow evaluation and optimisation of human performance within system constraints and indicate problem areas in system design and functioning. They are particularly useful in selecting a viable system approach from numerous alternatives (e.g. different in-vehicle navigation systems, different road layouts for toll-posts) and evaluating system performance before field testing. Different simulation scenarios can be created to match the requirements of the particular experiment. Environmental effects such as foggy roads, snowy or slippery roads or night-time driving conditions can be created. Vehicle characteristics can be altered quickly – steering ratios, spring rates, damping factors, driven wheels. New roadways can be created in the simulator where the test situation is difficult or impossible to create on the road.

Driving simulators can often represent the most cost-effective approach in a given application. In particular, stimuli and events external to the driver's vehicle are substantially cheaper to implement, control and vary in a simulator than they are on a test track. Simulators make it possible to control experimental conditions over a wider range than field tests and can be easily changed from one condition to another, thus allowing back-to-back comparisons of disparate experimental conditions. Criterion variables can easily be made available in a driving simulator. Many performance measures can be easily mechanised. Digital computer systems can further provide on-line data processing, formatting and storage and the reduction and compact arrangement of data.

Simulators provide an inherently safe environment for driving research. There is no endangerment to the driver or other road users under critical driving conditions or when testing innovative in-vehicle devices. They can be used where approval for an on-road experiment is unlikely to be forthcoming from the relevant authorities without some prior evidence on behavioural and safety issues. They also can be used for studies of driver impairment (fatigue, alcohol). However, the social and economic pressures that may lead to unsafe real road driving are absent in the simulator. Although monetary penalty/reward schemes can been used to create a motivational basis for behaviour in the simulator, it is not clear that this will result in correlation with behaviour in the target environment. The penalty and reward structure that motivates driver behaviour is substantially altered in the simulator (Greenberg and Park, 1994). Allen, Mitchel, Stein and Hogue (1991), also noted the critical issues of "operator motivation" and traffic scenarios in the simulator. Traffic scenarios can have a strong influence on the "realism" of the simulation and thus some influence on subject motivation too. They suggested that "*incentives must be set up creatively in order to* *minimise game playing and generally encourage speed/accuracy trade-offs consistent with real world conditions*".

Factors affecting the use and credibility of research driving simulators are the issues of validity, the acquisition cost and simulator sickness. It is well accepted that research simulators will never be able to replicate the real world in all its complexity. Research driving simulators have a high initial acquisition cost. In addition, operating and maintenance costs are slightly higher than for training simulators because research simulators are more complex. Simulator sickness can vary widely among individuals who experience it and among simulators that induce it. Effects may range from mild disorientation and nausea to full emesis (vomiting). The most critical variables are the visual horizontal field-of-view and the level of moving scene detail, which seem to increase simulator sickness (Casali and Wierwille, 1986; Frank, Casali and Wierwille, 1986).

2.4. Application areas and cost of driving simulators

Driving simulators can be either fixed-base or moving-base and they usually use digital computer generated imagery. Advancement in PC (Personal Computer) and associated technologies are dramatically reducing the cost of creating realistic driving environments. Increased understanding of the computational requirements in simulating the driver tasks allows for enhancement of the realism and validity of the simulation sensory environment. The extent of the applications depends on the realism, validity and cost of the simulations as well as their objective (training or research driving simulators). The objective of the training simulators is to impart some new skill on the subject. For the research simulators, rather than receiving training, the subject is instead part of an experiment in which their driving behaviour is studied (human factor studies).

Training applications often utilise a simulator to reduce the risk of training in an actual environment or when training is necessary for situations that are hard to recreate in real life. Examples could be for basic vehicle operation, conversion between vehicle types, emergency services (e.g. police pursuit) and post-injury rehabilitation. Decision-making situations that involve such factors as interactive traffic, route guidance and signalised intersections could be contrived to exercise students' perceptual and cognitive driving skills and to encourage defensive driving techniques. However, a significant research program, including studies of the transfer of training to real world conditions will be required to validate the effectiveness of simulator training for driver education. Training driving simulators are used today for training truck drivers (Boidin, 1994, 1997; Kelada, Kemeny and Lailler, 1997; Weiler, Henschen and Kuhlmann, 1997).

Human factors studies when limited to transportation, includes the study of the driver when interacting with the vehicle, the road environment and generally the overall transportation infrastructure. Simulators have already been used to investigate numerous human factors issues related to civil engineering, transport, psychology and ergonomics fields. These include innovative road design (e.g. testing the design of new tunnels, innovative highway design and road delineation, traffic calming); intelligent transport systems (e.g. new in-vehicle navigation systems, Head-Up-Displays, active pedals); impaired driver behaviour (driving behaviour affected by drugs, alcohol, severe brain damage, fatigue); vehicle dynamics and layout (e.g. testing ABS, 4-wheel drive; vehicle interior design) and driver support and vehicle control systems (e.g. AICC: Autonomous Intelligent Cruise Control).

Virtual proving ground prototyping (Haug, Cremer, Papelis, Solis and Ranganathan, 1998) is a relatively new use of advanced driving simulators and refers to the utilisation of a driving simulator in lieu of an actual model for the purpose of conducting engineering design of a vehicle or a vehicle component.

Driving simulators can be classified as low, medium and high-cost simulators according to their acquisition cost or low-level, mid-level and high-level according to the capabilities of their software and hardware (Weir and Clark, 1995).

Low-cost simulators are PC-based. In the recent years, as the capability of PCs and associated technologies has increased, it has become possible to develop new low-cost simulations which can provide relatively high-end capabilities in the visual, auditory and control-feel cueing (Allen, Rosental, et al, 1998; Stein, Allen, et al, 1995). PC-based simulators have been developed in a wide variety of configurations from desk-top versions to multiple-window, wide-angle displays used in conjunction with car and truck simulators (Allen, Rosental and Aponso, 1999).

Medium-cost driving simulators employ advanced imaging techniques (using real-time animation to create a scene that is projected in front of the driver) using workstations than

PCs, a large projection screen, a full-sized and complete vehicle with all the normal controls. Low and medium cost driving simulators can be either fixed-base (no kinaesthetic feedback) or can provide trivial motion feeling. This is achieved by using either systems which simulate the normal vibrations experienced while driving and provide minimal car cab pitch for each corner of the car cab, or limited capabilities motion system like the one of the TNO driving simulator (Hogema and Hoekstra, 1998).

High-cost driving simulators provide an almost 360 degree field of view and an extensive moving base (e.g. the NADS driving simulator, Papelis, 1998a). The motion system may include a hexapod with more than six degrees of freedom and it is usually built using the aircraft flight simulators' technology but not necessarily (e.g. the VTI driving simulator, Nilsson, 1989; the Mazda driving simulator). The translational motion capability can be greater than 2m (Weir and Clark, 1995). They usually employ hardware and software of advanced capabilities (for examples see Papelis, 1998).

Cost justification is quite different between training and research simulators. For training, the balance of justification on cost-effectiveness alone is very difficult, as today all training is performed successfully on the real vehicles, whilst the cost of a simulator of sufficient fidelity usually far exceeds the cost of the vehicle it simulates. The exception here, which itself probably represents the most immediate opportunity for viable training simulation, is where the end-user is not the general public but rather a "specialist user" (e.g. police; military vehicles; HGV, cranes, earth movers). In this case, the vehicle is very expensive; often training may be unacceptable in the real vehicle; simulation is valued for the "normal" reasons that it does not excel in; there is weather variation, dangerous situations, environmental considerations.

2.5. Criticism on driving simulators

Driving simulators, whatever their use and/or cost are usually "home-made", i.e. each university, research institute, automotive industry builds their own machine according to their own research needs. Most of the times the software is also developed to cover their respective needs (related to the task(s) and/or device(s) under investigation). There are no standards for the development and operation of driving simulators, no thresholds determining their validity, nor a formal categorisation of the different types of simulators existing today according to their hardware and software capabilities. It is extremely difficult to buy an "off-the-shelf" research simulator, since the simulator is an integration of subsystems and even more difficult to run and maintain it in a cost-effective way. Usually, it is the software that dominates the cost of a simulator. Customised and/or specialised software is limited, the one that exists usually confines the user/operator to comply with the abilities of the provided software and do not allow any interference (upgrading) to it. The paradox of having affordable hardware but software of whose capabilities do not make full use of the available hardware tends to become a common practice today. Finally, whatever the cost of the "off-the-shelf" simulator, the customer cannot be sure for the validity of the simulator because the supplier cannot provide any relative standards and/or thresholds. The urge for developing tests to measure simulator validity will emerge in the next years when the technology used for simulators will be even cheaper than it is today and more people will wish to use simulators for research or training purposes.

The National Advanced Driving Simulator (NADS) in Iowa, United States is the most expensive simulator under development to date. It is still not in operation and its budget is equivalent to the budget of tens of high-cost (type e.g. VTI or Daimler-Benz), hundreds of medium-cost and thousands of low-cost driving simulators. It is not known if it runs cost-effectively when it will operate and there were numerous objections in US from various authorities, researchers, universities and private companies for the investment of such an enormous capital in a single driving simulator.

As Evans (1991) stated, the fact that a less sophisticated driving simulator could lead to the same valid results for a particular type of application should always be considered. Therefore, the question of the degree of capabilities (in terms of software and hardware) in relation to the use of the simulator emerges. The author's tried for the past 2 years to develop a driving simulator in Greece. Greece is the European country with the worse accident rate and of the worse road driving attitude and behaviour, therefore a driving simulator should be its top priority both for research and training. A rough estimation of the annual cost of road accidents to the Greek state using 1996 prices is 344 million ECU (ELPA and NTUA, 1999). On the other hand, the cost of a medium-cost driving simulator (i.e. with a limited motion system) is equal to the hospital and insurance costs of 200 injured people in road accidents in Greece. Having in mind that approximately 250 to 300 people are injured every weekend in Greece and the annual cost of accidents, it is obvious that the cost of a simulator should not be the major issue (Blana, 1998).

However, the feasibility study conducted for the capability to sponsor and use a driving simulator in Athens, did not give very positive results in terms of sponsorship (ELPA and NTUA, 1999). The study was based on a questionnaire and personal interviews of private and public sectors relevant to road safety in Greece (e.g. Ministries, Local Authorities, Universities, hospitals, automotive companies, software and hardware private businesses, insurance companies, and road safety experts). It was agreed by all sectors that driving simulators are useful tools to enhance road safety. They can contribute to the decrease of road accidents by studying driver behaviour (66% private companies; 70% insurance companies and private research institutes; 80% universities and 100% ministries and local authorities). They can improve the training of both novice drivers and instructors (66% private companies and ministries; 70% insurance companies; 85% universities and private research institutes and 100% local authorities). They can decrease the construction cost of innovative road design (66% private companies and ministries; 75% insurance companies; 85% universities and private research institutes and 100% local authorities). Subjects were also asked their opinion about the use of driving simulators from universities to support research related to road safety. Only 33% of the ministries and 50% of the local authorities believed that the use of driving simulator by universities would enhance research on road safety (the percentage for all other sectors varied between 66% and 80%). This means that the Greek state does not seem very willing to support and sponsor the development and operation of a driving simulator in Greece operating by a university.

In addition, it was found very difficult and almost impossible to convince private sponsors to invest even on a low cost simulator (approximately 70,000 ECU including PCs and 3 17'' monitors, vehicles dynamic model and graphics model). They claimed that such a simulator does not provide any valid results in terms of driving behaviour and they compared this type of simulator to a SEGA game! As no validation studies have been performed in low-cost simulators, there was no way to prove to sponsors the validity of such simulators.

This does not mean that driving simulators are not valuable tools for the improvement of road safety. Still it is a good example to demonstrate the necessity for more research in the area of simulator validity, standardisation and commercialisation.

2.6. Chapter summary

The main advantage of driving simulators is that they can provide an inherently safe environment for driving research, which can be easily and economically configured to investigate a variety of human, behavioural and engineering factors research problems. They also make it possible to control experimental conditions over a wider range than field tests and can be easily changed from one condition to another. They are linked to digital computer systems, which can further provide on-line data processing, formatting and storage and the reduction and compact arrangement of data.

On the other hand, driving simulators provide drivers with an artificial environment, which could never be the same as the real one. The differences between the simulator and the real driving environment may influence subjects' driving behaviour and performance. Hence any performance measurements observed in a driving simulator may differ from the same measurements observed during real driving. Therefore, the issue of evaluating the driving simulators emerges in order to ascertain how far they produce transferable, reliable, and valid results.

3. CHAPTER THREE

A REVIEW OF BEHAVIOURAL VALIDATION STUDIES

3.1 Introduction

The existing validation approaches, methodologies and criteria will be analysed and earlier and recent behavioural validation studies will be reviewed and compared in detail. Emphasis will be given to the interpretation of the findings from these comparisons and in particular to their applicability in real-road traffic situations. As an introduction to these studies, the definition of validity and its different types will be presented first so that the reader will be already familiar with these terms as s/he reaches the presentation of the validation studies.

3.2 Behavioural validity of driving simulators

Defining the validity of a driving simulator is a multi-disciplinary and complicated task. Mudd (1968) defined validity as the way in which the simulator "*reproduces a behavioural environment*", where according to Allen et al (1991) "*validity is only defined to a specific research question*". Rolfe, Hammerton-Frase, Poulter and Smith (1970) stated that "*the value of a simulator depends on its ability to elicit from the operator the same sort of response that he would make in the real situation*". According to Leonard and Wierwille (1975) "*simulator validation is a problem of obtaining parallel measures in full-scale and in simulation and bringing these two sets of measures into correspondence*". It is clear that the term "validity of a driving simulator" is not precisely defined and needs further specification.

On the other hand, validity from the standpoint of psychology is widely used for the assessment of psychological tests, and there are already standards relative to the validity of a test. Validity refers to the appropriateness, meaningfulness, and usefulness of the specific inferences made from test scores. Test validation is the process of accumulating evidence to support such inferences. Traditionally, the various means of accumulating validity evidence have been grouped into categories called content-validity, criterion-related and construct-related evidence of validity (American Psychological Association, 1985). However, psychological tests have not been developed for investigating human performance that is confounded with system performance and unfortunately driving simulators are man-in-the-loop systems. A literature review of the typical psychological measurement assessment theory and its application to driving simulators showed that it has proven extremely difficult to apply the psychological definitions of validity to driving simulators (Ebel, 1961; McCoy, 1963; Blana, 1996b).

"Behavioural validity" of a driving simulator could be defined as the comparison of driving performance indices from a particular study on a real road with indices from an experiment in a driving simulator which are as close as they can be to the field study.

The issue of behavioural validity was not addressed before 1975 for driving simulators because they were still in the developing stage, but it was already a problem for aircraft simulators. However validity had been addressed in terms of fidelity and its effects on transfer of training (Mudd, 1968; Blaiwes, Puig and Regan, 1973; Caro, 1973; Provenmire and Roscoe, 1973; Valverde, 1973; Williges, Roscoe and Williges, 1973).

3.2.1 Driver performance, driver behaviour and driver behaviour levels

Driving is a "*self-paced*" task (Näätänen and Summala, 1976). In other words, drivers choose their own desired levels of task difficulty. For example, although there are general restrictions in terms of compliance to the speed-limit and keeping the vehicle between the road delineation, the driver has a lot of freedom in determining how to perform the driving task. The driver can adapt the driving speed in case information processing demands are high, or increase the amount of swerving they allow themselves. This means that driving speed chosen or accuracy in lane-keeping are adapted by the driver, not only on the basis of external demands but also dependant upon strategy and self-set goals.

Driver behaviour is what drivers do at a particular moment and it relates to the particular psychological and physical condition of the driver (internal variables) as well as to the particular road environment and traffic conditions (external variables). On the other hand, driver performance relates to what a driver can do generally but his/her abilities to do so can change according to various factors and parameters associated to him/herself and the external environment. According to Näätanen and Summala (1976) "*crucial to traffic safety is what the driver actually will do in a given situation, rather than his maximal level of performance* *and the environmental demands*", therefore driving simulators are the most suitable tools for investigating driving behaviour. Occasionally these measures (driver behaviour and driver performance) are confused in literature.

Traffic psychologists have tried to develop driver behaviour models and theories that could assist to the interpretation of driver behaviour. Janssen (1979) defined three driver behaviour levels –strategic, tactical and control, which were later adopted by Michon (1985). Rasmussen (1987) presented a hierarchical model, including knowledge, rules and skills. He defined eight steps with the decisional process and linked them with potential errors that can occur. Huguenin (1988) based driver behaviour on three levels: (i) the dispositional level including "driving suitability", "driving qualification" and "driving capability", (ii) the action level including action determinants such as "attitudes", "information assimilation" and "motor skills", (iii) the situational level including routine and complex situations which accordingly affect the individual in different ways, depending upon their complexity. Reason (1994) based on the Rasmussen's model presented a Generic Error Modelling System differentiating between knowledge-, rule- and skill-based errors. Ranney (1994) adapted his classification of driving tasks after Janssen (1979) defining knowledge, rule and skill for each of the three driver behaviour levels (strategic, tactical and control). It becomes evidence that most of traffic psychologists based their theory or model on Janssen's three level analysis of driver behaviour.

The contribution of traffic psychology models to the understanding of the driving task is rather questionable (Grayson, 1997). Problems relate to the dichotomization of theory and practice (Deutsch and Krauss, 1976); indifference towards theories (Feyerabend, 1978); individual results are placed alongside each other in an unrelated way and the benefits of a theory which would integrate this knowledge remains unexplored (Huguenin, 1997). As Huguenin (1997) stated "*understanding the complexity of road-user behaviour remains at the forefront of the problems which must be solved before useful models can be created. That is why approaches range from empirically insufficiently comprehensible meta-theories to laboratory-tested models concerning certain aspects of the overall behaviour of the driver*".

Driver behaviour of this validation study was based on Janssen's (1979) model and in particular on the control level as this is defined in the following paragraph. Each level is defined by different action patterns and a different "preview" which is the time in which the events, that are correlated with and dependent on the behaviour in the actual situation, will take place.

The strategic level is mainly related to the process of route planning, and following of a route using various means of route information. The preview can be as long as the whole drive. The driver is fully aware of the different tasks. Usually in-vehicle navigation systems are tested in the simulator at this level. The tactical or manoeuvring level is mainly characterised by manoeuvring behaviour. The preview is of the order of seconds to a few minutes. The assimilation of information, and decision-making, are more conscious than at the control level. Simplified in-vehicle information systems, mobile phones, speed limiters can be tested in the simulator at this level. The control or operational level defines automatic action patterns. The tasks, which are situated here, have the purpose of adjusting the position of the vehicle on the road both in longitudinal and lateral directions. In this instance the "preview" is of the order of a few seconds or less. New road design, impaired driving and experiments which are directly related to the longitudinal and lateral control of the vehicle (e.g. testing adaptive cruise controllers) are tested in the simulator at this level.

Relative to the use of the three driver behaviour levels in recent behavioural validation studies, about equal number of researchers used the control (Blaauw, 1982; Tenkink, 1989a,b, 1990; Tenkink and van der Horst, 1991; Kappé and Körteling, 1995; all three VTI validation studies by Harms, 1993; Alm, 1995 and Harms, Alm and Törnos, 1996) and tactical level (Alicandri, Roberts and Walker, 1986; Hogema, 1992; Boulanger and Chevennement, 1995; Duncan, 1995; Malaterre, 1995; Reed and Green, 1995; Kaptein, van der Horst and Hoekstra, 1996) to investigate driving performance in the simulator and in real life. The strategic level is rarely used (e.g. the validation study in TNO driving simulator by Janssen, van der Horst and Hoekstra, 1991; 1992a,b). The use of questionnaires on the subjective realism of the simulator and mental workload is not a common practice by researchers (Blaauw, 1982; Alm, 1995; Duncan, 1995; Malaterre, 1995). This suggests that face validity may not be such an important factor for most researchers regarding the validity of the simulator. On the other hand, researchers of the early behavioural validation studies considered face validity an important factor (Wheaton, Kinslow and Krumm, 1966; Leonard and Wierwille, 1975).

3.2.2 Most commonly used performance criteria in validation studies

One of the difficult challenges posed by driving simulation is the question of which variables to measure and analyse, especially during a validation study. It is usually assumed that all types of real road environment cues (e.g. visual information, sound, self-motion) are provided more or less in the simulator. However this assumption is not always correct since it depends on the fidelity of the cues provided and the capabilities of the simulator itself. In addition drivers rarely use all the available cues to perform a task (Flexman and Stark, 1987), thus it is not always necessary to provide in the simulator identical cues to those of real life. The way the measures are actually chosen in a study are strongly dependent on the hypothesis to be tested in that specific study and can be any variable in the simulator model. Physiological measures can be used, although more seldom, to monitor the physical and mental stress of the body from the environment (e.g. pulse rate, blood pressure etc). Other miscellaneous measures include ordinary questionnaires and interview procedures to detect the participants' subjective opinions and evaluation concerning the test task, conditions etc.

The most frequently used driving behaviour measures in a simulator study are:

1. driving speed (used by Blaauw, 1982; Alicandri et al, 1986; Tenkink, 1990; Tenkink and van der Horst, 1991; Harms, 1993; Duncan, 1995; Harms et al, 1996) and speed variation (used by Riemersma, van der Horst and Hoekstra, 1990; Harms, 1993; Alm, 1995; Boulanger and Chevennement, 1995; Duncan, 1995; Reed and Green, 1995; and Harms et al, 1996);
2. lateral position and lateral position variation (used by McRuer and Krendel, 1974; McLane and Wierwille, 1975; McRuer and Klein, 1976; McRuer, Allen, Weir and Klein, 1977; Blaauw, 1982; Tenkink, 1990; Harms, 1993; Alm, 1995; Reed and Green, 1995; and Harms et al, 1996);
3. steering wheel angle and the steering wheel torque (used by McRuer and Klein, 1976; Blaauw, 1982; Alicandri et al, 1986; Hogema, 1992; Harms, 1993; Reed and Green 1995);
4. braking performance and gap acceptance (used by Duncan, 1995; Kaptein, Theeuwes and van der Horst, 1995; Malaterre, 1995; and Staplin, 1995) and as an additional measure to the above driving performance measures;
5. mental workload (using the NASA-TLX or built-in-house questionnaires to check this aspect) (used by Alicandri et al, 1986; Malaterre, 1995; Alm, 1995; Duncan, 1995; and Reed and Green, 1995).

Speed- and time-control directly determine mobility, one of the basic high-level goals in transportation (Summala, 1996). Speed serves as a primary control tool through practically all the guidance task levels; the driver learns for example to adjust speed to maintain lane position and following distance (Lee, 1976; Godthelp, Milgram and Blaauw, 1984; Summala, 1994). The standard deviation of lateral position (SDLP) and steering wheel measures are examples of primary-task performance measures (McLean and Hoffmann, 1975; O'Hanlon, Blaauw and Riemersma, 1982). In particular, the ability of the driver to control weaving the car, measured as SDLP, appeared to be a very sensitive indication of drug-induced sedation (O'Hanlon et al, 1982; Brookhuis et al, 1991).

Braking performance refers to Time-To-Collision (TTC). TTC is defined as the time that remains before reaching an obstacle, and thus the time available for taking action. It is considered to be a crucial parameter in controlling avoidance behaviour. TTC is involved in complex judgement tasks such as overtaking or left-turns manoeuvres; braking (van der Horst, 1991); trajectory control (Gothelp, Milram and Blaauw, 1984); car following (Cavallo, Bardy and Laurent, 1991; Ohta, 1993; Hoffman and Mortimer, 1994; van Winsum and Heino, 1996), traffic merging conditions (van Wolffelaar, Rothengatter and Brouwer, 1991), curve taking (Cavall, Brun-Dei, Laya and Neboit, 1988), stop-or-go decisions at intersections (Groeger, Grande and Brown, 1991).

The concept of mental workload is important for investigation of the usability and acceptability of new information technologies by the human operator. It is not clearly defined and is used in distinctly different ways by different authors. One of the possible definitions is that it is the ratio of the task demands to the average maximal capacity for each individual, i.e. the workload is not only task specific but also person specific (Rouse, Edwards and Hammer, 1993). The individual maximal capacity is related to the motivation to perform a task, to the strategies applied in task performance, as well as to operator's mood and state (De Waard, 1996). The NASA-TLX method (Hart and Staveland, 1988) assumes that the workload is influenced by mental demand, physical demand, temporal demand, performance, frustration level and effort.

3.3 A review of driving simulator validation approaches, methodologies and criteria

A review of driving simulator validation approaches, methodologies and criteria is presented in the following sections. It should be noted here that researchers use the term "driver behaviour "and "driver performance" interchangeably (i.e. there is a clear confusion between the two terms).

3.3.1 Driving simulator validation approaches

The validity of a simulator can be approached through two main concepts:

a) The correspondence between the real vehicle and the simulator car and

b) The correspondence of driver behaviour between the real and the simulator road environment.

The correspondence between the real vehicle and the simulator car centres on a model-matching procedure in which the dynamics of a given vehicle are represented in the form of equations of motion to be matched by the simulator. It has been called "analytic evaluation" (Mudd, 1968; McCormick, 1970); "physical correspondence" (Brown, 1975; Blaauw, 1982); "open-loop technique" (Bertollini, Johnston, Kuiper, Kukula, Kulczycka and Thomas, 1994) and "face validity" (Moraal, 1981; Alicandri et al, 1986).

The correspondence in driver behaviour between the two environments centres on the comparison of performance differences between the simulator and the real world under similar conditions and the rating of accuracy/realism of simulation by means of subject commentary and/or rating scales. It has been called "empirical evaluation" (Mudd, 1968; McCormick, 1970); "behavioural correspondence" (Brown, 1975; Blaauw, 1982); "closed-loop technique" (Bertollini et al, 1994); "functional validity" (Moraal, 1981; Alicandri et al, 1986) and "man-in-the-loop validation" (Allen et al, 1991). Table 3-1 summarises the ways these two approaches were followed by various researchers. It is clear that researchers proposed exactly the same procedures for the behavioural and physical validation of a simulator, they just used different wording.

Allen et al (1991) distinguished the conditions under which the real road experiment takes place when referring to the comparison of performance differences between the simulator and real road environments. These can be either controlled experimental or uncontrolled observational conditions. They suggested that when simulator data are compared to uncontrolled observational real road data, then this method "*might be considered the highest form of validation*".

Both behavioural and physical correspondences are important for the successful validation of a simulator and have been mentioned in all approaches to the validation of simulators. Generally the behavioural correspondence is assumed to be more important for the validity of a simulator for a specific task. Blaauw (1982) stated that the two aspects of validity do not have to be necessarily related. However the author believes that the level of physical correspondence between the simulator and the actual car should at least be known. Physical correspondence can minimise the internal variability due to the simulator configuration that may affect behavioural correspondence and facilitate the interpretation of results obtained from the behavioural correspondence.

Allen et al (1991) mentions also the **"cognitive and/or perception correspondence"** between real road and simulator driving. According to Michon (1985), the unsatisfactory cognitive approach to the real driving task from most of the driver behaviour models could be due to the lack of new, "striking" ideas about this topic and thus lack of money to support this type of research. A study was conducted using the Leeds simulator to take into consideration not only the behavioural and physical correspondence but also the perceptual correspondence by investigating the perception of speed and distance when driving the simulator (Groeger, Carsten, Blana and Jamson, 1997).

Table 3-1 Summary of driving simulator validation approaches

Researchers	Approaches		
Mudd (1968), McCormick (1970)	**Empiric evaluation** 1. operator commentary and/or rating scales 2. evaluation transfer effects		**Analytic evaluation** 1. the simulator model generates an output that falls within standard engineering tolerances of the parent vehicle
Brown (1975), Blaauw (1982)	**Behavioural** 1. comparison of two systems during identical tasks and circumstances in terms of system performance and/or driver behaviour 2. measurement of physical and/or mental workload		**Physical** 1. comparison of the simulated and the actual vehicle (e.g. geometry of control and their response characteristics)
Bertollini et al (1994)	**Closed-loop** 1. performance and performance trends 2. subjective ratings correspond		**Open-loop** 1. simulated and actual vehicle response characteristics
Allen et al (1991)	**Operator behaviour** 1. operator's subjective reaction (simulator fidelity) 2. operator's objective behaviour (perceptual and control responses, judgements and decision making)	**Operator/simulator performance** 1. transient response to isolated events and mean and variance response to random inputs 2. demonstration of transfer of training to real world performance	**Verification of simulator component response characteristics** 1. simulated vehicle response behaviour (i.e. vehicle dynamics or equation of motion) 2. response behaviour of the various simulator cueing devices (e.g. visual, motion, auditory displays)
Moraal (1981), Alicandri et al (1986)	**Functional** 1. comparison of performances between the simulator and the real world		**Face** 1. physical correspondence between the simulator and the real vehicle

3.3.2 Methodologies for assessing validity of driving simulators

Numerous validation theories and approaches have been proposed since the inception of simulators (either flight and/or driving). However, there is only one methodology, in the author's opinion, in terms of describing in detail all the steps to be followed in order to validate a simulator, the one proposed by Leonard and Wierwille in 1975. However, no researcher ever adopted their methodology for assessing the behavioural validity of driving simulators possibly due to the complicated nature of the methodology.

Leonard and Wierwille (1975) proposed a methodology for assessing both the physical and behavioural validity of a driving simulator by adjusting *"the simulator experimental conditions to obtain matching measure values between full-scale and simulation"*. The independent variables were the adjustable parameters. Each adjustment e.g. roll, yaw, roll damping, lateral translation gains and steering sensitivity in the simulator may affect the subject's responses. The dependent variables were measures, which theoretically can be obtained both in the simulator and on the test vehicle (or "full-scale" vehicle). These could include average steering wheel reversals over time, lateral acceleration and average velocity standard deviation. The analysis of the results followed two steps. The first included the detection and removal of the simulator data that prove to be significantly different from the real-road data by using analysis of variance and the "t" or "F" or Dunnett's test to examine the nature of these significant differences. The second one determined which of the remaining non-significant conditions produces the best matching data to the full-scale system by using correlation analysis.

They found that *"the concept of performance validation is both α-level and sample size dependent, indicating that careful preliminary consideration should be given to the size of experiment to be performed"* (α-level is the significance level).

They concluded by suggesting five criteria for a successful validation study:

A. *"The simulator must possess good fidelity in those aspects corresponding to the measures taken.*

B. *The simulator must have the capability of parameter (independent variables) adjustment.*

C. *A sufficient number of properly selected independent variables and corresponding settings must be employed.*

D. Performance data must be obtainable for the standard full-scale vehicle and for each adjustment of the simulator and

E. Accepted methods of experimental design must be used to ensure unbiased data and correct conclusions regarding validity".

3.3.3 Driving simulator validation criteria

Whichever approach or methodology has been used for validating a simulator, the final issue is the interpretation of the results after comparison of the two environments. To date, the criteria used for the validation of driving simulators are based on the criteria used for the validation of the psychological tests as refined by Blaauw (1982) and Kaptein et al (1995) for driving simulators.

Blaauw (1982) introduced the **"relative"** and **"absolute"** validity criteria. They are primarily concerned with the comparison of driver performance differences between experimental conditions in the simulator with performance differences between similar conditions in the car. Relative validity, a qualitative criterion, is achieved when "these differences are of the same order and direction in both systems" and absolute validity, a quantitative criterion, is achieved "if the numerical values are about equal in both systems" (Blaauw, 1982).

Kaptein et al (1995) defined the **"internal"** and **"external"** validity criteria regarding driving simulators. Internal validity refers primarily to the recognition of a possible apparent relation between a manipulation and an obtained effect. It can be achieved if there are no alternative explanations for an obtained effect but can be lost if driver behaviour is specifically affected by the limitations of a driving simulator. That is to say by the limited resolution of a computer-generated image, the delay until vehicle position and images are updated and a limited horizontal field of view. External validity refers to the extent the results obtained with a specific set of subjects in a specific environment during a specific period of time can be generalised to other persons, environments and time periods. Problems may be caused by careless choice of road environment (e.g. road type) or subject selection (e.g. amount of driving experience), motivation and mental and physical condition (fatigue of subjects). External validity mainly relates to the design of an experiment on the basis of a specific research question.

In addition to the above criteria, "**face**" validity is also used to describe how realistic the simulator environment appears to subjects. In terms of psychology, face validity refers not to what the test actually measures, but to what it appears superficially to measure. Face validity pertains to whether the test "looks valid" to the examinees who take it, the administrative personnel who decide on its use and other technically untrained observers (Anastasi, 1988). Face validity, when used for driving simulators, should never be regarded as a substitute for objectively determined validity. As Harms et al (1996) concluded after the third behavioural validation study of the VTI driving simulator, "*increasing the face validity of the VTI simulator did not necessarily enhance the overall behavioural validity of the simulator*".

3.4 Review of earlier and recent behavioural validation studies

A number of behavioural validation studies have been examined here. For the early studies all the technical characteristics of the simulators used are not precisely known, nor are the type of statistical analysis, nor a great detail about how the simulator and real road experiments have been conducted. More details about the later validation studies are known. Technical characteristics of the simulators used for these studies as well as details relative to their test protocol can be found in relevant papers as well as in two papers by Blana (1996a,b). Results of earlier and recent validation studies will be presented using the absolute and relative validity criteria as defined by Blaauw (1982) and as used by all researchers to present their results.

3.4.1 Early behavioural validation studies

The earlier simulator studies mentioned physical correspondence only and paid less attention to behavioural correspondence. Behavioural validation studies of simulators started around 1970 and referred to driving simulators with limited graphics presentation and computing abilities (Allen and O' Hanlon, 1979).

The behavioural validation of the first driving simulators showed low absolute correspondence but high relative correspondence between driver behaviour in the simulator and the real road (Barrett, Nelson and Kerber, 1965; Wojcik and Weir, 1970; Breda, Kirkpatrick and Shaffer, 1972; Allen and O'Hanlon, 1979). Usually simulator data were compared to standard references (existing results from earlier field studies, engineering evaluation data) (Allen, Schwartz, Hogue and Stein, 1978), data obtained from an instrumented vehicle (Barrett et al, 1965; Allen and O'Hanlon, 1979) or subjective data (Wheaton et al, 1966). Allen et al (1978) were the only ones who used a monetary penalty to motivate drivers to complete their driving task as instructed.

Types of statistical analyses employed were usually analysis of relative trends, sensitivity analysis, correlation analysis and comparison of means. The most commonly used driving tasks were overtaking, driving on a curved road, lane keeping with side wind and following a lead vehicle. The early behavioural validation studies suffered in great percentages from simulator sickness. Barrett et al (1965) reported 64 percent simulator sickness. Breda et al (1972) reported that the problem of simulator sickness affected several subjects and 7.5 percent of the subjects had to quit the experiment.

The results obtained from the early behavioural validation studies are difficult to interpret since a number of these studies are usually only a reference in a more recent article, hence there is limited access to the original set of data. In addition, within the recent article very few details are given for the test-protocol of the simulator experiment and/or the field study of the early validation study. Usually, no arithmetic values e.g. mean and standard deviation are given for the investigated variables. Thus, there is a potential for misinterpretation of the results given and no further conclusions can be derived relative to the behavioural validity of the tested simulator. Since the range of deviation of the simulator values compared to the real road values are known, no indisputable conclusions can be derived relative to the validity of those simulators.

3.4.2 Recent behavioural validation studies

The definition of "recent behavioural validation studies" means validation studies in driving simulators after 1980 and generally after the development of simulators with powerful visual simulation workstations and computer-generated image subsystems. There is a limited number of driving simulators that have been behaviourally validated *per se*. These are the VTI and JARI moving-base simulators in Sweden and Japan respectively and the TRL fixed-base with limited motion movement simulator in England. VTI researchers have conducted three behavioural validation studies; their test protocol was the one closer to the test protocol of this behavioural validation study. Therefore, it was decided to present the TRL validation study and the three VTI validation studies in detail. For all other simulator studies, which compare a simulator experiment with a field study conducted a different date only the results for the parameters, which were considered significant to the interpretation of our behavioural validation study are presented in the following sections.

3.4.2.1 The TRL validation study

Duncan (1995) investigated the validity of the TRL driving simulator by comparing individual drivers' performance of the same driving task in the simulator and on a test track using an instrumented vehicle. The primary driving tasks included speed estimation and maintenance with and without a speedometer, lane keeping, headway maintenance and reaction to an in-vehicle display where the secondary tasks were drivers' estimations of safe speed and safe headway and eye glance behaviour. Braking tests were also conducted in both environments, to test driver ability to brake smoothly to a specified position under normal and harsh braking conditions.

The majority of experimental effects observed on the real track were also detected in the simulator environment, although between-subject variation was larger. The visual distraction task, in particular, appeared to cause greater degradation of steering performance in the simulator due to the more demanding nature of the steering task. The results of the post-experimental questionnaire confirmed the objective findings by identifying tasks, which feature lateral or longitudinal acceleration, such as curve-following and smooth braking as the most demanding aspects of driving the simulator.

It was found that in both environments, initial speed estimates were on the low side, although only the difference for the real track (-0.56 mph) reached significance. Initial speed estimates did not differ significantly between the simulator and the track. After the "speedometer" circuits, mean speed increased significantly in both environments, especially in the simulator (+2.08 mph). The between-subjects speed variance was three times greater in the simulator than on the track. Subjects' mean choice in safe headway was 62.8 m in the simulator compared to 50.8 m on the track. The results suggest that perception of distance is different in the simulator compared to real life and subjects need a longer distance to the leading vehicle in order to feel safe. This finding should be taken into serious consideration when testing innovative driver assistance devices in the simulator. It was also found that a larger proportion of subjects appear to stop short of the target point in the simulator than on the track and braking accuracy improved along the three runs in the simulator but not in the instrumented vehicle. This means that subjects may use a different braking strategy in the simulator or may need more time to adjust to the simulator controls.

3.4.2.2 The VTI validation studies

The behavioural validity of the VTI moving-base driving simulator (Nilsson, 1989, 1993) has been examined by Harms (1993), Alm (1995) and Harms et al (1996). The results of these validation studies are presented in the following paragraphs and summarised in Table 3-2.

Harms (1993) tested simulator validity using speed and lateral position as performance measures. At that time the VTI simulator animation software was relatively unsophisticated (only the carriageway and plain scenery could be simulated and no other traffic could be simulated besides the simulator car). She found both relative and absolute validity of the simulator for speed but only relative validity for lateral position. She suggested that this problem could be due to the absence of other traffic, or that the subjects use other visual cues for their lateral control in a driving simulator than during field driving.

Alm (1995) using the updated version of the VTI driving simulator (complex road environment and other traffic could be simulated) repeated Harms (1993) validation study using exactly the same real road, instrumented vehicle and vehicle dynamics of the simulator car. In addition to Harms study, he compared driving simulator experimental data with and without kinaesthetic feedback. He found absolute validity of the simulator for mean speed and lateral position. However, statistically significant differences in speed variance were found between the two environments and in lateral position variance between the two environments when the movement system was on and between the moving system on and off. It was also found that driving in the simulator produces higher mental workload compared to real car driving (using the NASA-TLX test of Hart and Staveland, 1988). He concluded that the moving-base system is better when driving in curves, minimises the nausea effects from the simulator road environment and helps the driver to keep the car on a steady course on the road. Comparing the first two validation studies it can be seen from Table 3-2 that differences were observed in both real road and simulator environments between the two studies. That is to say drivers using the instrumented vehicle drove 6% faster and 20% closer to the centre of the road in the second study compared to the first study. Simulator subjects drove 3% faster but 10% further away from the centreline compared to the first study. This means that oncoming traffic did have a significant effect on simulator subjects' lateral position in the second study.

Table 3-2 Comparison of the three VTI behavioural validation studies

	Road characteristics			Type of vehicles		Mean Speed (km/h)		Displacement ° (m)	
STUDIES	Type of road	Lane width (m)	Speed limit (km/h)	Instr. vehicle	Simul. vehicle	Field trials	Sim. trials	Field trials	Sim. trials
First study (Harms, 1993)	Single c/way	3.50	70-90	Volvo 240 Sedan	Volvo 240 Sedan	79	81.7	-0.03 [0.92]	0.20 [0.71]
Second study (Alm, 1995)	Single c/way	3.50	70-90	SAAB 9000	SAAB 9000	83.9	84.02^{x}	0.15 [0.73]	0.08 [0.78]
Third study (Harms et al, 1996)	Tunnel (3 lanes)	3.25	70	SAAB 9000	SAAB 9000*	73.4	81.0^{+}	0.04	-0.09

^{x} mean driving speed with the moving system on (with the moving system off it was 85.07 km/h)
°displacement is measured from the front right wheel to the edge-line, positive values indicate driving closer to the centre of the road, negative values indicate driving closer to the road edge.
[...] parentheses give the values of lateral position of the left rear wheel of the vehicle relative to the centreline
* some of the dynamic properties of the real SAAB 9000 were actually simulated (this was not the case in the two previous studies)
$^{+}$ mean driving speed with access to the speedometer (without the speedometer it was 84.7 km/h)
Source: Part of data has been adapted from Table 1, Harms et al (1996)

Harms et al (1996) in the latest validation study compared driver behaviour in a real and a simulated tunnel (3 lanes, one direction). Driving speed and lateral position were used as dependent variables, as in the two previous validation studies. The position of the tunnel wall (appearing either at the right or at the left side of the driver) and access to speedometer values of driving speed were used as independent variables. The results showed a statistically significant difference in mean driving speed between the two environments (8 km/h higher in the simulator than in tunnel) whether or not there was access to speedometer values. Statistically significant differences between the two environments were also observed for lateral position and the side of the tunnel wall. Subjects drove 40 cm closer to the right wall compared to the left wall in both environments. In simulator trials the distance to the edgeline nearest to the tunnel wall, was 13 cm smaller than in field trials. Overall, access to speedometer and position of the tunnel wall both significantly affected driving speed and lateral position. Their overall conclusion was that "*the presence of critical but unnoticed source of variance, influencing subjects speed and lateral position both in the field trials and simulator trials, may result in unreliable conclusion of behavioural validation studies*".

3.5 Discussion on behavioural validation studies

The interpretation of the results obtained from the different behavioural validation studies is a complicated task and comparison of results obtained from the different studies is even more strenuous and elaborate. There are a number of factors involved in the interpretation and comparison of results such as: the objectives of the experiment; the type of the simulator used; the technical characteristics of the particular simulator at the time of the experiment; the simulator experimental protocol; the number of genuine road users and subjects used and their personal characteristics; the way real road data was collected and their reliability and finally various confounding variables that might affected the field study and the simulator experiment. These factors must be taken into serious consideration before any attempt for the interpretation and comparison of any of the obtained results. The following subsections summarise the results from the recent behavioural validation studies in terms of demographic effects, statistical, behavioural and technical issues.

3.5.1 Driver characteristics effects

Differences in driving behaviour were observed between experienced and inexperienced drivers (Blaauw, 1982). Experienced drivers performed better in the simulator. However, Kappé and Körteling (1995) reconstructed Blaauw's (1982) experiment using the second TNO simulator (description of the new system can be found in Kaptein et al, 1995) and they found no difference between inexperienced and experienced drivers. A possible reason for the observed differences between the two experiments could be the characteristics of the two simulators used. However, if indeed experienced drivers perform better than inexperienced drivers in the simulator, this suggests that when testing innovative car components and/or car devices where driving performance may be of primary importance, experienced drivers should be preferred as simulator subjects.

Differences in speed, lateral position and steering behaviour have been observed between young and old drivers when a secondary task is involved (Ponds, Brouwer and van Wolffelaar, 1988; Alm and Nilsson, 1991; Nilsson and Alm, 1991; Reed and Green, 1995) and under normal driving conditions (Duncan, 1995).

3.5.2 Statistical analysis issues

Results of twelve behavioural driving simulator validation studies are summarised (see Table 3-3) relating to the number of subjects, the use of training sessions or not, the type of statistical analysis used, the three most commonly used dependent variables and the three most commonly used independent variables. Six of them conducted on fixed-based simulators, (Blaauw, 1982; Alicandri et al, 1986; Hogema, 1992; Malaterre, 1995; Reed and Green, 1995; Kaptein et al, 1996) five on moving-base (Riemersma et al, 1990; Harms, 1993; Alm, 1995; Harms et al, 1996; Soma et al, 1996) and one in a fixed-based driving simulator with hydraulic actuators (Duncan, 1995).

Table 3-3 Results of twelve validation studies

Parameters		
No of subjects		
min	mean	max
7	20	48
Real road experiment		
Real road and genuine road users	Real road & instrum. vehicle	Test track & instrum. vehicle
1	6	5
Training sessions		
yes	no	N/A
8	1	3
Statistical analysis		
ANOVA	Comp. of Means	Correlation
9	8	6
Dependent variables		
Speed	Lateral position	Steering behaviour*
9	7	6
Independent variables		
Two conditions	Driving instructions	Moving system on-off
12	5	2

* Steering behaviour means either steering-wheel angle or steering-wheel reversal rate

It can be seen that on average twenty subjects are used for either the simulator experiment and/or the field trial. Almost all validation studies have been conducted using an instrumented vehicle (92%) either on the real road (50%) or on a test track (42%). Only one study compared the simulator results with results obtained from genuine road users, but it was not designed as a behavioural validation study per se (Riemersma et al, 1990). The three most commonly used dependent variables are speed, lateral position and steering performance. The most commonly used type of statistical analysis is the analysis of variance (ANOVA) and besides the comparison of the two conditions (field and simulator trials), a number of researchers investigated different instructions in driving (e.g. slow v. fast) between the two conditions.

3.5.3 Behavioural issues

Most of the researchers have observed higher speed and speed variation in the simulator compared to real life (Alicandri et al, 1986; Riemersma et al, 1990; Tenkink and van der Horst, 1991; Hogema, 1992; Harms, 1993; Duncan, 1995; Reed and Green, 1995; Alm, 1995; Boulanger and Chevennement, 1995; Harms et al, 1996). It has been proven that the use of a moving-base simulator produces speeds much closer to field speeds compared to fixed-base simulators and reduces speed variation (Alm, 1995; Soma et al, 1996). This suggests that the introduction of kinaesthetic feedback improves driver speed perception and their ability to better and more easily control the simulator driving speed.

Another problem relating to speed and lateral position in the simulator is the definition of "safe speed". It has been reported that "safe speed" is not a meaningful quantity in the simulator since the sense of risk is absent from the simulator environment (Hogema, 1992; Duncan, 1995).

Higher lateral position variation has been observed in the simulator compared to real life (McLane and Wierwille, 1975; Allen and O'Hanlon, 1979; Blaauw, 1982; Tenkink, 1990; Harms, 1993; Alm, 1995; Duncan, 1995; Harms et al, 1996). It has been observed that position of side objects affect subjects' lateral position (Harms et al, 1996). In particular, if objects are placed closer to the lane, speed and lateral position variation decreases (Tenkink, 1989; Tenkink and van der Horst, 1991). The same applies when road width and curve radius decreases (Tenkink and Van der Horst, 1991). This suggests that cautious introduction of roadside furniture and vertical signing may produce the proper cues for the simulator drivers to improve their ability to estimate lateral distance and better control the lateral displacement of the simulator vehicle.

Difficulties in estimating speed and distance, particularly long distances have been observed from a number of researchers (Malaterre, 1995; Duncan, 1995; Groeger et al, 1997).

Subjects probably due to the poorer visual cues in the simulator could not estimate speed and distance properly.

Alm (1995) and Alicandri et al (1986) observed that driver mental workload is higher when driving in the simulator compared to real life. Subjects of this behavioural validation study also commented that they needed more concentration to drive the simulator car compared to real life. This observation should be taken into serious consideration especially when a secondary task is involved in the simulator study. It could be assumed that when testing for example the use of mobile phones in cars, driver's capacity for the secondary task is greater in real life. On the other hand, real life traffic conditions and real road environment are always more complicated than the simulator one. The exact trade-off between the two environments is still not exactly known.

Harms et al (1996) concluded that access to speedometer is one of the elements to better estimate and control speed in the VTI simulator. This is a positive finding in a way that at least we know one of the elements that improve drivers' speed estimation and control in the simulator. Subjects of this validation study commented that in real life they usually use the engine noise as a cue to estimate and control their speed. However, this was impossible in the simulator since they found it confusing, hence, they have to depend on the speedometer (they claimed that in real life they rarely did that).

The effect of variable message signs on route choice and driving behaviour was investigated by Janssen, van der Horst and Hoekstra (1991, 1992a,b) and Van der Mede and Van Berkum (1993). It was shown that both the individual cost of time loss and the degree that surrounding traffic follows the advice displayed affected driver's choice behaviour in both environments.

3.5.4 Technical issues

A problem that usually applies to simulators is the "feeling" and sensitivity of the steering wheel. It is very difficult to simulate the forces that a driver feels when driving on a real road, especially in a fixed-base simulator. Moving-base simulators have the ability to recreate most of the forces, therefore what the driver feels when s/he grips the steering wheel is much closer to what s/he feels in real life. In a number of fixed-base simulators it has been reported that it was more difficult to steer in the simulator compared to real life, especially if a visual distraction task was included in the experiment (Malaterre, 1995; Duncan, 1995). Alicandri et al (1986) observed less steering movements in the simulator compared to real life, but it involved driving only on a straight road section

Differences in braking between the real road and the simulator were observed for speeds higher than 30 km/h (Kaptein et al, 1995a). It was reported that smooth braking is more demanding in the simulator compared to real life. Although braking may not be critical in the control behavioural level, it is part of the tactical level where manoeuvring is taking place. This means that braking behaviour may be an insignificant factor when investigating for example speed and speed variation under free-flowing conditions but it is important when testing an innovative vehicle braking system e.g. ABS or the use of speed limiters in vehicles.

A number of researchers investigated the effect of scene complexity on subjects' driving behaviour (Reed and Green, 1995; Kaptein et al, 1996). In the Reed and Green (1995) study the low fidelity scene was black except the white road-edge lines and the centre dashed line. The high fidelity scene was coloured and textured and there was also road environment. For the Kaptein et al (1996) study the plain scene was textured road without lines and no road environment projected at 40^{o} horizontal field of view and the complex scene was textured road with lines and road environment (houses, post, delineator posts) projected at 120^{o} horizontal field of view. It was found in both studies that scene complexity was not an important factor in the simulator. This is a positive finding since it is very beneficial for the technical team involved in simulator graphics. It is known that a complex scene induces problems with the update rate of the simulator and that is the main reason why experimenters try to keep the scene sparse.

The effect of a compensation technique for the delay in the visual display of a driving simulator was investigated by Hogema (1992) but the results showed no statistically significant improvement in subjects' driving behaviour.

3.6 Chapter summary

Various approaches, methodologies and criteria have been proposed so far regarding the behavioural and physical validation of a driving simulator. The review of these approaches showed that all researchers agree that a simulator has to be validated both behaviourally and physically. Most of the recent behavioural validation studies have been focused on the absolute and relative validity of the simulator without taking into consideration the issue of face and cognitive/perception validity.

The literature review of early and recent validation studies relative to the main strategies followed to approach the problem of validation showed that two main strategies have been proposed. The first one considers the validation of the simulator per se, i.e. the same measurements taken on the road and in the simulator are part of the same experiment (very few of the simulators have been validated this way). At the second one, a specific experiment has taken place on the road at some time and a similar experiment (but not necessarily the same) has been conducted some other time in the simulator (the majority of the simulators have been validated this way). This is possibly the reason why most of the behavioural validation studies are totally different from each other and no standard methodologies and criteria have been formed to date.

4. CHAPTER FOUR

LADS BEHAVIOURAL VALIDATION APPROACH

4.1. Introduction

Each simulator validation study has employed a different approach and/or methodology to meet the criteria of behavioural validity in general and has suited the explicit purposes for which the simulator was validated in particular. This has resulted in a lack of homogeneity in the design process of simulator behavioural validation studies.

The following sections describe the way the behavioural validation of the Leeds Advanced Driving Simulator was approached and how the limitations pertaining to this approach were manipulated for this study. The exact experimental design followed for this validation study will also be described in detail.

4.2. Validation approach specification

The primary reason for developing and utilising driving simulators in transportation research programmes is their potential to provide information about driver behaviour that is too expensive, labour intensive, difficult or dangerous to gather in the field. Their ultimate suitability to address research questions relies on their ability to provide valid data. If data that are collected by their use is not valid, generalisations to the real world, which is where the information is needed, cannot be made.

The Leeds Advanced Driving Simulator has been developed mainly for research reasons. It is a medium-cost fixed-base driving simulator (for a detailed description of the simulator, see section 5.4.1, in Chapter 5). The usefulness of LADS depends on its ability to accurately simulate certain essential characteristics of real driving tasks and to provide representative data about drivers' performance in various real situations.

The objective of this study was the behavioural validation of LADS (see also section 1.3 in Chapter 1). Driving behaviour in terms of speed and lateral position (mean and standard deviation values) was monitored under normal free-flowing traffic conditions on a single carriageway rural A road with different geometric features and the presence of oncoming traffic. Using the criteria of absolute and relative validity as those defined in section 3.3.3 in Chapter 3, the behavioural correspondence between LADS and the real road was determined. The dependent and independent variables as well as the type of road, data points and the number of subjects were carefully chosen so that the results of this study could be generalised and could be compared with results obtained from other similar validation studies. The face validity of the simulator was determined by the exploitation of the subjective data.

4.2.1. Driving performance measures

Speed and lateral position were selected as the driving performance measures for this validation study for the following reasons (see also the discussion in section 3.2.2 in Chapter 3):

a) In terms of traffic psychology, measures of speed and lateral control are important primary-task performance measures in car driving (De Waard, 1996). They represent the most automated characteristics of driver performance i.e. they are tasks of the control level (which is one of the three driver behaviour levels described in section 3.2.1 in Chapter 3). Speed works as a major long term and temporary motivational aim of driving. Trip decisions set the approximate desired or target speed level, together with driving costs and speed limits. Target speed level largely determines lower-level goals such as overtaking; and maintaining speed is suggested to be a strong momentary goal in the same vein as continuing any activity which is going well (Summala, 1988).
b) In terms of highway and traffic engineering, speed is one of the most crucial components of road design and road safety. Drivers regulate their speeds upon a road in accordance with the layout environment in which they are travelling, that is to say the speed characteristics of the length of the road over which they have just driven and their perception of what lies ahead (Highway Link Design, 1989). Although drivers usually wish to drive with a "desired speed", which is the speed they would choose to travel at if unimpeded by other traffic, roads are designed using "design speed". In Britain, design speed is defined as "*the highest continuous speed at which an individual vehicle can travel with safety on the highway when weather conditions are favourable, traffic density is low and design features of the highway are the governing condition for safety*" (O'Flaherty, 1986). However, in practice one can only observe "free speeds", as one can

only observe that proportion of all drivers able to travel freely. Free speed is defined as the speed of an isolated vehicle or the head vehicle of a platoon or when the headway of two moving vehicles is between 6-12 seconds. This time range has been established after numerous field studies. Spot speeds of free-flowing vehicles (spot speed is the instantaneous speed of a vehicle at a specified point along a road, Taylor and Young, 1988) are very important for the study of driver behaviour. They are repeatedly used by traffic engineers when assessing the need for appropriate traffic control devices, speed limits, advisory speed signing, drivers' responses to new warning signs, road marking, street lighting and pavement surfaces, overtaking manoeuvres and the effects of lane widths and lateral clearances. They provide estimates of the prevailing distribution of speeds at a site under different environmental conditions, and of a range of likely vehicle speeds. Besides the design speed, rural roads are designed taking into consideration the 85^{th} percentile of free-flowing speed. The variation between the design speed and the 85th percentile of speed comprises a quantitative criterion for classifying rural segments as poor, fair and good design (in terms of road safety) (Lamm, Choueiri and Mailaender, 1991).

c) In almost all behavioural validation studies, speed and lateral position are the most commonly used variables and the key factors for determining the success of the study (see sections 3.2.2 and 3.5.3 in Chapter 3). Choosing similar or the same variables for this validation study that other validation studies had used before, gives us the possibility and ability to compare our results with the results of those studies. The advantage of this comparison is the knowledge we gain about the strengths and weaknesses of our simulator and the improvements we can make to increase the face and relative validity of our simulator.

4.2.2. Data collection method

The literature review of the most commonly proposed and/or used approaches for driving simulator behavioural validation studies showed that the main approach regarding the conditions under which the real road study takes place is the comparison of simulator data with controlled experimental real road data. Subjects, who are paid for their participation to the experiment, are used for the real road experiment. Subjects can drive either an instrumented vehicle or a rented vehicle on a test track and less often on a real road. They are more or less aware that their driving behaviour is monitored.

For this particular behavioural validation experiment, uncontrolled observational real road data were compared with simulator data, and such a comparison has never been attempted before. In this approach, genuine road users driving behaviour is observed using traditional traffic engineering data collection methods (e.g. vehicle detectors such as pneumatic tubes, inductive loops) or more recently video imaging vehicle detection systems. Road users are unaware that their driving behaviour is monitored. The uncontrolled observational data were collected using hidden video cameras along the investigated section of the road in order to enable the monitoring of both speed and lateral position.

4.2.3. Type of road

In the process of identifying the type of road to be used, different features of different classes of roads have been examined. Overall, a single carriageway A road was considered to be the best choice for this validation study for various reasons:

A single carriageway road can provide various horizontal curvatures. Speed and lateral position can be studied on both straights and curves of a variety of radii (see respective literature review in Appendix 4-1). Studies have consistently found that curves are more accident-prone than straight sections of the road due to higher crash rate and greater crash severity (Glennon, Neuman and Leisch, 1985; Zeeger, Stewart, Reinfurt, Council, Neuman, Hamilton, Miller and Hunter, 1990; Evans, 1991). A curve requires the driver to perceive a change in the road alignment and to take appropriate action such as braking and steering changes. On sharp curves or under adverse environment conditions (e.g. at night during rain or in fog), these tasks can be quite difficult. Therefore, curved and straight road sections will be investigated separately. Driver behaviour can be investigated not only at an indifferent point on a straight section but also at distinctive points along a curve (e.g. at the approach, entry, apex and exit point of a curve). This type of road, due to its various road geometry, road environment and oncoming traffic conditions forces the driver to follow a different behaviour while traversing the various road sections and adapt accordingly his/her behaviour. This means that a particularly rich set of data result from just a single road. In driving task analysis, curves can be considered as specific driving situations from two points of view: the physical properties of the road and drivers behaviour.

On the other hand, an urban road would be improper for the nature of this study, i.e. observation of driver behaviour in the control level. It includes complicated traffic conditions, that is to say drivers' behaviour is influenced by a number of factors such as traffic lights, pedestrians crossing the road, traffic calming measures, thus they behave at the manoeuvring level. The influence of any of those factors on drivers' behaviour is very difficult to estimate and it becomes impossible to reproduce the situations in the simulator. In addition it is extremely difficult to achieve free-flowing conditions which were one of the prerequisites of this study.

A dual carriageway road or a motorway would also be improper because this type of roads result in a rather "monotonous" driving pattern due to their higher geometric design standards (i.e. straight sections are linked to smooth curves). Drivers drive at higher, more constant speeds and more constant lateral position and make lane-changes.

4.2.3.1. Road selection

The selected rural A road should fulfil the requirements of both the field study and simulator experiment and on this road the most appropriate sites should be selected for the validation experiment.

The selected road should preferably fulfil two major categories of prerequisites: those necessary for the successful simulation of any road in LADS and those desirable for the real road data adopted methodology. These were:

I. prerequisites for the real road study

   a) The road should include a combination of straight and curved road sections, providing "natural" traffic measures to constrain speed and thus allowing accelerations and decelerations and different steering behaviours, i.e., resulting in variation in driving behaviour;

   b) the traffic volume should preferably be moderate (no more than 12000 AADT) because very low traffic volume could result in an extended time of the survey for an adequate number of free-flowing cars to be measured and high traffic volume can result in a limited number of free-flowing cars;

   c) in order to compare the results with other similar studies (conducted both on real roads and simulators), the road must fulfil some preconditions such as (Lamm et al, 1991):

      i) no influence of intersections;

ii) the whole investigated length of the road must be delineated;

iii) the grade must be less than 4%

d) the road environment must include at least some trees and/or lamp posts on which the video cameras could be mounted.

II. prerequisites for the simulator experiment

a) the road should be flat, since the current simulator software is not able to simulate vertical curvature;

b) the road environment should be sparse in order to reduce the number and complexity of items that are required to be simulated.

4.3. Validation approach limitations

The limitations on a simulator behavioural validation study are directly related to the way real road data are collected and the capabilities of the driving simulator subsystems to represent the real road environment.

4.3.1. Real road data collection

It is usually assumed that speed data collected from the real road is free of errors. This is not exactly true. The accuracy of the methods collecting real road data which are later compared with simulator data has to be taken into consideration (for example, the accuracy of Nu-Metrics, one of the latest and easier to handle vehicle detectors has an accuracy of ±5 mph). Traditional traffic engineering road data collection methods have almost been the same from the time the first behavioural validation studies started and there has been little improvement in the accuracy with which the data are measured until today. These methods are distinguished into two main categories: the direct and the indirect (Taylor and Young, 1988). The direct ones enable measuring speed directly on the basis of the Doppler principle (such as radar meters) and the indirect involve the estimation of speed from a travel time observation such as the enoscope (Kennedy, Kell and Homburger, 1973), the electronic timing and vehicle detectors.

None of the above mentioned methods was specifically developed for the simultaneous measurement of speed and lateral position of the detected vehicle. Nowadays, this can become reality with the use of video imaging vehicle detection systems. As an alternative way, an instrumented vehicle can play the role of the detected vehicle itself using again part of the video imaging technology. The main difference between the use of video cameras and the use of instrumented vehicles is the type of observation requested by the researcher: in the first case the researcher will obtain uncontrolled observational data and in the second case partially controlled experimental data. Almost all the validation studies carried out until today (see Table 3-3, Chapter 3) have used instrumented vehicles to record and analyse drivers' behaviour (see Appendix 4-2 for more details on traffic engineering traditional methods, instrumented vehicles and video imaging vehicle detection systems).

Recent video imaging vehicle detection systems include ViVAtraffic (Hupfer, 1996), Autoscope™ wide area video vehicle detection system by Image Sensing Systems, Golden River traffic information and management systems and Peek Traffic Video Track®-900 Image Processing System by Peek-Traffic Ltd. However of the above mentioned systems, only ViVAtraffic system specialises in the areas of driving behaviour and traffic safety (whereas the other systems are mainly used for motorway surveillance). By the time of the study, ViVAtraffic was the most publicised video analysis software in the market for observing driver behaviour and measuring driver performance. Thus it appeared to be the most applicable to the study and it was decided to consider it for the analysis of the video data (for detailed descriptions of the system see Appendix 4-3).

4.3.2. Simulation of road environment

It is usually assumed that the simulator road environment, which is defined here as the road itself and the road furniture (e.g. objects like traffic signs, houses, fences and other vehicles), has been built as close as it can be to its real counterpart. However, this assumption cannot always be true because it depends on various elements, which are not always predictable, measurable and easy to define all of their parameters.

The simulator road environment depends heavily on how accurate the real road environment has been recorded. Assuming that a "real" (existing) road has to be simulated, the following alternatives may be followed:

a) Find the original real road layout (horizontal and vertical alignment of the investigated road) and copy the original geometric characteristics of the road from the layout (e.g.

radius, length of curve, road width, superelevation, and longitudinal gradient). This way, a lot of time is saved, since all data is available at hand; or,

b) If it is impossible to find the original road layout, then get road data from an Ordnance Survey map (or any equivalent high quality map). The map can be digitised or not, i.e. the data of the map can be in electronic format or not. Today the majority of the maps is digitised and can be offered to the customer in computerised form or on paper according to his/her needs. The best alternative would be to use the digitised map in computerised form since it would save time in terms of measuring the data from the map and increases the accuracy compared to measuring data from its paper format. However, it is not always possible, since the simulator road database software and the Ordnance Survey map software may not be compatible. A second option would be to use the digitised map on paper and measure the geometric characteristics of the road from the map; or

c) Conduct a survey and measure the geometric characteristics of the road on site. The accuracy of the derived data is almost of the same level as the one obtained from the Ordnance Survey digitised maps (assuming that the scale of the Ordnance Survey map is such as to obtain the highest accuracy); or

d) Finally, use an instrumented vehicle to measure the geometry of the road. For example TRL's instrumented vehicle has been fitted with sensors to measure and record vehicle speed, accelerator pedal position, brake pressure, steering wheel angle and the status of direction indicators. Video cameras are used to make a synchronised record of driver's eye movements, headway to the vehicle ahead and lane position (Duncan, 1995).

When the geometric characteristics of the existing road are available (whichever the method used to obtain them), then the next step is to try to create a simulator road that will match the geometric characteristics of the existing road as exactly as possible. This procedure can be achieved by using road-database software, which can be either specifically built-in house graphics software or off-the-shelf software (e.g. MultiGen). The capabilities of the software will determine the level of precision in matching the two maps (the real and the simulator). For example, if the existing road is a combination of transitional curves and straights and the software has the ability to simulate only circular curves, then the precision is limited. If the existing road is hilly and the software has the ability to simulate only horizontal curvature, then, again, the precision is limited.

The replication of the road furniture depends also on the road database graphics software. The real road furniture in terms of objects can be replicated using photographs, and/or video cameras. Real road traffic conditions can be replicated using video cameras. The number of objects that will be replicated in the simulator depends on the capability of the main computer (workstation) of the simulator and in particular, in terms of traffic conditions on the available software for modelling the drone traffic and the event traffic.

For this particular validation experiment, the measurement of the geometric characteristics of the real road (a single carriageway A road) was accomplished by using a digitised Ordnance Survey map on paper and the simulator road was built by using a built-in house software. The real road environment was replicated using scenes from video-tapes. More details on the matching of the real road and the simulator road are given in section 5.4.2 in Chapter 5.

4.4. Innovative elements

This study approached the behavioural validation of LADS in three unique ways:

a) For the first time, controlled experimental simulator data was compared with uncontrolled observational real road data, i.e. data obtained from subjects driving the simulator was compared with data obtained from genuine road users whose driving behaviour was monitored using hidden video cameras;

b) For the first time 100 subjects were used for a validation study and for the first time this number was compared with equal number of genuine road users. For the field study (and generally for this type of field study, i.e. measuring free-flowing speed), in order to minimise drivers' variation and to have a statistically significant sample of drivers, at least 100 drivers are required as sample size. It was decided to use the same number of subjects for the validation experiment;

c) For the first time, behaviour of the same driver was observed along a series of distinctive points on a stretch of road (either curved and/or straight) and not at one particular distinctive point (usually the apex of the curve and a random point on a straight). To the author's knowledge, this type of study has never been performed before on a real road (in terms of collecting and using the data only for traffic and/or highway engineering purposes and not for simulator validation studies). The common practice in traffic engineering studies (surveys) is to measure speed of different drivers at the apex of various geometric curves. Subsequently, speed data is classified according to the radius (or degree of curve) and possibly other parameters (e.g. road width, superelevation, longitudinal gradient) and conclusions are derived about driver behaviour. In this particular study, behaviour of the same 100 drivers was observed along various geometry curves, not only in their apex but also in their approach, entry and exit. In other words, discrete data was collected in a "continuous" way. Collecting driving behaviour data in a simulator in a "continuous" way is very easy, actually this is what happens by definition, since data is collected for every time step of the simulation, i.e. between twenty and thirty times per second along the whole stretch of the investigated road. On the other hand, this is extremely difficult for the real road environment (actually impossible using the traditional traffic engineering data collection methods) and can only be achieved by using either an instrumented vehicle or a large number of "on-line" video cameras. For this particular experiment, driver behaviour in a "continuous" way was observed on two road stretches by using on-line video cameras (the respective number of cameras for each stretch was 17 and 19) (for a detailed description of the two stretches see section 5.3.1.2 in Chapter 5).

4.5. Validation design

This section focuses on a description of the experimental design employed for the LADS behavioural validation study. In practical psychological research three main designs are available to the researcher. Each has its own advantages and disadvantages and experimental suitability. Background to the selection of the appropriate experimental research design is given below.

4.5.1. Consideration of Experimental Designs

There are three main experimental designs that can be employed in research studies using a sample of subjects undertaking different experimental conditions: the repeated measures design, independent samples design and matched-pairs design (Coolican, 1994).

The "repeated measures design" also called "within subjects design" or "related design" involves the allocation of the same subjects to more than one experimental condition. The advantages of this method are that subject variables are cancelled out since all subjects undertake all conditions. However, the method suffers from order effects, which can lead to confounding unless suitable counterbalancing can be introduced (Harris, 1986). The design is therefore not suitable for application where previous subject knowledge of experimental requirements could influence behaviour in subsequent experimental conditions, unless counterbalancing is applied.

The "independent samples design" or "between subjects design" or "unrelated design" involves allocation of different subjects to individual experimental conditions. Because it introduces individual subject differences to the conditions, samples should be larger and subjects are required to be allocated to the conditions on a random basis. This partially reduces the problem of subject variable bias. The main advantages of the design are that it does not suffer from order effects and it can be used when a participant's performance in one condition would affect their performance in another (Heyes, Hardy, Humphreys and Rookes, 1993).

The matched-pairs design is also a "related design" and involves pairing subjects together by matching them on a number of variable characteristics of importance to the study. Each subject in a pair then is being allocated to only one of the experimental conditions. Disadvantages are that the choice of characteristics for matching is very subjective and pre-testing of subjects prior to experimental allocation can be time consuming (Heyes et al, 1993).

4.5.2. Adoption of the independent samples design

The behavioural validation study consists of two studies: the real road study, which is a non-experiment and the simulator experiment. For the second study, an experimental design had to be adopted. The repeated measures design was adopted (the same subjects were allocated to three experimental conditions within the simulator trials and counterbalanced in order to minimise the order effects).

For the comparison of real road and simulator data (i.e. the behavioural validation study), the independent samples design was used by definition. However, because the same subjects drove the simulator more than once, the design had to be modified (for more detail see section 5.4.3.1 in Chapter 5).

4.5.3. Independent variables

In a laboratory experiment, the independent variables are those manipulated or systematically altered by the researcher (Miller, 1984). The independent variable for the validation study was the presence of oncoming traffic (oncoming traffic versus no oncoming traffic) and the different road geometry (driving on curves versus driving on straights).

4.5.4. Dependent variables

The dependent variables are those which cannot be manipulated by the experimenter in a laboratory experiment and generally those which are affected by the independent variables. For this validation study, those were speed and lateral position under free-flowing traffic conditions.

Free-flowing speed was defined as the speed of vehicles that were the head of platoons or vehicles that had a headway of at least 7 seconds. Although headway can vary usually between 6 to 12 seconds, the actual real road oncoming traffic conditions and video recording needs (see also section 5.3.1 in Chapter 5) dictated the lower limit of 7 seconds.

Lateral position was defined as the distance between the right side of the road edge white line and the front nearside wheel of vehicles. Negative values mean that vehicles were driving on the verge of the road (crossing the edge line).

4.5.5. Stating of hypotheses

The experimental and null hypotheses are stated explicitly in the following subsections. The hypotheses under examination relate to testing the differences between driving behaviour, when genuine road users are driving on real roads and subjects driving in simulators, using the absolute and relative validation criteria (as those defined and discussed in section 3.3.3 in Chapter 3). Subjects drove under three different experimental conditions relative to oncoming traffic. Condition C included no oncoming traffic at all; condition M included medium oncoming traffic and condition H included heavy oncoming traffic. The reason for having three different experimental conditions was to test if there is any influence on driver behaviour (in terms of speed and lateral position) from oncoming traffic.

4.5.5.1. Experimental hypotheses

The principal experimental hypothesis is that according to the absolute validation criterion, there will be a noticeable difference (in terms of arithmetic values) between the performance (in terms of speed and lateral position) of genuine road users and subjects' behaviour when

driving in the simulator. The sample size and the power of the statistical test employed determine the magnitude of difference.
A secondary experimental hypothesis is that if the simulator does not prove to be absolutely valid in terms of driving behaviour, then according to the relative validation criterion, there will be a systematic difference in the direction of the performance of genuine road users and subjects' behaviour when driving in a simulator (i.e. values will tend to be systematically higher or lower).

Other secondary experimental hypotheses relate to the effect of oncoming traffic and road geometry on driver behaviour. In particular, using again the criteria of absolute and relative validity, two hypotheses were tested. The first one is that there will be a noticeable difference between the performance (in terms of speed and lateral position) of genuine road users and simulator subjects' behaviour when driving on different road geometry road sections. That is to say when driving on curves v. straights, left v. right hand curves and on characteristic points along the curve. The second one is that there will be a noticeable difference between the performance (in terms of speed and lateral position) of genuine road users and simulator subjects' behaviour when driving with the presence of oncoming traffic or not.

4.5.5.2. Null hypotheses

The "null hypothesis" is that there will be no statistical significant difference in results when comparing the real road and the simulator data as the differences were defined above.

4.6. Chapter summary

This chapter outlined the key factors that may significantly influence a behavioural validation study of a driving simulator and addressed the ways these factors were taken into consideration in this study. These key factors were the driving performance variables to be measured; the field data collection method and the way the real road environment was simulated.

The driving performance variables to be measured were speed and lateral position. It was decided to measure uncontrolled observational real road data, and such a comparison has never been attempted before. The field data was collected using "on-line" video cameras on a single carriageway A road.

The novelties of the study relate to three factors:

a) the way the real road data were collected (and later compared with the simulator data), namely uncontrolled observational data;
b) the number of subjects used for the simulator experiment, that is to say 100 subjects (the same number of subjects was used for the real road study); and
c) the way the real road data was measured, that is to say the behaviour of the same driver was measured along a stretch of a road at different data points i.e. in a "continuous" way.

The experimental design and the hypotheses used for this study were explicitly stated in this chapter too.

5. CHAPTER FIVE

DATA COLLECTION

5.1. Introduction

This chapter details the data collection exercise for the validation study, which consisted of two pilot studies, the real road study and the simulator experiment. In particular for the real road study it includes the road selection, its measurement points and the work required during data collection in the field. For the simulator experiment, it includes the equipment used, simulation of the real road environment, subject recruitment, allocation of subjects to experimental conditions and the interview procedure adopted.

5.2. Pilot studies

In the previous chapter ViVAtraffic, a purpose-built software to monitor, measure and analyse driver behaviour using videotaping, was initially considered to be one of the alternatives to record the real road (for detailed description of the system see Appendix 4-3). The alternative solution was to analyse manually the videotapes. Since both alternatives included advantages and disadvantages, it was decided that before taking any final solution relative to the way of analysing the video data, two pilot studies should take place to evaluate these two different approaches. The first study evaluated ViVAtraffic and the second one the manual analysis.

5.2.1. Pilot study using video-analysis software

The first pilot study took place in Kaiserslautern, Germany. The author visited the University of Kaiserslautern, Germany in January 1996 and had a personal demonstration of ViVAtraffic. During the demonstration, all the capabilities of ViVA were presented in full detail and the German colleagues provided all the prerequisites for successful video taping and analysis.

ViVAtraffic evaluation should have been undertaken by using video data from one bend and one straight of the investigated road. Data was collected using high cameras, i.e. cameras mounted on telegraph or electricity poles. The prerequisite for obtaining the best accuracy from video data is the calibration of the cameras (Hupfer, 1996). As ViVAtraffic technical people suggested, the best calibration can be achieved when a 3m x 4m oblong can be recognisable on the screen.

A private company (Sky High Traffic Data) was hired to make the videotaping. However, due to technical problems and bad weather conditions (fog) in England, the company was able to measure the dimensions of a very long and large rectangle (100m x 100m) for only one bend using one camera. Using the above calibration, the accuracy of lateral position in the beginning of the curve was 10 cm, in the middle 50 cm and in the last part almost 1m (as measured in the screen). It was suggested by the German colleagues that more than one camera should be used for each investigated curve, actually one for each investigated point where we wanted to measure speed and lateral position and the cameras should be correctly calibrated if we wanted to achieve the best accuracy.

It became very clear that if ViVAtraffic software was to be used for the analysis of the video data, very accurate measurements for the calibration of the cameras had to be taken. However, the only private company in England, which agreed to undertake our traffic study, could only provide very low accuracy relative to camera calibration and this accuracy was not adequate for the assessment of ViVAtraffic software. On the other hand, they claimed that they could undertake the survey themselves (i.e. not only videotape the road but also analyse the data manually). Therefore, before taking any final decision about the way of analysing the video road data, a second pilot survey took place in order to evaluate the manual analysis of relevant video road data.

5.2.2. Pilot study using manual video-analysis

The second pilot study took place on April 4, 1996. The venue was a quiet, access road (i.e. no other traffic) in Tadcaster, West Yorkshire, England. For this study, a ground camera was used i.e. the camera was positioned on a tripod, pointing down to the ground. Black tapes (50 mm wide) defined the layout of the test-area and white tapes (18 mm wide) were placed on top of them to enable tyre marks to be easily identified. The layout of the road and the camera location is shown in Figure 5-1.

A vehicle passed a number of times over the white tape at a constant speed of 20 mph and each time a new tyre mark (due to wet tyres) was left on the white tape. An experimenter measured after each pass the different lateral position of the vehicle, i.e. the distances from the mark left by the front left tyre to the right edge of the left white tape (see Figure 5-1). These measurements were later compared with measurements taken from the video screen.

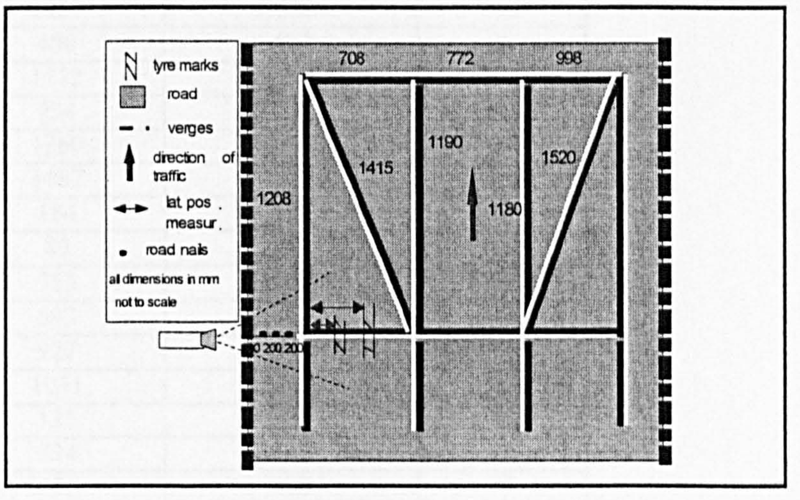


Figure 5-1 Road layout and camera location for the second pilot study

The methodology followed to measure these distances from the video screen was relatively simple. The video operator measured a number of fixed distances on the ground, three distances every 200 mm and put nails on the road at the exact points (as shown in Figure 5-1). Those points were visible from the video camera. He then measured the distances from the front left wheel to the right edge of the left black tape (see the distance defined by the two points red arrow in Figure 5-1) on the flat video editor screen (as the experimenter did on the actual road). Using as a reference value the 200 mm distances he found the actual lateral position of the vehicle on the real road. The distances were measured on the screen using a hand-held ruler. The actual (real road) measurements and the measurements derived from the above method are given in Table 5-1.

Table 5-1 Comparison of real road and video measurements for the second pilot study

Drive No	Measurements on site (mm)	Measurements from screen (mm)	Difference (mm)
1	674	680	+6
2	1314	1304	-10
3	1228	1232	+4
4	416	409	-7
5	1432	1440	+8
6	963	969	+6
7	1422	1420	-2
8	749	745	-4
9	220	211	-9
10	582	578	-4
11	1489	1500	+11
12	480	480	0
13	1172	1171	-1
14	934	950	+16
15	1360	1344	-16
16	1167	1157	-10
17	184	182	-2
18	89	82	-7
19	555	542	-13
20	693	690	-3
21	927	931	+4
22	1051	1057	+6
23	133	124	-9
24	334	326	-8
25	401	400	-1
26	832	825	-7
27	90	74	-16
28	777	760	-17
29	957	956	-1

5.2.2.1. Assessment of the lateral position accuracy

Generally, the overall accuracy of video measurements depends on the scale, lens and decentering distortion. Since the methodology used to derive the lateral position measurements from the screen was very simple, it was not possible to identify the exact contribution of each type of distortion to the overall accuracy. Ideally the error in accuracy of measurements should be random i.e., no correlation between the screen measurements and the difference in accuracy should exist. Therefore, the screen measurements were plotted against the error (difference in accuracy) and the best-fit line was plotted. As it can be seen from Figure 5-2, the correlation between the two variables is very small (R^2=0.1462), so that it can be concluded that the variables (field measurements and error) are generally independent and not interrelated. That is to say, the error was random. Its mean value was 7.172mm with standard deviation of 4.943mm, where the minimum value was 0 mm and the maximum 17mm.

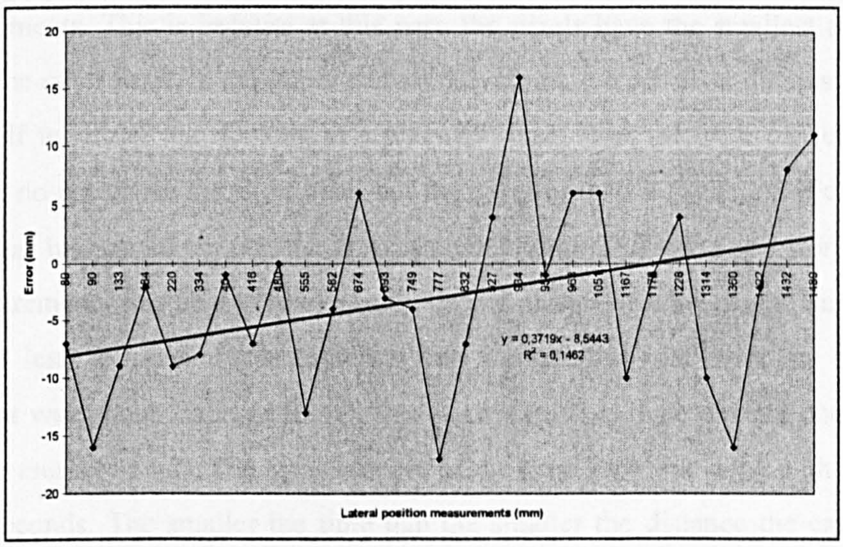


Figure 5-2 Best fit line for lateral distance and error for the second pilot study

5.2.2.2. Assessment of the speed data accuracy

Velocity measured by videotape recording is always an average velocity in a time gap. The smaller the time gap, the higher the requirements for the measurement of the distance a road user moves in that time gap. Similar studies using videotape recordings to analyse free-flowing speeds on rural roads have indicated an accuracy of 3 km/h and less (Hupfer, 1999). This has been calculated out of the resolution of the videotape (the "real-dimension" of a screen-pixel) and the taken time-gap between two position-markings of one road user. It would be possible to compensate for using videotapes with less quality or a perspective with a larger dimension of a screen-pixel by using a larger time gap to calculate the average speed in this time gap.

Table 5-2 indicates the possible error of velocity using time gaps of 0.125 seconds and 0.5 seconds. Using a time gap from 0.5 seconds enable us to do measurements of velocity with an inaccuracy of less than 1 km/h (one position of the road user exactly and one position ±1 pixel).

Under the conditions speed measurements were taken and analysed in this study (see also section 5.3.1.3) one pixel in the videoscreen had the dimension of ca. 8cm high and 5cm width in the last third of the screen. That is to say, the video-screen is divided horizontally into three parts, the upper, the middle and the lower. In the used tape recordings, the lower is the one closer to the camera and in this part of the screen we have the highest accuracy in our measurements. This is because at this part, the pixels have the smallest dimension in reality. On the other hand, in the upper part of the screen, we get pixel dimensions of more than 50cm. If we make the marking at a pixel of 10cm, then the error can be as high as 10cm. If we do not chose the right pixel but the pixel next to it (again of 10cm), then the error can be as high as 20 cm (i.e. the error is cumulative). The video operator who did the speed measurements was able to mark the footprints of the car wheels with an accuracy of 10 cm and less for each measurement. This means, that the error in the distance measurement was about 20cm or less in the worst case (i.e. if he did not chose the right pixel for the measurement). The measurement of the time gaps was done with an accuracy of 1/1000 seconds. The smaller the time gap the smaller the distance the car moved in-between. This means that with a time gap of 1/1000 we were able to get the exact position of a car in one single picture. Therefore, the measurements of velocities had a possible error of ~1.4 km/h and less (see Table 5-2 below).

Table 5-2 Possible error of velocity

Velocity m/s	Time gap (secs)	Real distance (m)	Accuracy of distance measurement	Possible error of velocity
1	0.125	0.125	0.10	±80% (±2.9 km/h)
10	0.125	1.250	0.10	±8% (±2.9 km/h)
30	0.125	3.750	0.10	±0.27% (±2.9 km/h)
1	0.500	0.500	0.10	±20% (±0.7 km/h)
10	0.500	0.500	0.10	±2% (±0.7 km/h)
30	0.500	15.00	0.10	±0.7% (±0.7 km/h)

The error of 1.4 km/h is highly acceptable. This error is the smallest compared to any other mobile instruments for speed measurement. For example, using hand-held radar, the error depends on the angle between the path of the car and the position of the hand-held radar. Under optimum conditions the error can be approximately 1.5 km/h.

5.2.3. Selection of the video-analysis data method

Since the average error of lateral position from the manual analysis of the video data was less than 1 cm and for ViVAtraffic could vary between 1cm and 1m depending on the video-shooting, it was decided to analyse the data using this method and not the ViVAtraffic software. The error in speed measurement could not influence our decision since it was the same irrespective of the way analysing the video data. The final decision was also influenced by the cost of each method and the location where the analysis of data would take place. In particular, the cost of ViVAtraffic software and the frame grabber was £14000 in early 1995 whereas SkyHigh quotation for analysing the data was £5000. Video data collection would have been in England and the analysis of data in Germany whereas for the manual analysis both data collection and analysis would be completed in England.

5.3. Field study

The following subsections will detail the procedure followed to select the road for the study, the points where the measurements should be taken on that road and the geometric characteristics of each curve and straight which were investigated.

5.3.1. The final road selection - the A614

A number of roads in W. Yorkshire and Humberside (east of Leeds) were excluded at the initial phase of the research due to very low traffic volumes (data were provided by Leeds City Council and Humberside County Council) or longitudinal gradient more than 4% (Ordnance Survey maps were used).

The A614 was judged to be the most suitable road. It offered a good combination of curved and straight sections, longitudinal grade no greater than 4%, sparse road environment and moderate to low traffic volume. That is to say, it fulfilled the prerequisites for the simulator experiment as those were defined in section 4.2.3.1, Chapter 4.

5.3.1.1. Potential survey sites on the A614

The investigated road section of A614 is located between Junction 37 on the M62 (east bound) and Holme-on-Spalding-Moor and is approximately 6 kilometres long (see map of the area, Appendix 5-1). This part of the road includes twenty curves of different geometry (e.g. shape, radius, length, road camber) either adjacent or linked by small length straight sections and two long straight sections (approximately one kilometre and 500 m respectively). Major or minor access roads and intersections affect most of these curves.

It was decided that four out of the twenty curves and a part of each of the two straight sections would be investigated thoroughly. These curves were selected for three main reasons:

a) because of their different road geometry (radius and length of curves) they could provide variation in speed and steering behaviour of road users;
b) they were not affected by access roads and/or intersections;
c) they had the minimum longitudinal grade.

A 1:2500 map shows the investigated curved and straight sections of the A614 (see Appendix 5-3).

5.3.1.2. Geometric characteristics of each curve

After the four curves have been selected, the geometric characteristics of each curve had to be measured. Those measurements would be later used for the representation of the road environment in the simulator. As it was mentioned earlier in section 4.3.2 in Chapter 4, there are four ways to measure these characteristics:

1. Find the original road layout of the A614 from Humberside County Council;
2. Get the road data from an Ordnance Survey map (or any equivalent high quality map);
3. Conduct a survey and measure the geometric characteristics of the road on site;
4. Use an instrumented vehicle to measure the geometry of the road.

The first method and most accurate one, had to be abandoned because a visit to Humberside County Council showed that no original construction plans of the road were available and only plans for the realigned sections of the road could be provided. The last one had to be abandoned too because no instrumented vehicle was available.

The third method was rejected after long discussions with surveyors from the Department of Civil Engineering, University of Leeds. Their opinion was that the expected accuracy from an on-site measurement would not be better than the accuracy of the digitised maps of the Ordnance Survey. In addition, an experienced team of surveyors would be necessary, equipped with the appropriate surveying equipment to carry out the measurements; the police and the local County Council would have to be contacted for permission and more than a week would be necessary for the completion of the survey.

Thus, it was decided to adopt the second method, i.e. the traditional maps of Ordnance Survey (the "so called" Superplan digitised maps in 1:2500 scale, see Appendix 5-1) would be used to measure the geometric characteristics of the A614.

The next step was to determine the type of horizontal curvature to be used to "simulate" the curves on the Superplan. It was decided that the curves would be considered as circular, rather than transitional and all the geometric characteristics measured would be those that apply to circular curves.

The reasons were:

1. Literature review of the development of design standards for horizontal alignment at the beginning of modern British roads (late 18^{th} century) revealed that road alignment usually included sharp unsuperelevated circular curves (unsuitable for fast motor vehicles) connected by straight tangents (Good, 1978). Research in the archive of the Humberside County Council in 1996 showed that the road existed already by 1855 (see relevant Ordance Survey maps, Appendix 5-2) and the road alignment was almost the same as today's one (see relevant Ordance Survey maps, Appendix 5-3).
2. The importance and necessity of transitional curves was recognised after the development of the railways (Holbrook, 1880) but introduced to roads later (Shortt, 1909; Leeming, 1927). However, it was not until the late nineteen-thirties that Royal-Dawson discussed in detail the elements of transitional curves (Royal-Dawson, 1936, 1938). Since the investigated road existed already by 1855, the horizontal alignment of the road was, most probably, designed as circular curves connected with tangents.

The methodology used to calculate the properties of the circular curves was the following:

a) the tangents $T_1I=IT_2$ to the circular curve and the deflection angle ∂ of the curve were measured from the map (where I is the cross-section of the two tangents and T_1, T_2 the cross-sections of the tangents with the circular curve) (see Figure 5-3);

b) the radius R of curve derived from the formula $T_1I=IT_2 = R \tan \partial/2 \Rightarrow R= T_1I / (\tan \partial/2)$

c) the length of curve (L) derived from the formula $L= 2\pi R\partial/360^{o}$

The resulting R, ∂ and L were later used for the creation of the same road in the simulator.

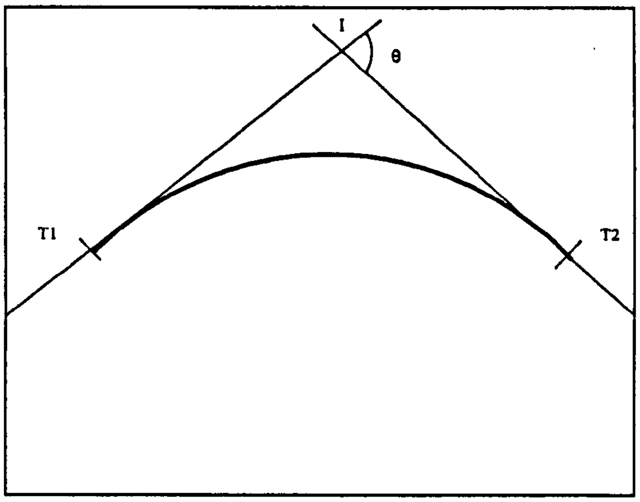


Figure 5-3 Geometric properties of a circular curve

5.3.1.3. Data points

Speed and lateral position were measured simultaneously on four points along each curve, namely its approach, entry (beginning of circular curve), apex (centre of circular curve) and exit (end of circular curve) points. The data points depended on the properties of the circular curve and the adjacent road sections.

The reasons for taking the speed and lateral position measurements on those specific points are the following:

1. To be able to investigate driver behaviour along the whole length of the curve and not only at one particular point (usually the apex) which is the common practice in most of the studies (field and/or simulator studies);
2. To be able to compare the results of this study with results from other field studies relative to speed measurements on curves. The literature review on driver behaviour on curves showed that although speed should be measured at least at the approach, entry, apex and exit points of a curve, in practice and mainly for simplicity reasons, traffic engineers usually measure speed only on the apex of the curve;
3. To be able to compare the results of this study with results from other validation studies which have used instrumented vehicles to "map" the road curvature. Whether transitional (of any type) or circular curves have been "mapped", the apex of any of these curves is located always in the middle of the length of the curve;
4. To be able to identify differences (variation) in driver behaviour along the curve and test the hypothesis that there is indeed speed variation along the curve (there is a

contradiction between researchers relative to driver behaviour along a curve; a literature review on this issue was given in Appendix 4-1).

The speed and the lateral position of the free-flowing vehicles were measured using ground based and high cameras. Ground cameras were positioned at the exact points of measurements (approach, entry, apex and exit) and high cameras in such places as to overlook the whole area. The ground cameras were used to measure the speed and lateral position of the free-flowing vehicles whereas the high cameras were used to identify the free-flowing vehicles. In order to achieve the recording of free-flowing traffic, headway of at least 7 seconds was maintained at each camera position. The recorded data for the speed and lateral position are given in Appendix 5-4.

The ground video cameras were placed inside grey wooden prefabricated boxes, the intention being to disguise the fact the vehicles were being monitored. The boxes were manufactured to replicate the ubiquitous grey British Telecom street furniture usually seen by the roadside. Each box contained two video cameras: a camera to record lateral position and a camera to record speed. Figure 5-4 shows the exact position of the cameras inside the boxes, the blue camera is the speed camera and the red camera is the lateral position camera. The exact location of each camera on site is given in Appendix 5-5. Four road nails were located within each camera view to provide a reference for lateral distance calculations. The position of each set of the control points is shown in Appendix 5-6. Both cameras had superimposed time to one tenth of the second. All cameras used to calculate speed and lateral distance were Panasonic AG455.

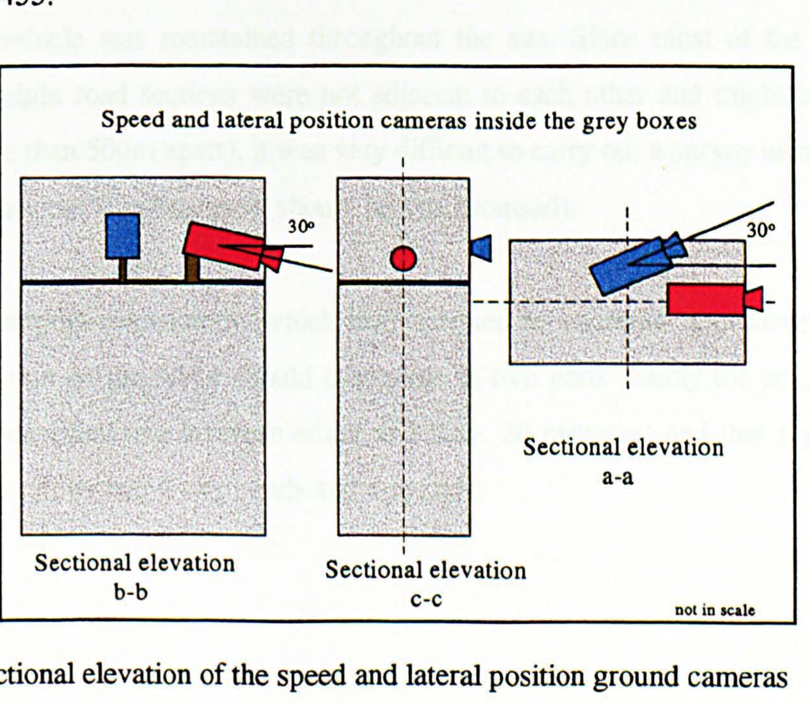


Figure 5-4 Sectional elevation of the speed and lateral position ground cameras

The speed camera was placed at a horizontal angle of approximately 30 degrees and on the opposite site of the cabinet to oncoming traffic to further conceal the fact that vehicles were being monitored. Markings, 10 meters apart, were located on the road surface enabling a time/distance calculation to be undertaken to determine individual vehicle speed local to the cabinet (Figure 5-5). The lateral position cameras were placed perpendicular to traffic flow. Only data from nearside traffic were collected (vehicles travelling from South to North).

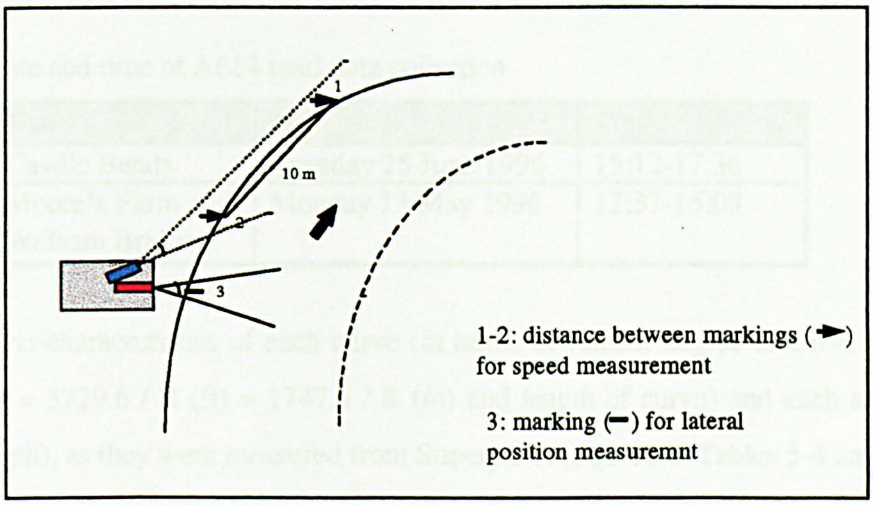


Figure 5-5 Speed and lateral position cameras and road layout for measurements on a right-hand curve

In order to measure speed and lateral position along the fifteen points on the four curves (the exit point of curve 1 coincided with the entry point of curve 2) and six points on the straight sections (three points in each straight), forty-two ground cameras were required. In addition eight high cameras were required to confirm that a minimum of seven seconds headway for an individual vehicle was maintained throughout the site. Since most of the investigated curved and straight road sections were not adjacent to each other and might be a distance apart (e.g. more than 500m apart), it was very difficult to carry out a survey using forty-eight cameras simultaneously (all cameras should be synchronised).

The private transport consultancy, which had accepted to undertake the survey, suggested that data collection on the A614 should take place in two parts mainly for practical reasons (since it only possessed one 4-screen editor and max. 20 cameras) and that suggestion was accepted. Each part included two bends and a straight.

5.3.2. Road measurements

The survey took place on two different days. The weather for both days was fine and the pavement was dry. Although for both sites surveys had been conducted the same week, due to technical problems related to the camera's position the measurements of the first site had to be discarded and the survey had to be repeated some weeks later. The final dates and time of the surveys for both sites are given in Table 5-3.

Table 5-3 Date and time of A614 road data collection

Site	Name	Day	Time
1	Caville Bends	Tuesday 25 June 1996	15:12-17:36
2	Moore's Farm and Welham Bridge	Monday 13 May 1996	12:37-15:08

The geometric characteristics of each curve (in terms of radius, degree of curve in degrees per 100 feet = 5729.6 / R (ft) = 1747.5 / R (m) and length of curve) and each straight (in terms of length), as they were measured from Superplan are given in Tables 5-4 and 5-5.

Table 5-4 Geometric characteristics of curves of sites 1 and 2

Site	Curves	Radius (m)	Degree of Curve	Length of curve (m)
1	C1	55.59	31.44	65.98
	C2	108.25	16.14	113.36
2	C3	200.60	8.71	125.54
	C4	141.51	12.35	120.38

Table 5-5 Geometric characteristics of straights of sites 1 and 2

Site	Straights	Length (m)
1	S1	444
2	S2	160

The road environment (tree, lampposts, hedges, traffic signs, houses and farms) and road geometry were videotaped for later use in the simulator. Each site is described in full detail in the following paragraphs.

The first site is located close to Howden. It starts from Caville Hall and ends at the Royal Oak pub. It includes two consecutive curves and a straight section. The position of the ground and high cameras for site 1 are shown in Figure 5-6. The curves are located very near to Caville

Hall (measurement points 1 to 7, respective ground cameras 1 to 7 and two high cameras 11 and 12). The straight road section is located approximately two kilometres further down the road, very close to the Royal Oak pub (measurement points 8 to 10, ground cameras 8 to 10, high cameras 13).

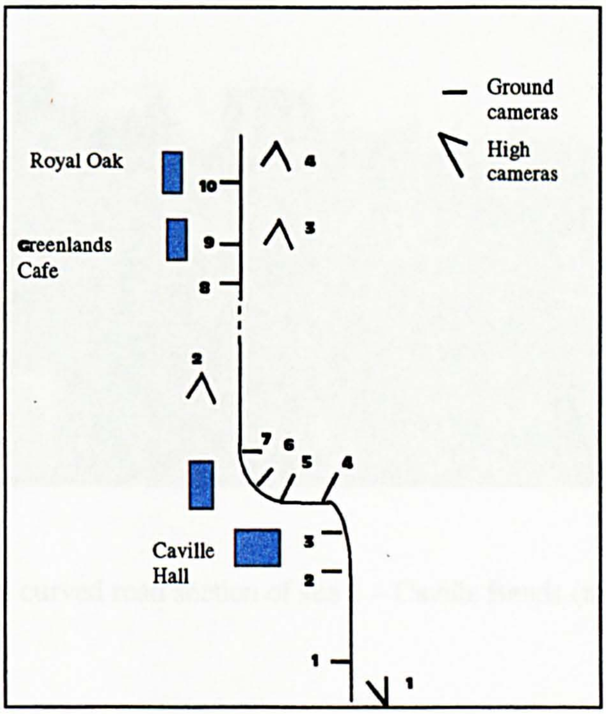


Figure 5-6 Position of ground and high cameras for site 1

Figures 5-7 and 5-8 show a view of the curves and the straight road section of the first site respectively. The first picture (Figure 5-7) was taken from the exit point of curve C1. The second picture (Figure 5-8) was taken from the first measurement point of the straight section of site 1.

Figure 5-7 View of the curved road section of site 1 – Caville Bends (real road)

Figure 5-8 View of the straight road section of site 1 (real road)

The second site is located between Moores' Farm and Welham Bridge and it also includes two consecutive curves and a straight section. The position of the ground and high cameras for site 2 are shown in Figure 5-9. The first curve of site 2 is located at Moores' Farm (measurement points 11 to 14, respective ground cameras 11 to 14 and high camera 5) and the second one at Welham Bridge (measurement points 15 to 18, respective ground cameras 15 to 18 and high camera 6). The second investigated straight section is located approximately six hundred meters further down the road from the second curve of site 2 (measurement points 19 to 21, respective ground cameras 19 to 21, high camera 7).

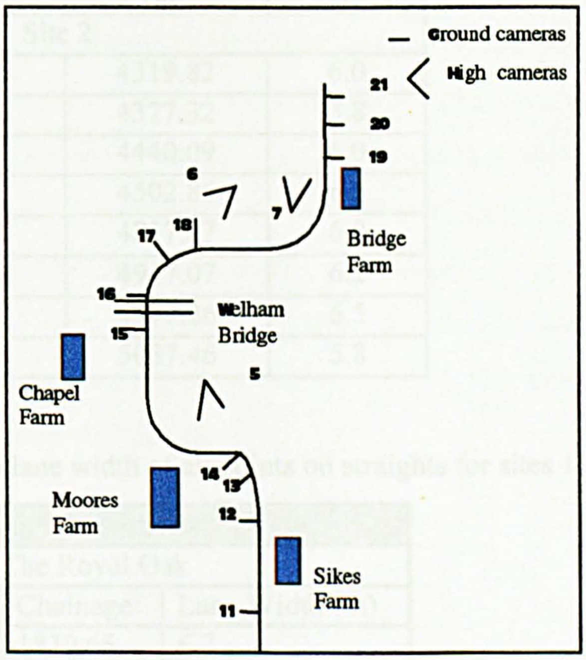


Figure 5-9 Position of ground and high cameras for site 2

The chainage of all points (both for the curved and straight road sections) where the measurements were taken as well as the lane width (as it was measured on site) for each point are given in Table 5-6 (for the curves) and Table 5-7 (for the straights). The reference point (chainage=0) for the chainage of all points was an intersection of an access road and the A614, which was located 17.5m before the approach point of the first curve.

Table 5-6 Chainage and lane width of all points of curves for sites 1 and 2

A614 study - curved sections			
Curves	Measurement points	Chainage (m)	Lane Width
Site 1			
C1	1 (approach)	17.50	7.1
	2 (entry)	118.60	7.0
	3 (apex)	151.59	7.5
	4 (exit)	184.58	6.4
C2	4 (approach)	184.58	6.4
	5 (entry)	259.58	6.7
	6 (apex)	316.26	6.5
	7 (exit)	372.94	6.5
Site 2			
C3	11 (approach)	4319.82	6.0
	12 (entry)	4377.32	5.8
	13 (apex)	4440.09	6.0
	14 (exit)	4502.86	6.2
C4	15 (approach)	4817.07	6.0
	16 (entry)	4917.07	6.2
	17 (apex)	4977.26	6.5
	18 (exit)	5037.46	5.8

Table 5-7 Chainage and lane width of all points on straights for sites 1 and 2

A614 - straight sections			
Site 1- The Royal Oak			
Straights	Points	Chainage	Lane Width (m)
S1	8	1830.65	6.7
	9	1930.65	6.7
	10	2274.65	6.7
Site 2 - Bursea Lane Ends			
S2	19	5577.55	6.6
	20	5657.55	6.6
	21	5737.55	6.6

5.3.3. Sample of drivers

The literature review in regard to the number and type of subjects used for the validation of driving simulators (see Section 3.9, Chapter 3), showed that most researchers (92 percent) use an instrumented car for the real road data collection. Almost half of them (42 percent) conduct their experiment on a test track and the average number of subjects used for a validation study is 20. Subjects, who drive the instrumented car, have to drive the simulator afterwards or vice versa and are paid for their participation in the experiment. Although the behavioural validation studies, which use genuine road users and observational data, are regarded as the highest form of validation (Allen et al, 1991), they have never been performed before. To fulfil the requirements of this study, genuine road users' behaviour was monitored unobstructively and only free-flowing vehicles were measured.

5.3.3.1. Size of sample

The sample size for the genuine road users was dictated by a number of reasons related to the combination of the real road study and the simulated study:

a) For a road survey the sample size depends on three factors: i) the estimated sample standard deviation; ii) the desired confidence level and iii) the precision required in the estimated mean. For most of the free-flowing speed surveys on single A carriageways (or two-lane rural highways) about 120-140 passenger cars under free-flowing conditions are measured (to determine the 85^{th} percentile speed and design speed) in order to obtain statistically significant results. With regard to spot speed measurements, Kennedy et al (1973) recommended the measurement of at least 50, preferably 100 vehicles. According to Box and Oppenlander (1976) the number of speeds to be measured is derived from the formula:

$$N = (SK/E)^2$$

where: N= minimum sample size

S= estimated standard deviation

K= constant corresponding to the desired confidence level

E= permitted error in the speed estimate.

For the 95% confidence level the constant is 1.96. According to the authors the error may range from ±5.0 to ±1.0 mph or even less and the standard deviation of spot-speeds for an urban two-lane road equals to 4.8. Adopting the permitted error equal to 1 mph and applying these values to the formula above, gives a sample size of 88 drivers (however the standard deviation of speed on rural roads is usually higher than that on urban roads).

b) An adequate sample size would allow saying with more confidence that the results obtained from the simulator study can be transferred to the real world and that they can be generalised to other similar types of research studies too.

Therefore, it was judged that a sample size of 100 drivers would be satisfactory to fulfil the requirements of the validation study.

5.4. Simulator experiment

The simulator experiment took place from the beginning of May until the end of the second week of June 1997, one year after the real road experiment. The simulated road, a single carriageway A road, was developed to match as precisely as possible the straight and curved road sections of the real A614 road (the format of the design of the simulated road is given in Appendix 5-7). Pre- and post-experiment questionnaires were used to assess the realism and controllability of the simulator.

5.4.1. The equipment - The Leeds driving simulator

The driving simulator at the University of Leeds is a medium-cost simulator and its development has been funded by the Science and Engineering Research Council (now EPSRC) (Carsten and Gallimore, 1993). It has been fully operational since mid-1993 for rural-road scenes but nowadays can simulate urban environments too (Gallimore, 1996). The system developed at Leeds involves the following major hardware components: a) a Rover 216GTi donated by the manufacturer; b) a Silicon Graphics Onyx RealityEngine2 with MCO and 4xRM4; c) three Barco BD808 video projectors for a 120^{o} horizontal x 40^{o} vertical forward view; d) a Sony 1270 video projector for a 50^{o} horizontal x 40^{o} vertical rear view; e) a Roland S-760 digital sampler and f) CTX stand alone TFT-Panel. The TFT panel, which sits in the middle of the car dashboard, has been used to simulate a number of existing and prospective in-car advice systems in order to evaluate their effectiveness and any possible safety implications of their use. The car stands in front of a purpose-built, cylindrical projection screen. The images are soft-edge blended so there is no obvious "join" between images. An illustration of LADS projector set-up and visual scene is given in Figure 5-10.

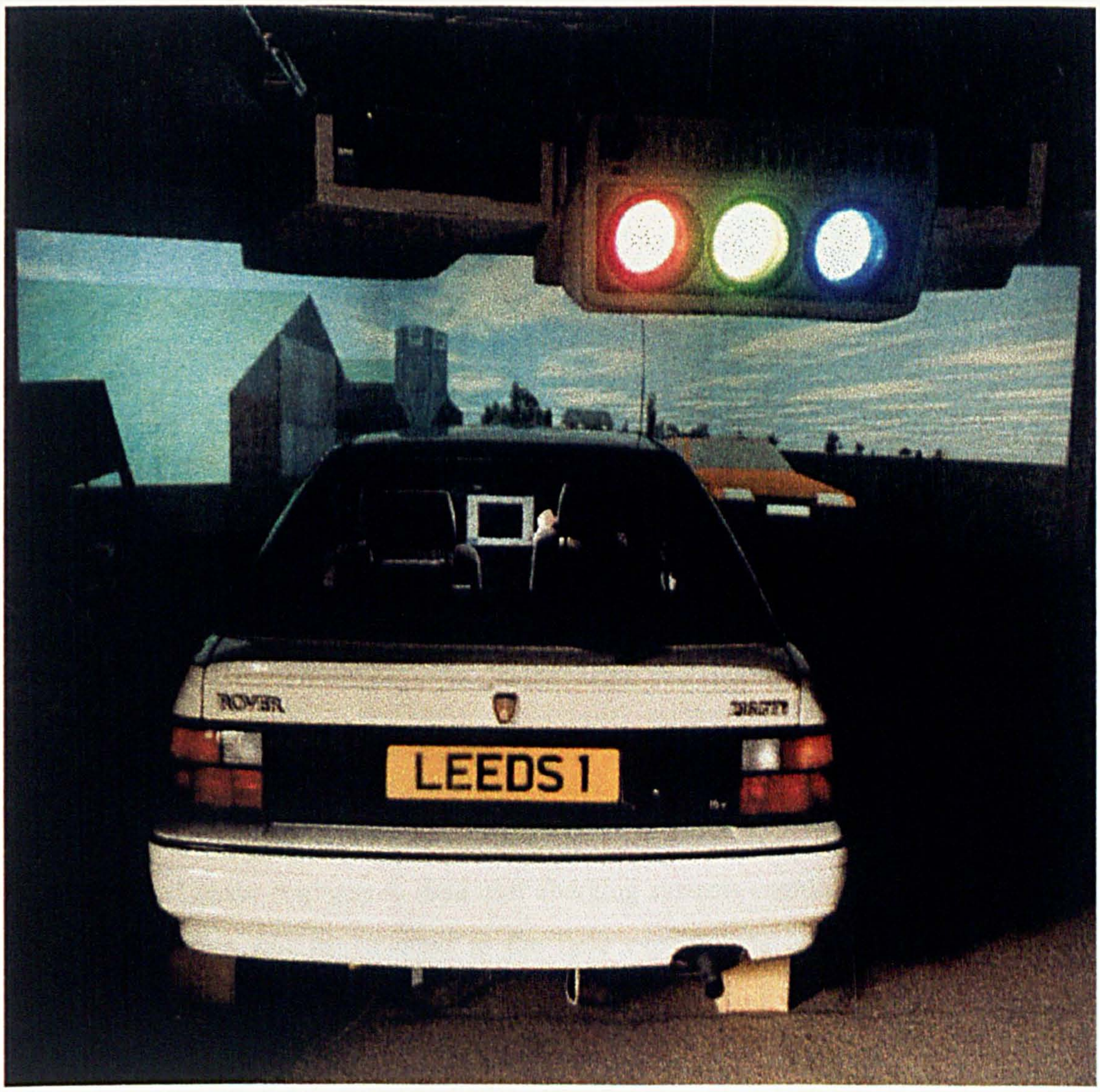


Figure 5-10 The Leeds Advanced Driving Simulator projector set-up and visual scene

The Silicon Graphics RealityEngine2 provides fully textured and anti-aliased images at a frame rate of at least 20 Hz at a screen resolution of 960x620 pixels per channel. It is possible, if necessary, to produce a high resolution (1280x1024) front-middle view with low resolution (640x480) front-left and front-right views, but no rear view is possible with such an arrangement.

The software in the Leeds Driving Simulator has been produced in-house (Gallimore, 1996). The current software suite allows: a) road networks to be created and previewed, b) "drone" vehicles (moving vehicles without "intelligence") to be added to the road network; c) random terrain to be added to the road network; d) experimental runs to be played back (for visual analysis); e) images to be imported from real objects to improve the realism of the virtual environment; f) complex scenario development; g) realistic fog to be added to the scene; h) realistic vehicle dynamics.

The simulator (LADS) has been used on numerous research projects. Blana (1996c) gives a detailed description of the projects undertaken in LADS. A summary of those projects is given below.

- investigation of the effects of a range of visual and non-visual variables on performance in the standard time-to-collision task;
- identification of practical and cost-effective remedial treatments in order to reduce the frequency and severity of accidents on single carriageway rural roads (Pyne, Dougherty, Carsten and Tight, 1995);
- the "Urban simulation on an advanced driving simulator" project (Gallimore, 1993; 1996);
- evaluation of a route guidance system (Rothengatter and Heino, 1994);
- testing novel sound patterns for emergency vehicle sirens and other devices;
- investigation of drivers' behaviour to automatic speed control in urban areas (Comte, 1996);
- evaluation of driver response to road user charging systems enabling to decide whether real-time charges can be included in the field experiments using ADEPT-equipped vehicles (Palmer and Bonsall, 1997).

5.4.2. The design of the simulator driving environment

The simulation of the A614 was based upon the geometry and environment of the real A614. The road network (i.e. road curvature and furniture such as trees, traffic signs, buildings) and traffic conditions of the real A614 were regenerated using the purpose-built software of the simulator. The following subsections describe the methodology followed to simulate the real A614 road and its traffic conditions.

5.4.2.1. Road network simulation

The A614 road network including road markings, signs and other road-side furniture such as trees, hedges and houses was created using a simple "text-based" language that describes all of the above elements. A translation program uses this description to create a scene database, to which landscape and moving cars may be added using other tools created for those purposes (Gallimore, 1996). The text description of the road is translated into two different presentations of the road. The first is a set of graphical objects that represent the road surface and are drawn by the simulation software (graphical road network). The second is a directed graph of paths linking together junctions (logical road network).

The road network is a compilation of different sections. Each section includes a number of *paths*. Paths are formed by different road segments, such as constant width straights; constant width, constant radius curves; and varying width straights or patches. They are connected to each other by junctions. When the road is built, other road elements are added, i.e. white lines (straight or curved, solid and/or dashed); signs; free standing objects (on the road or by the roadside); traffic lights; and drone vehicles. A library is available for a number of objects (houses, trees) and for most signs.

The simulator road should match exactly the road alignment of the A614, if realistic driving by subjects was to be achieved. Therefore, the road had to be replicated using exactly the same geometric characteristics of the curved and straight sections, which were used earlier for the real road experiment. That meant that a new map had to be created and match exactly with the Superplan. However, as these geometric characteristics had been measured directly from the Superplan (1:2500 scale) using a ruler, minor mistakes (e.g. in the estimation of the length of a straight or the length of the circular curve) in the range of mm could lead to major inaccuracies in the simulator, since the simulator has the capability of measuring lengths in the scale of 1:1. During the procedure of creating the simulator map, it was found that the first two curves matched perfectly between the two maps and there were minor inaccuracies in the position of the first straight. However, more mismatching between the two maps occurred when moving towards the other two curves. To solve this problem and to succeed a perfect matching, a "trial and error" procedure was followed. That is to say various lengths of tangents were measured from the beginning on the Superplan, which derived to various radii and as a consequence to various lengths of curves and each new length was plotted in the simulator map and then checked if it matched the Superplan).

The result of this procedure was a simulator map which perfectly matched the Superplan, but the curves and straights of the second site had slightly different chainage than the ones measured from the real map (the radii for all four curves were exactly the same for both maps). However, the field study had preceded the simulator experiment; therefore there was no way to repeat the field measurements using the measurements from simulator map. Table 5-8 compares the chainage of data points for the field study and the simulator.

Table 5-8 Comparison of field and simulator chainage for both sites

Comparison of field and simulator chainage					
Site 1			Site 2		
Points	Field chainage	Simulator chainage	Points	Field chainage	Simulator chainage
1	17.50	17.50	11	4319.82	4249.45
2	118.60	118.59	12	4377.32	4311.95
3	151.59	151.58	13	4440.09	4386.72
4	184.58	184.57	14	4502.86	4461.49
5	259.58	252.57	15	4817.07	4765.69
6	316.26	309.25	16	4917.07	4865.69
7	372.94	365.93	17	4977.26	4922.88
8	1830.65	1830.65	18	5037.46	4984.32
9	1930.65	1930.65	19	5577.55	5457.41
10	2274.65	2274.65	20	5657.55	5537.41
			21	5737.55	5617.41

Due to the special requirements of this experiment, i.e. the simulator road side furniture should look as similar as possible to the real one, the existing library could not be used for the creation of the A614 objects (houses, farms, trees). The road environment of the real A614 was videotaped and the images were scanned and imported to the computer. Based on these images the houses, farms, trees and other objects of the road were created and added to the appropriate road segments of the simulated A614 using texture mapping. An example of simulated road section is given in Figure 5-11 and Figure 5-12.

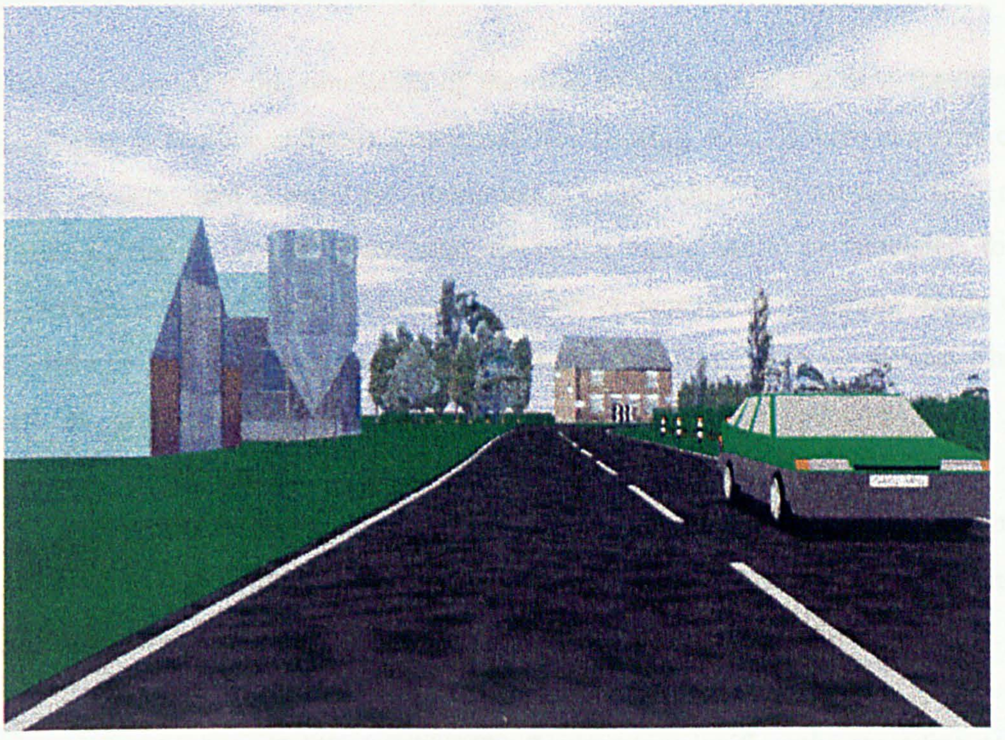


Figure 5-11 View of the curve road section of site 1 – Caville Bends (simulator)

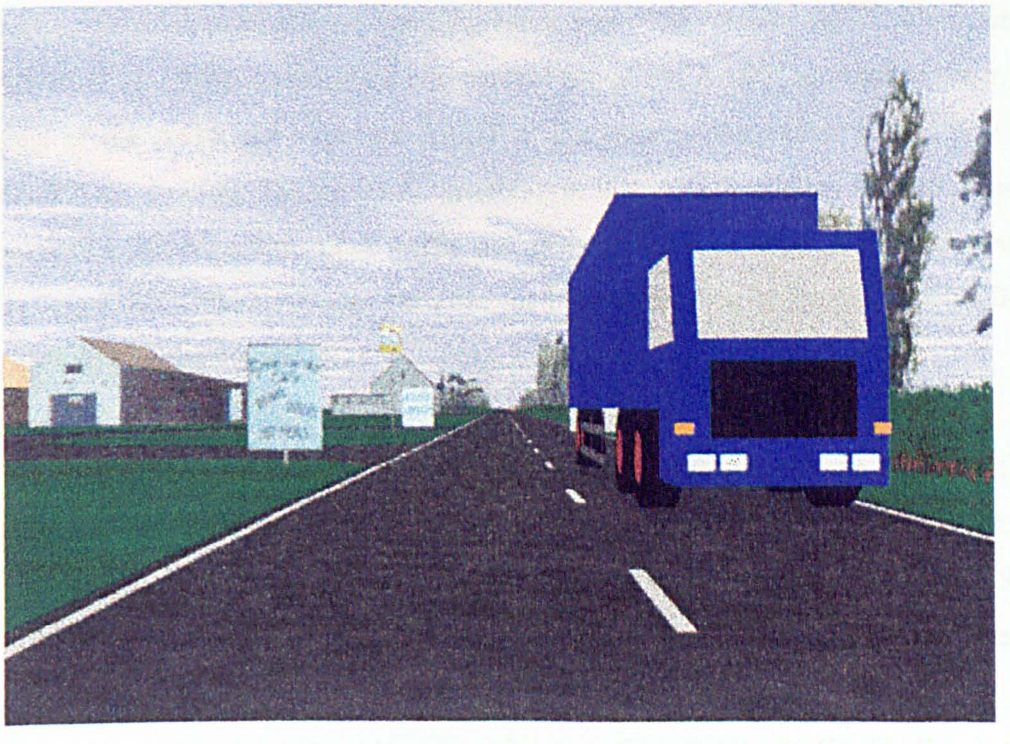


Figure 5-12 View of the straight section of site 1 (simulator)

5.4.2.2. Generation of oncoming traffic

The next step after the simulation of the road alignment and roadside furniture was the simulation of traffic conditions. Since only free-flowing vehicles were observed on the real road, it was decided to avoid the simulation of drone vehicles on the same lane, mainly for simplicity reasons. On the other hand, oncoming traffic had to be simulated, to resemble natural oncoming traffic conditions. The effect of absence of oncoming traffic on subject behaviour (especially in terms of lateral position) when driving in the simulator has already been recognised (Harms, 1993).

The real road oncoming traffic conditions were investigated both by on-site observations and existing data of the Annual Average Daily Traffic (AADT) of the A614 provided by the Humberside County Council (East Yorkshire Borough Council (EYBC) et al, 1994).

The A614 (Goole to Bridlington) traffic flow varies significantly according to the exact section of the route and the time of the year and usually it is nearly double at summer holiday times on some sections compared to winter times. The average AADT for the section Howden to Holme-on-Spalding-Moor was 6800 vehicles (1993 values, provided by EYBC et al, 1994). Assuming a two percent growth of AADT per year in the investigated area of the A614, the expected AADT at the time of the experiment (1997) would be 6800*1.02^4=7360. Taking into consideration that AADT applies to both directions and assuming that represents peak traffic (i.e. measured for 12 hours daily), the hourly traffic flow is 7360/12=613 vehicles per hour for both directions, or approximately 300 vehicles per hour per direction (613/2).

An on-site observation in September 1996 showed that the average number of AOV per hour was 164 (a decrease of thirty-one percent). However, because this value was from only one hour's observation, not at peak hour, it was assumed that the 1993 values (adjusted to 1997 values) were still valid and all calculations were based on these values.

The length of the investigated road section was 6 km (point A: Caville Bends to point B: Bursea Lane Ends Crossroads). The average headway was 12 seconds (300 vehicles/3600seconds). Assuming an average speed of 60 km/h (=16.66 m/sec), it takes 6 minutes to traverse the 6 km road section. Having an average headway of 12 seconds, a vehicle moves 200m (=16.66*12) at that speed. Therefore, the number of on-coming vehicles moving on the investigated length when a driver arrives at point A is 30 (6000m/200m). The number of oncoming vehicles that will arrive at point B in the time that the driver takes to traverse the section was 30 (300vehicles*6min/60minutes). Therefore, the total number of oncoming vehicles encountered on the investigated road section is 60 (=30+30) (defined as "average traffic").

After calculating the number of oncoming vehicles on the investigated road section, the second step was to distribute those vehicles along this stretch of the road in such a way as to resemble natural oncoming traffic conditions. The scenarios of the real oncoming traffic could not be simulated exactly the same as in real life because the average oncoming traffic flow not only varied between the day but also in terms of composition and number of vehicles at particular points.

Therefore, as a first step, different oncoming traffic conditions had to be tested and depending on the results, the most appropriate to be compared with the real road data would be chosen. Three different oncoming traffic conditions were defined: condition C (the simulator vehicle met no oncoming traffic); condition M (the simulator vehicle met medium oncoming traffic and condition H (the simulator met heavy oncoming traffic). The M condition was defined as 20% less traffic than the average traffic (48 vehicles) and the H condition as 30% more traffic than the average traffic (78 vehicles). The composition of the traffic flow is approximately 20% heavy good vehicles (HGV) and 80% any other vehicle (AOV).

As a second step, the composition and number of oncoming vehicles at the investigated curved and straight road sections had to be defined. On-site observation showed that oncoming traffic was "formed" depending on the geometric conditions of the road (e.g. radius and length of curve, sight distance) and the type of the leading vehicle. The common pattern of oncoming vehicles at the investigated sections were 4 to 5 vehicles forming a queue or 1 leading HGV and 6 to 7 following vehicles. The aim was to distribute the number of oncoming vehicles in such a way as each driver would encounter the same number and the same composition of oncoming vehicles at each investigated road section. To achieve this, the simulated A614 was divided into 7 main sections (1 to 7), each section included the respective measurement points for each investigated curved and straight road section on the A614 plus the road sections in-between the investigated sections. In each section, the distribution of the oncoming vehicles was based on the on-site observations.

During the design of the simulated road, it was found that two subsections (A and B) had to be added to facilitate the programming of the drone oncoming vehicles. That is to say, a distance was required in the beginning of the road in order for the drone vehicles to have time to accelerate properly and not disappear suddenly inside the length of the first curve (Caville Bends). Similarly, the end of the investigated section required a distance so as the drone vehicles would not disappear suddenly before the subjects reached the end of the investigated section.

Extreme care was taken during the design phase of the simulator oncoming traffic and it was proved difficult for all simulator drivers to meet exactly the same number of oncoming vehicles at all measurement points. A "trial-and-error" method was used to identify the appropriate "average simulator car speed" and the drone vehicles "target speed" for each of the nine sections, and in particular for sections 1, 3, 4, 6 and 7 where the 21 measurement points were included. Drone vehicles *per se* have a "target speed" and are limited to this. For example if the predefined speed is 50 km/h, this means that drone vehicles start at zero (0) speed and accelerate until they reach the target speed. They do not have the capability of adapting their speed to the speed of the simulator car. Drone vehicles are designed to be triggered (i.e. to start) according to the "simulator car speed", which can vary depending on the driver and the road geometry. Therefore, the simulator car was initially driven at a number of fixed speeds for each section (since each section differed in terms of geometry) and the drone vehicles were triggered according to the respective "simulator car speed". Each time the drone vehicles had different target speed. This "trial-and-error" procedure was very tiresome and time-consuming. The best combination of "simulator car speed" and drone vehicle "target speed" was defined for each section after a number of trials. The major drawback of this procedure is that, if subject speed differed significantly from the "simulator car speed", then it is probable that the subject may not meet any oncoming traffic at some of the measurement points and may meet the oncoming vehicles at another location, not significant for the purpose of this experiment.

The distribution of the drone vehicles as well as their respective target speeds for each of the nine sections of the road is given in Table 5-9. An example of the format used to generate the oncoming traffic in the simulator is given in Appendix 5-8.

Table 5-9 Distribution of traffic flow on the simulated A614

Sec	Site (Measurement points)	Length (m)	Target speed km/h (m/s)		Light traffic		Heavy traffic	
			AOV	HGV	AOV	HGV	AOV	HGV
A	Start to Caville Bends	500.0	55 (15.0)	45 (12.5)	4	1	7	2
1	Caville Bends (1 to 7)	531.0	75 (21.0)	60 (16.7)	4	1	7	2
2	Caville Bends to Royal Oak	724.7	75 (21.0)	60 (16.7)	5	0	8	0
3	Royal Oak (8 to 10)	552.3	90 (25.0)	70 (19.4)	4	1	7	2
4	Moore's Farm (11 to 14)	931.2	85 (23.6)	65 (18.0)	10	2	15	4
5	Moore's Farm to Welham Bridge	865.3	80 (22.2)	65 (18.0)	9	2	14	4
6	Welham Bridge (15 to 18)	920.0	70 (19.4)	65 (18.0)	6	2	9	3
7	Bursea Lane (19 to 21)	355.3	85 (23.6)	70 (19.4)	2	0	4	1
B	Bursea Lane to End	500.0	85 (23.6)	70 (19.4)	4	1	7	2
Tot		5879.7			48	10	78	20

5.4.3. Experimental design

The repeated measure design was adopted for the allocation of subjects to the different oncoming traffic conditions of the simulator experiment of the validation study. This design was selected on the basis that we wanted each of the subjects to experience all three different oncoming traffic conditions. There were two reasons for that. The first one was that it is not exactly known if simulator subjects can perceive differences in traffic volume moving in the opposing lane. The second one was to investigate if there are any "learning" effects since subjects' stated that during the third run they felt more comfortable to control the simulator and drive it as they would drive a real car on a real road. "Learning" effects here means to test whether subjects were sufficiently familiar with the simulator. Because the repeated measure design suffers from order effects, subjects were randomly distributed to the three counterbalanced oncoming traffic conditions (the test design is given in Appendix 5-9). Each oncoming traffic condition (C, M, and H) constituted a different run.

5.4.3.1. Simulator data

Before proceeding to the comparison of the real road and simulator data it had to be decided which of the three aforementioned simulator traffic conditions will be compared to the real oncoming traffic conditions which were very similar to the M condition. The following alternatives were considered.

a) to completely ignore the C and H simulator conditions and compare the real road data directly with the M simulator condition (whichever the run);
b) to compare the real road data directly with the M condition of the third run (taking into account subjects' comments); and finally
c) to examine if the overall presence of oncoming traffic had an effect on subjects' driving behaviour in the simulator, taking into account at the same time the learning effect. In this case, if there was no difference in subject speed and lateral position between the different oncoming traffic conditions and no difference between the three different runs, then the sum of simulator data (all three runs and all three oncoming traffic conditions) could be compared with the real road data.

Although the oncoming traffic volume along the overall length of the investigated real road section was medium, the precise amount of oncoming traffic was not exactly known at each measurement point during the real road data collection (it could vary from light to heavy). Thus, the first alternative had to be abandoned. The second alternative was abandoned due to the fact that the number of subjects running under M condition in the third run was only 34. Thus, it would not be possible to fully exploit the total number of subjects which was 97 (97 instead of 100 subjects data was used due to problems retrieving 3 subjects' data from the simulator).

It was decided to carry on with the third alternative. There were two null hypotheses to be tested here:

a) there is no difference in mean speed and lateral position within the three different oncoming traffic conditions whether driving the simulator car for the first, second and/or third time);
b) there is no difference in mean speed and lateral position within the three different runs whether driving the simulator car at C, M, and/or H oncoming traffic conditions.

Analysis of variance (ANOVA) was performed to test the above hypotheses. One-way ANOVA (i.e. one variable is used to classify cases into the different groups) was used to test both hypotheses. This analysis can be used only if each group is an independent random sample from a normal population and in the population the variances are equal. The statistics group for the null hypothesis (Ho) that all groups have the same mean in the population is based on the F Ratio. This means that the within-groups mean square and the between-groups mean square (the two estimates of variability in the population) should be close to each other and if we divide one by the other, the ratio should be close to 1.

The observed significance level is obtained by comparing the calculated F value to the F distribution (i.e. the distribution of the F statistic when the null hypothesis is true). The significance level (from now on and in all following tables of this section it will be written as "Sig. F") is based on both the actual F value and the degrees of freedom for the two mean squares. It is the probability that a difference at least as large as the one observed would have arisen if the means were really equal. If it is small, e.g. Sig. F<0.05, then Ho is rejected (Norusis, 1993).

The equality of variances was tested using the Levene test (see section 7.2.1). It is a homogeneity-of-variance test, less dependent on the assumptions of normality than most tests and is thus particularly useful in analysis of variance. It is obtained by computing, for each case the absolute difference from its cell mean and performing a one-way ANOVA on these differences. If the two-tailed significance (from now on and in all following tables of this section it will be written "Levene") is small, e.g. Levene<0.05 then the null hypothesis that variances are equal is rejected (Norusis, 1993).

If the null hypothesis that the population means from the three different groups are equal is rejected (either referring to oncoming conditions C, M and H or runs 1, 2 and 3), then a multiple comparison procedure can be used to determine which means are significantly different from each other. The Bonferroni test was used to check if the difference between two means was different. This test adjusts the observed significance level based on the number of comparisons made, for the difference to be significant at the 0.05 significance level (Norusis, 1993).

The results for testing the first null hypothesis (relative to the different oncoming traffic) on driver behaviour are summarised in Table 5-10 and Table 5-11, whereas the results for testing the second null hypothesis (relative to the three different runs) are summarised in Table 5-12 and Table 5-13. For all analyses, the number of cases accepted were 2037 (therefore the between groups degree of freedom was 2 and within groups 2034) besides for when testing run 1 for the effect of different oncoming traffic conditions on driver behaviour where the number of cases accepted were 2031 (6 cases were rejected due to missing data). In this case, the between groups degree of freedom was again 2 and the within groups 2028). The significance level used was 0.05.

Table 5-10 Testing the effect of different oncoming traffic conditions on driver behaviour (simulator data)

One-way ANOVA				
Runs	Variables	Sig. F	Levene	Null Hyp.
Run 1	Speed	0.622	0.094	Accept
	Lat. Pos.	0.000	0.010	Reject
Run 2	Speed	0.108	0.134	Accept
	Lat. Pos.	0.000	0.014	Reject
Run 3	Speed	0.373	0.458	Accept
	Lat. Pos.	0.000	0.000	Reject

From Table 5-10 it can be seen that for all three runs, subject speed did not differ whether the subject was driving in C, M and/or H oncoming traffic conditions. On the other hand, subject lateral position for all three runs did differ when driving under the C, M and/or H oncoming traffic condition. The Bonferroni test at the 0.05 significance level was used to determine which means are significantly different from each other. It was found that, in each of the three runs, lateral position for condition C differed significantly between any of the other two conditions, whereas conditions M and H did not differ between each other. This means that oncoming traffic does have a significant effect on driver behaviour in terms of lateral position, i.e. it forces drivers to move to the edge of the road, whether it is medium or heavy (see Table 5-11).

Table 5-11 Testing the significance of differences between oncoming traffic conditions (simulator data)

Bonferroni Multiple Range Tests			
Lateral position			
Runs	Condition C	Condition M	Condition H
Run 1	687*	500	504
Run 2	641*	433	432
Run 3	678*	460	433

*: indicates significant differences of this group from every other group

Overall, in all three runs, speed data did not differ between the different oncoming traffic conditions and lateral position did not differ between the oncoming traffic conditions M and H. Therefore, simulator speed and lateral position data from conditions M and H of all three runs could be combined.

The results from testing the second null hypothesis (different runs) are shown in Tables 5-12 and 5-13. It was shown that for condition C and in all three runs, subject speed and lateral position did not differ. On the other hand, when driving at M and/or H oncoming traffic conditions, subject speed and lateral position differed for all three runs (see Table 5-12).

Table 5-12 Testing the effect of different runs on driver behaviour (simulator data)

One-way ANOVA				
Condition	Variables	Sig. F	Levene	Null Hyp.
Condition C	Speed	0.160	0.964	Accept
	Lat. Pos.	0.146	0.012	Accept
Condition M	Speed	0.002	0.257	Reject
	Lat. Pos.	0.006	0.321	Reject
Condition H	Speed	0.016	0.151	Reject
	Lat. Pos.	0.001	0.059	Reject

The Bonferroni test at the 0.05 significance level was used to determine which means are significantly different from each other. It was found that for condition M, the speed of run 3 differed from the other two, whereas lateral position of run 1 differed from the other two runs. For condition H, speed and lateral position of run 1 differed from the other two runs (see Table 5-13). In the majority of the cases, simulator data (in terms of speed and lateral position) did not differ between runs 2 and 3, so that data from runs 2 and 3 could be combined.

Table 5-13 Testing the significance of differences between each run (simulator data)

Bonferroni Multiple Range Tests						
Conditions	Run 1		Run 2		Run 3	
	Speed	Lat. Pos	Speed	Lat. Pos	Speed	Lat. Pos
Condition M	66.04	500*	66.20	433	69.87*	460
Condition H	65.41*	504*	68.62	432	68.21	433

*: indicates significant differences of this group from every other group

Since oncoming traffic conditions M and H did not differ from each other and runs 2 and 3 did not either differ from each other both in terms of speed and lateral position (except for condition M, in terms of speed only), it was decided to analyse the simulator road data of runs 2 and 3 both for medium and heavy oncoming traffic conditions. Because some subjects appeared twice in this set of data, it was decided that for these particular subjects, the average of the two values should be taken as the final value.

5.4.4. Control of extraneous variables

Extraneous variables arise from five general factors: subjects, experimenters, setting, apparatus and procedure. In order to control these confounding situational variables a number of measures were undertaken.

Subjects' individual characteristics and personal comments were recorded in order to identify possible influences on the outcome of the experiment. The general characteristics of subjects were collected in the initial pre-experiment questionnaire. Details of the questions used appear in Appendix 5-10. An equal number of males and females were collected, 50 subjects in each category. A test protocol was used for all subjects in order to control the "running" phase of the experiment. This protocol will be fully described in section 5.4.7.

Because experimenters like subjects, pass on a variety of characteristics and expectations that might influence the outcome of the experiment, it was decided to use only one experimenter (the author) during the whole duration of the experiment unless a serious reason occurred and another experimenter had to be used. In that case, the author trained the other experimenter so he/she would be able to do exactly the same as her and written instructions were given to him to consult them when in doubt (see Appendix 5-11).

The simulator was the apparatus used to monitor subjects driving behaviour. Although it was frequently checked to make sure that it was functioning properly, some problems with the steering wheel occurred. Subjects who experienced such problems were excluded from the analysis.

It has been observed from earlier studies in the Leeds simulator, that in a simulator experiment that involves more than one experimental condition and when the experiment lasts more than 40 minutes, subjects become, as the experiment progresses, bored and/or tired. In order to control these factors, subjects had at least a 5 minutes break between each experimental condition.

5.4.5. Source of subjects

During the experimental design it was decided to concentrate on acquiring subjects from an everyday background of living and working within the area of Leeds. The first approach recruitment areas were the two universities of Leeds (University of Leeds and Leeds Metropolitan University). Although it was known that Academic/Research staff and students were not necessarily representative of the driving population at large (Koutsopoulos, Polydoropoulou, and Ben-Akiva 1993), the decision to do this was partly due to the fact that these large number of persons are always near at hand. Other organisations were approached such as the Leeds City Council and the Institute of Advance Motorists as well as recruitment lists from earlier simulator studies were used. A total number of 112 drivers took part in the experiment (eleven subjects suffered from simulator sickness, i.e. 10 per cent).

Only one criterion was required for subjects to be eligible to take part in the experiment: they should have more than three years driving experience. This was done in order to avoid novice drivers who may not feel very comfortable yet with the driving task, and may probably find it more difficult to drive an unfamiliar car in a laboratory environment and control the simulator.

As in the real road experiment, one hundred subjects (100), both males and females, took part in the simulator experiment. An on-site observation of genuine A614 road users, showed that the driving population is predominantly male (85 percent) and their average age was forty-five years old. However, it was decided that the number of male and female subjects should be equal as well as the size of age categories in order to enable detection of sex and age differences.

5.4.6. Subject data

Subject data included data related to subjects' individual characteristics and their personal opinions relative to the realism of the simulator and data that was recorded automatically when subjects' drove the simulator.

For data points 1 to 21, the following parameters from the simulator were recorded: a) Subject number; b) Condition; c) Order; d) Point; e) Carriageway width; f) Spot Speed (s) in km/h; and g) Lateral position (l_l) where l_l: the distance from the front left wheel of the car to the left white line by the edge of the road in mm (see Figure 5-13).

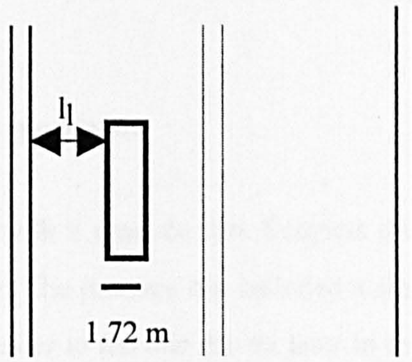


Figure 5-13 Definition of the lateral position of the simulator car

The post-processed data were saved into six different files according to the oncoming traffic conditions and the sites are given in Appendix 5-12.

5.4.7. Running the experiment - Subject handling

One critical aspect for the successful completion of a laboratory behavioural study is the way subjects are handled. The following paragraphs will describe the standardised procedure (test protocol) ensued for this experiment. The test protocol consisted of three phases:

5.4.7.1. Phase 1: Pre- experiment

Each subject was welcomed to the simulator experiment and escorted from the waiting area to the handling area. There the experimenter introduced herself by name and invited the subject to sit down. The instructions relative to the nature and duration of the experiment were read to them aloud (see Appendix 5-13). Subjects were also made aware of the simulator sickness and the use of the wellbeing scale to measure it (see Appendix 5-14). Having heard the instructions and agreed to participate in the experiment, subjects were left to sign a consent form (see Appendix 5-15). They were then presented with a questionnaire related to their personal characteristics including age, gender, driving experience, annual mileage, their familiarity with computers and their vision acuteness. Examples of the subject characteristic questions are given in Appendix 5-10. Upon completion of the questionnaire, subjects had to fill in the pre-experiment wellbeing scale. Finally, subjects were escorted to the simulator room, briefed about the controls of the simulator, sat in the car, adjusted their seat and fastened their seatbelt.

5.4.7.2. Phase 2: The experiment

The experiment started with a practice run. Subjects drove approximately 6-8 minutes to get used to the simulator. The practice run included a single-carriageway rural A road. The road layout was very similar to the one driven later in the test run. During the practice run the experimenter was present, to assist the subject (make them feel more comfortable and answer any of the subjects' questions if they were in doubt about the use of the apparatus) and then after the practice run, the subject drove the three different test runs (conditions). During the test runs the experimenter was not present inside the simulator room but she retired to the control area where she could watch subjects' reactions through a monitor. After the end of each run (including the practice run), subjects had a short break (approx. 5 minutes). Each time, they were escorted to the handling area where they filled in the wellbeing scale for the simulator sickness (i.e. they filled in 5 wellbeing scales) (see Appendix 5-14).

5.4.7.3. Phase 3: Post-experiment

After the end of the third run, subjects were escorted back to the handling area. Subjects were reminded that this was the end of the simulator driving and the final stage was to complete a questionnaire, this time pertaining to impressions and opinions as well as the post-experiment wellbeing scale. Samples of the opinion questionnaire are given in Appendix 5-16. They were then given their payment (seven pounds) and signed the receipt form (see Appendix 5-15). The subject was thanked for their time and taking part in the research project. The overall experiment lasted between 30 to 40 minutes, depending on the breaks between each run.

5.5. Chapter summary

This chapter described the data collection both for the field study and the simulator experiment. Two pilot studies were conducted before the final field study in order to determine the best method, in terms of accuracy of measured data and value for money, for analysing the real road video data. It was decided to manually decode the data instead of using commercial software (ViVAtraffic).

Real road data was collected on the A614 single carriageway rural road (located near junction 37 on the M62 east). The investigated section of the road was six kilometres and it was divided into two sites to facilitate the video recording. For each site, speed and lateral position data of 100 drivers was collected on two curved and on straight sections using ground and high cameras. For each curve, four data points were taken, namely the approach, entry, apex and exit points of the curve and three points in each straight.

The replication of the real road alignment in the simulator was based on the geometric characteristics of each bend and straight of the investigated section of the A614. The characteristics were measured on a 1:2500 scale Superplan map by Ordnance Survey. The real road furniture (including oncoming traffic) was replicated as close as it could be within the capabilities of the existing configuration of LADS at the time of the experiment.

As for the real road study, 100 subjects took part in the simulator experiment. Subjects were allocated into three different oncoming traffic conditions and counterbalanced to minimise the order effects.

6. CHAPTER SIX

SUBJECT DATA ANALYSIS

6.1. Introduction

The previous chapter detailed the experimental procedure followed to validate the simulator. This chapter will state the major findings relating to the simulator subjective data. The following sections will present the descriptive, inferential and qualitative analyses applied to the data collected from the pre- and post-experiment questionnaires, i.e. subjects' individual characteristics and their responses as well as comments related to the face validity of the simulator respectively. The hypothesis that the increase of simulator face validity contributes to the increase of the simulator behavioural validity was tested.

6.2. Subject individual characteristics

The general characteristics of subjects were collected in the initial pre-experiment questionnaire. Details of the questions used appear in Appendix 5-10. Responses to each of the questions asked relative to their age and gender categories are given in detail in Table 6-1 to Table 6-8, Appendix 6.

The sample size for descriptive and qualitative analyses was 100 subjects unless stated otherwise. An equal number of male and female subjects took part in the simulator experiment, namely 50 males and 50 females. Both male and female subjects were allocated equally to four age categories, i.e. 34 in the first category (20-25 years old), 32 in the second category (26-30 years old), 24 in the third category (31-40 years old) and 10 in the last category (older than 40 years old). Despite the age range of subjects tending towards young (66% of subjects less than 30 years old), the level of driving experience (number of years holding a full driving licence) was reasonably high: 80% of subjects have held their driving licence for more than 5 years. The majority of subjects came from the university area, either being researchers or students (69%); drive less than 10000 miles annually (69%); had not driven the simulator before (73%); had not taken advanced driving lessons (84%) and were not particularly familiar with arcade and/or computer games (67%).

Female subjects seemed to have better driving experience in terms of years holding their driving licence and miles driven per year. In particular, in terms of holding their driving licence, 87.5% more males than females had held their driving licence less than 5 years and 46% more females had held their driving licence more than 10 years. In terms of miles driven per year, 57% more males than females drove less than 5,000 miles annually and 36% more females than males drove more than 10,000 miles annually. There was an almost equal distribution in some of the subjects' individual characteristics between the two genders. An equal percentage of males and females were students (21% and 22% respectively), had taken advanced driving lessons (8% respectively), had driven the simulator before (13% and 14% respectively) and had the same vision deficiency (in terms of wearing glasses and/or contact lenses, 21% and 23% respectively).

6.2.1. Inferential statistics

Analysis of Variance (ANOVA) was used to test if there was any effect of subjects' individual characteristics (age and gender) on their driving behaviour when driving on curved and straight road sections in the simulator with the presence of oncoming traffic. An introduction to this statistical test is given in section 5.4.3.1 in Chapter 5. The 0.05 statistical significant level was used for the interpretation of the ANOVA results.

The results showed that

i. there was <u>no effect of age</u> on subjects' driving behaviour, in terms of speed ($F_{3,89}$=2.449, p=0.069 for curves and $F_{3,89}$=2.649, p=0.054 for straights) and lateral position ($F_{3,89}$=1.703, p=0.172 for curves and $F_{3,89}$=0.646, p=0.587 for straights);

ii. there was <u>no effect of gender</u> on subjects' driving behaviour, in terms of speed ($F_{1,89}$=2.664, p=0.106 for curves and $F_{1,89}$=0.012, p=0.914 for straights) and lateral position ($F_{1,89}$=2.138, p=0.147 for curves and $F_{1,89}$=0.763, p=0.384 for straights);

iii. there was <u>no interaction of age by gender</u> on subjects' driving behaviour, in terms of speed ($F_{3,89}$=0.547, p=0.652 for curves and $F_{3,89}$=0.566, p=0.639 for straights) and lateral position ($F_{3,89}$=0.660, p=0.579 for curves and $F_{3,89}$=0.881, p=0.454 for straights);

It could be concluded that subjects gender and age do not affect their performance (in terms of speed and lateral position) when driving the simulator car on a rural road in the presence of oncoming traffic and different geometric road features.

6.3. Subject opinions

Subjects' opinions on the realism and ease of controlling the simulator were collected at the conclusion of the experiment during the post-experiment questionnaire. The questionnaire was fixed choice where subjects were asked to select an answer from five alternatives. In particular, subjects were asked to comment on five different categories relating to different aspects of the simulator. The first category related to the realism of the simulator; the second one related to the ease of controlling it; the third one related to the monotony of the journey; the fourth one relative to the effect of the oncoming traffic to the speed and lateral position of the simulator vehicle and the last one related to the use of the rear-view and right-wing mirrors. A five-point attitude scale was used to assess the answers of the subjects (see Appendix 5-14 for an example of the questionnaire). An attitude scale is designed to produce scores indicating the intensity and direction (for or against) of a person's feelings about the objects or event (Sommer and Sommer, 1991). The reason for choosing an odd number scale was that comparing to an even number scale it has a middle point. The middle point represents subjects' neutral feeling towards the object or event. For all categories besides the third one, 100% stacked column diagrams were used to represent the results. This type of diagram compares the percentage each value contributes to a total across categories.

In particular for the first category, subjects were asked to comment on the realism of the simulator in terms of speed and lateral position when driving on straight and curved road sections and the realism of the steering wheel and the brakes. The format of the questions asked was *"How realistic was it driving on [straight][curved] road sections in terms of [speed][lateral position]?"; "How realistic did you find the feeling of the steering wheel?"; "How realistic did you think the brakes feel?"*. The results showed that the least realistic feature of the simulator was the feeling of the brakes followed by driving on curved sections in terms of speed. However, no hard braking condition was included in the experiment, subjects only had to brake when they saw the stop signs at the end of the test run). Driving either on straight or curved road sections was almost equally realistic for subjects, slightly better on straights in terms of speed and significantly better in terms of lateral position. The most realistic feature was driving on straights in terms of speed (see Figure 6-1).

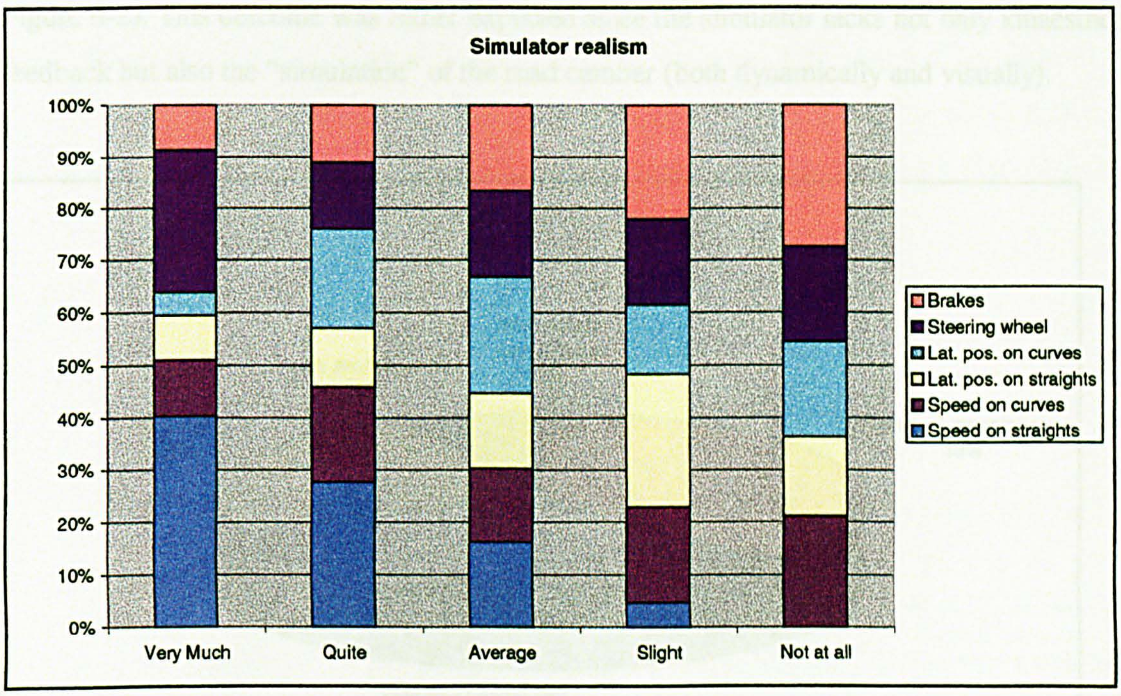


Figure 6-1 Subject opinions on simulator realism

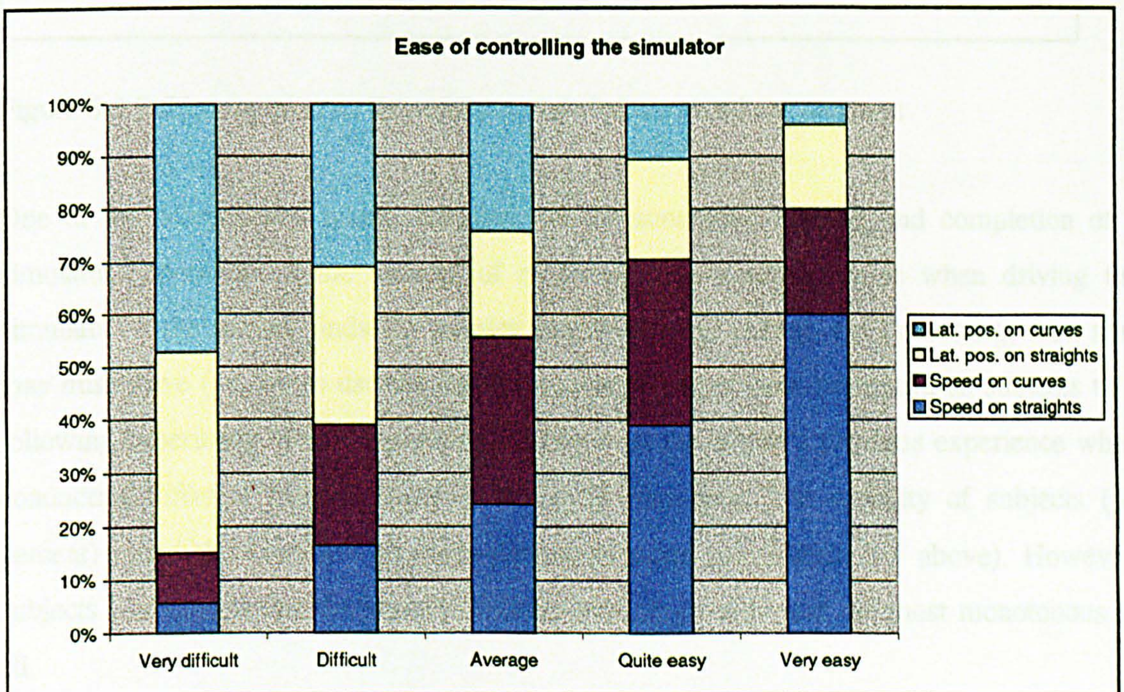


Figure 6-2 Subject opinions on ease of controlling the simulator

For the second category, subjects were asked to comment on the ease of controlling the simulator on straight and curved road sections. The format of the questions asked was *"How easy was controlling the [speed][lateral position] of the simulator on [straight][curved] road sections?* The results showed that controlling the simulator was much easier on straight than curved road sections in terms of speed. On the other hand, in terms of lateral position, subjects stated that it was more difficult to control it on curves compared to straights (see

Figure 6-2). This outcome was rather expected since the simulator lacks not only kinaesthetic feedback but also the "simulation" of the road camber (both dynamically and visually).

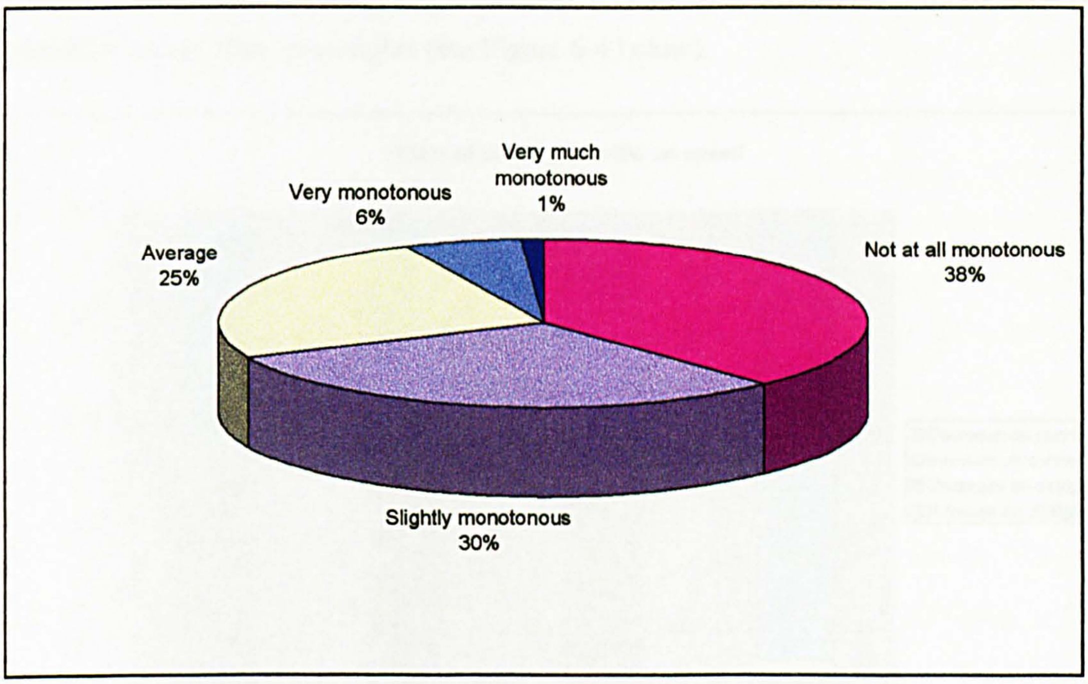


Figure 6-3 Subject opinion on the monotony of all three simulator journeys

One of the components, which contribute to the successful running and completion of a simulator experiment is the amount of monotony that a subject feels when driving the simulator. If the subject finds the journey monotonous or boring, not interesting, then s/he may misbehave (i.e. try to use the simulator as a game) or does not return as subjects to a following experiment. This conclusion was based on the author's previous experience when conducting different natured experiments in the simulator. The majority of subjects (68 percent) found the simulator journeys not monotonous (see Figure 6-3 above). However, subjects commented that the journey without oncoming traffic was the most monotonous of all.

Subjects were asked to comment on the effect of oncoming traffic on their speed and lateral position on the straight and curved sections of the investigated road. Only 17% said that there was no effect on their lateral position due to oncoming traffic when driving on straights and 14% when driving on curves. However, a significant percentage (31%) said that oncoming traffic did not affect their speed at all when driving on straights whereas only 8% said that there was no effect when driving on curves.

The majority of subjects replied that oncoming traffic made them reduce their speed on straights (69%) and even more on curves (92%). An equal percentage of subjects (18%) stated that oncoming traffic resulted in a slight decrease on their speed, but about 85% more subjects stated that oncoming traffic affected very much in a negative way (decrease) their speed on curves than on straights (see Figure 6-4 below).

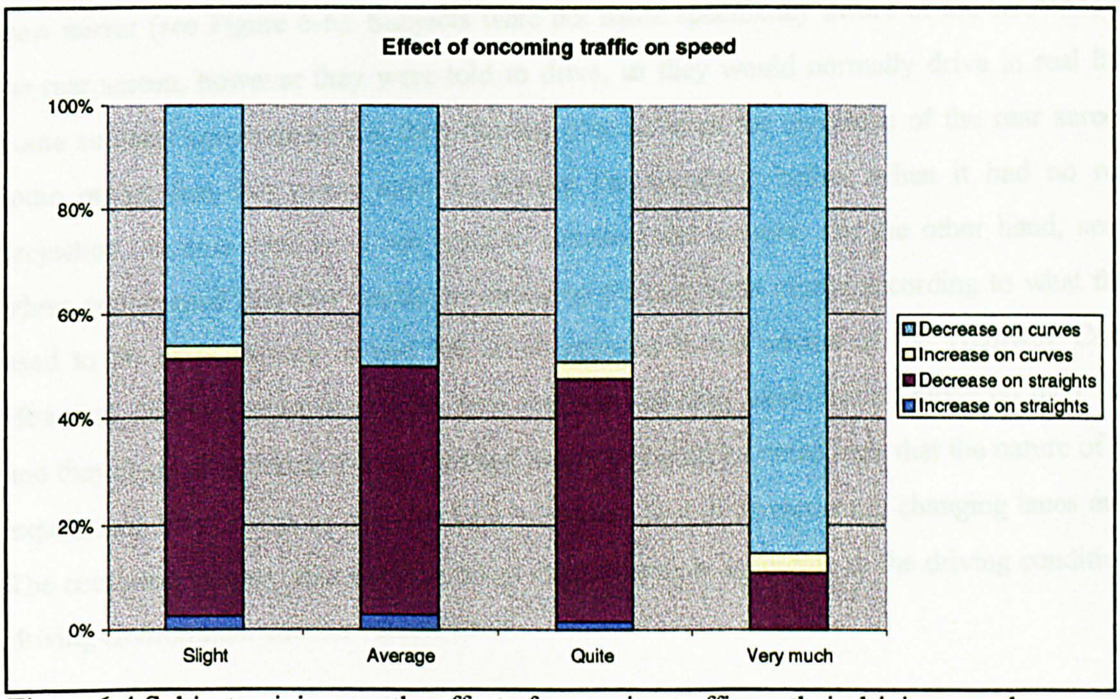


Figure 6-4 Subject opinions on the effect of oncoming traffic on their driving speed

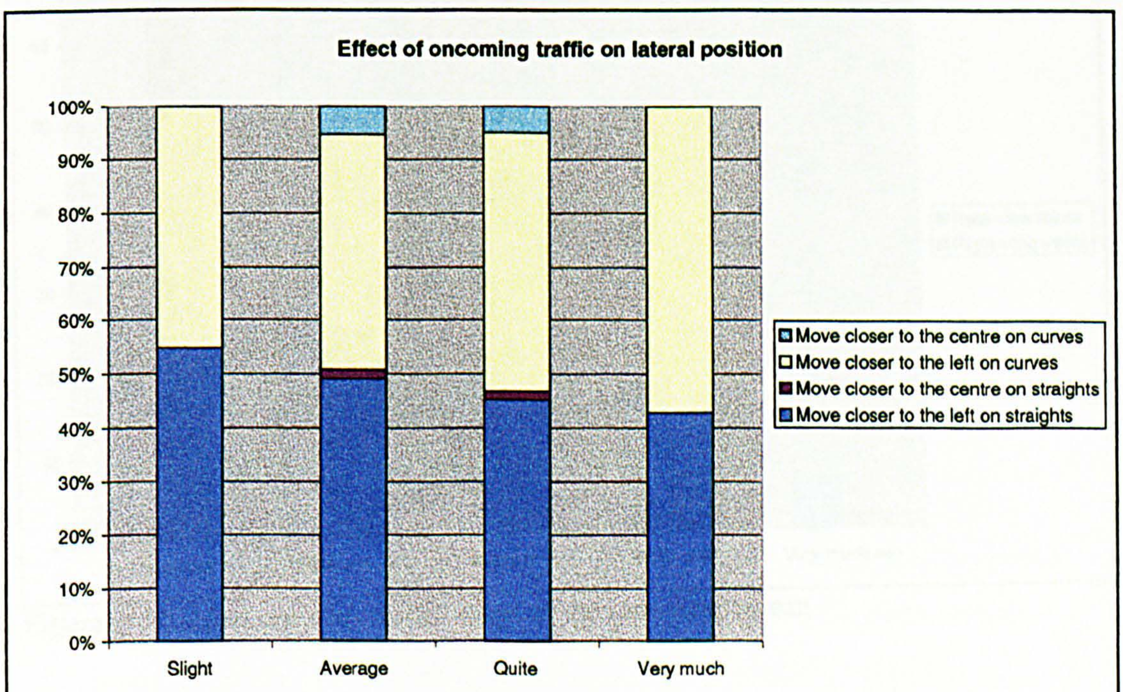


Figure 6-5 Subject opinions on the effect of oncoming traffic on their lateral position

On the other hand, in terms of lateral position, the majority of subjects replied that oncoming traffic made them move to the left (edge of the road) whether they were driving on straight or curved road sections (see Figure 6-5 above).

Relative to the view to the rear through the simulator car mirrors, the majority of subjects replied that they did not use the right-wing mirror at all, whereas they slightly used the rear-view mirror (see Figure 6-6). Subjects were not made specifically aware of the existence of the rear screen, however they were told to drive, as they would normally drive in real life. Some subjects commented that they did not even observe the existence of the rear screen, some others that they were used to driving the simulator before when it had no rear projection, so now they were not used to checking the mirrors. On the other hand, some others commented that they started by checking the rear-view mirror according to what they used to do when driving in real life in accordance to the advice of the Highway Code. However, after some initial checks, they realised that they were driving alone on their lane and they stopped checking the mirrors any more. It should be noted here that the nature of the experiment did not require any checking of mirrors (e.g. for overtaking, changing lanes etc.). The comments suggest that subjects adapt their behaviour according to the driving conditions, driving environment and the vehicle itself.

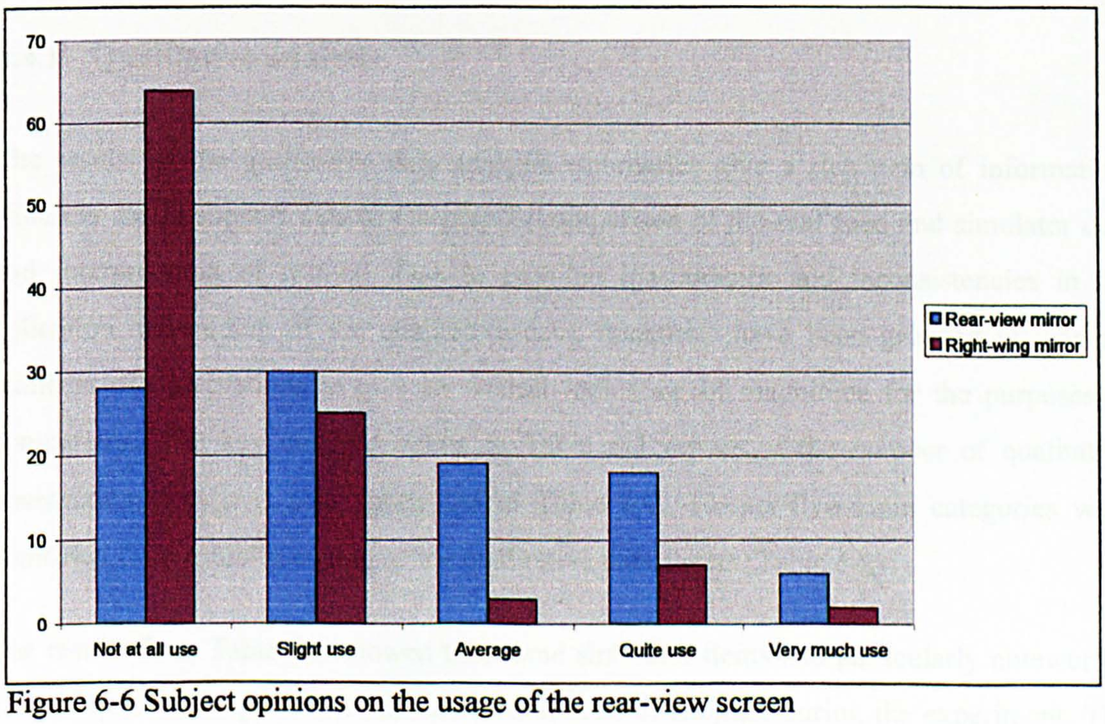


Figure 6-6 Subject opinions on the usage of the rear-view screen

6.4. Subject comments

The qualitative information was collected at the end of the simulator experiment. Upon completion of the post-experiment questionnaire subjects were asked to give their impression relative to the face validity of the simulator. At the end of the questionnaire an open-ended question was written, "*Please add any other comments, which you think would be useful to us*". Open-ended questions have several advantages such as: they deliver richer information; the respondent does not feel frustrated by the constraint imposed with a fixed-choice answer; there is less chance of ambiguity, since the respondent says what he or she thinks and does not have to interpret a statement and then agree or disagree with it and finally the questioning is more realistic. However, open-ended questions are difficult to code or quantify, where fixed-choice items make numerical comparison relatively easy (Coolican, 1994).

Subjects were free to state any other comment, positive or negative, relative to their driving experience in the simulator. Also, the experimenter noted any verbal comments made by subjects considered of interest or importance to the exercise when the subjects had finished the experiment and had left the room.

6.4.1. Qualitative analysis

The results of the qualitative data analysis summaries give a rich vein of information, which is useful support data to Chapter 7 (comparison of the real road and simulator data and interpretation of results). Due to possible inaccuracies and inconsistencies in the collection and coding of the qualitative data, quantities have been grouped by general numbers of observations to give an overall indication of magnitude for the purposes of comparison. The key outlined below in Table 6-1 relates to the number of qualitative observations and it is also applicable to Table 6-2. Twenty-five main categories were identified from initial scanning of the qualitative data sheets (Table 6-2).

The results from Table 6-2 showed that some simulator items had particularly noteworthy effects upon the responses, comments and actions of subjects during the experiment. The steering wheel (it was described as bumpy, weird, not realistic, sensitive, that the car generally oversteers and seems to move around laterally on its own), the difficulty to focus on distant objects and the unrealistic engine sound made the worst impact on the majority of subjects.

Table 6-1 Key to number of qualitative observations recorded by content analysis

No of observations	% in total no of subjects	Symbol
0	0	0
1 -2	2	1*
3-5	4	2*
6-10	8	3*
11-20	15	4*
>20	>20	5*

Table 6-2 Qualitative observations relative to the simulator face validity

No	Comments	Rating		
		Males	Females	Total
1	Problems with the steering wheel	5*	5*	5*
2	Difficulty to focus on distant objects	4*	3*	5*
3	Unrealistic engine sound	3*	4*	5*
4	Blurred or fuzzy screen	3*	3*	4*
5	Things causing nausea	2*	3*	4*
6	Too much concentration compared to real life	2*	3*	4*
7	Difficult to judge speed	2*	3*	4*
8	Difficult to judge braking	3*	0	3*
9	Speed of passing scenes does not correspond to the actual speed shown on the speedometer	3*	3*	3*
10	Difficulty in changing gears	3*	1*	3*
11	Did not feel the car	1*	2*	3*
12	Accelerator response slow	2*	1*	3*
13	Speed decreasing a lot by just releasing the accelerator	2*	0	2*
14	Rear view not clear	1*	1*	2*
15	Popping up of objects: unrealistic/ disturbing	1*	2*	2*
16	Unrealistic braking	0	2*	2*
17	Could not turn on radio	1*	1*	2*
18	Slowing down using gears in real life but cannot in the simulator	1*	1*	1*
19	Look at the surroundings, rear mirror losing control of the vehicle	1*	1*	1*
20	In lower gears simulator tends to lose control	1*	1*	1*
21	Too easy to get to high speeds	1*	0	1*
22	High view point	1*	0	1*
23	Stability in corners	1*	0	1*
24	Car too close to the screen	0	1*	1*
25	Depend on the instruments	1*	0	1*

For male subjects, the first factor, which contributed negatively to the realism of the simulator was the steering wheel, followed by the difficulty to focus on distant objects and the blurred or fuzzy screen. For female subjects the first factor was the same as for male subjects, whereas the second was the unrealistic engine sound and the third the increased mental workload while driving the simulator as well as the difficulty to focus on distant objects. This could imply that a realistic feeling on the steering wheel could possibly increase the face validity of the simulator.

Comparing the male and female observations for the less important factors, it becomes apparent that males have problems in estimating their speed and braking ability in the simulator as well as changing gears. On the other hand, females are more sensitive to minor details, which can cause either nausea or disturbance while driving the simulator. These details include the smell of the car, the oncoming traffic, driving on sharp bends, looking at the instruments, changing gears, and the increased amount of concentration needed to drive the simulator car.

Both genders commented that it was more difficult to drive a simulator than a car and needed more concentration; however females found it more difficult than males. This suggests that when testing the effects of a secondary task (e.g. the use of mobile phones while driving) on driver behaviour, it is expected that simulator results will be worse (in terms of mental workload and ability to control the vehicle) than results obtained from real life. Various researchers have already noticed these effects (Blaauw, 1982; Alm, 1995; Malaterre, 1995; Reed and Green, 1995).

The twenty-five categories were later unified into four groups. The first group included simulator items relative to its control, the second one relative to its visual/graphics subsystem, the third one relative to the simulator car itself and the last relative to the mental workload (in terms of concentration needed to control the simulator vehicle).

Controlling the vehicle was the most important group (about 130 comments), followed by the visual system (about 55 comments), the simulator car itself (about 20 comments) and the mental workload (about 15 comments). This implies that for the improvement of the face validity of the simulator relative to its control, one should probably pay attention first to a realistic steering wheel, followed by a realistic engine sound. The simulator technician should also try to improve the perception of speed by adding both the vehicle dynamics and the visual representation of any type of curvature as well as road furniture and oncoming traffic. Attention should also be given to subjects feeling while driving a fixed-base simulator, "*like floating in the air*". This feeling could be improved both by introducing the simulation of vehicle dynamics while driving on roads with horizontal and vertical curvature, the graphical representation of those curvatures as well as the simulation (software) and the implementation (vibration system) of vehicle suspension. For the visual subsystem, it is important for subjects as well as for the purposes of the experiment, that the front screen should have at least the highest resolution possible. It is very difficult to prove that the above suggestions for modification of some technical aspects of the simulator will improve its behavioural validity unless the simulator technician applies them and then records the effects on subjects' behaviour.

To verify the validity of subject comments so as their comments could be used later as a guide for further development and improvement of the existing configuration of LADS, the number of comments was tested against their importance. The hypothesis tested here was that irrespective of the number of comments subjects made, they always identify at least the most important factor related to the realism of the simulator. This factor is the most important not only for them but also for the majority of subjects who had driven the simulator too during the running phase of the experiment.

For both male and female subjects who made only one comment, the factor that was rated first was the steering wheel, followed by the difficulty to focus on distant objects. The same applied to subjects of both genders who made more than one comment. This means that subjects despite the number of comments they make, always include the most important factor for them that affects simulator realism. Generally the majority of subjects made two comments and an almost equal percentage of male and females made more than two comments, implying that both genders are sensitive to the distinct parts of the simulator configuration and both can be descriptive enough.

6.4.2. Practice run

The literature review of driving simulator validation studies showed that the majority of experimenters (66.7 %) include a practice run in the beginning of the experiment but only for the 12.5% of them is the duration of the practice run known. No other information was available about the nature/protocol of the practice run (Blana, 1996c). Relative to the

LADS experiments, the nature of the "ideal" format of the practice run, in terms of duration, type of road, road furniture and traffic conditions had not been investigated before. Thus, it would be very useful to know how subjects contemplate the idea of a practice run, not only for the purpose of LADS validation experiment, but also for any other simulator experiments.

The practice run included a rural road with no oncoming traffic. The practice road was almost the same as the one driven later in the test run. In particular, the road environment and road furniture was less detailed and the subjects were driving the road in the opposite direction. The practice road had almost the same length as the test road and it took approximately 6 minutes to drive it. Fifty subjects were specifically asked to comment about the format of the practice run. Forty-one valid responses relating to the nature and duration of subject "ideal" practice run are summarised in Table 6-3.

Table 6-3 Responses of subjects relative to the practice run

Practice run	Males (N=20)	Females (N=21)	Total (N=41)
1. sufficient time	11 (55%)	13 (62%)	24 (59%)
2. should be slightly longer	6 (30%)	4 (19%)	10 (24%)
3. include more features	7 (35%)	3 (14%)	10 (24%)
4. more than one run	0 (0%)	3 (14%)	3 (7%)

Overall, all subjects found the practice run useful in terms of getting used to the simulator and its peculiarities (i.e. the brakes and steering wheel, mainly due to the lack of kinaesthetic feedback) and to know what to expect in later stages of the experiment. None of the 41 subjects thought that the practice run was too long. The majority of subjects judged that the duration of the practice run was adequate. Twenty-four percent suggested that it should be slightly longer, i.e. 1 or 2 extra minutes but no longer because then it would become tiresome and maybe induce simulator sickness. Another twenty-four percent suggested that it should include more features, e.g. different traffic scenarios like overtaking and braking as well as oncoming traffic in order to get a better grip of the simulator. Seven percent suggested that the practice run should include more than one run and each one of them should include different traffic conditions (however no more than two runs).

6.5. Correlation analysis

The Pearson correlation coefficient has been calculated for each subject variable against all other variables that describe their individual characteristics, in order to determine the strength of relationship between variables. The correlation of all subjects' individual characteristics to their responses to the post-experiment questionnaire can be found in Table 6-9, Appendix 6. Where appropriate, statistical significance at the 5% and 1% levels have been highlighted by the symbols "*" and "**" respectively. Those correlations indicating significance between subject independent with dependent variables considered relevant to the simulator experiment will now be described.

Subjects' age was positively correlated to their familiarity to arcade games (0.362, P=0.001), to the years holding their driving licence (0.652, P=0.000), to occupation (0.538, P=0.000). The older subjects were more familiar with computer/arcade games, held for longer their driving licence and were coming from the university area. This was rather expected since 66 percent of subjects where younger than 30 years old. Their gender was positively correlated to their familiarity to arcade games (0.322, P=0.001), i.e. female subjects were more familiar with computer/arcade games compared to male subjects. This is an interesting finding since it is believed that mostly males are more keen on computer/arcade games than females.

There was no statistically significant correlation between subjects' age and gender to the realism and ease of controlling the simulator in terms of speed and lateral position when driving on curved and straight road sections.

Advanced lessons was negatively correlated to number of miles driven per year (-0.500, P=0.000) and the usage of the rear mirror (-0.360, P=0.000) and the wing mirror (-0.311, P=0.000). That is to say, subjects who had taken advanced lessons drive on average more miles annually and used more both the wing and rear mirrors of the simulator car. The usage of the rear and wing mirrors of the simulator car was highly correlated (0.643, P=0.000). This means that the usage of mirrors is connected and the more one mirror is used the more the other mirror is used to.

The realism of steering the simulator car was negatively correlated to the ease of controlling the simulator in terms of speed on curves (-0.372, P=0.000), positively correlated to lateral position on curves (0.304, P=0.000) and negatively correlated to lateral position on straights (-0.208, P=0.043). This means that when subjects believe that steering is more realistic they find it easier to control their speed on curves and their lateral position on straights but more difficult to control their lateral position on curves. This finding suggests that lateral control of a vehicle is more difficult on a curved than on a straight road section due to the centrifugal forces and the road camber. Therefore, the feeling that steering is not realistic make the subjects to better control the lateral position of the car on curves. This finding agrees with the results of section 6.3 from the post-experiment questionnaire relating to the ease of controlling the simulator in terms of lateral position.

The realism of speed on straights was negatively correlated to the ease of controlling the simulator in terms of speed on curves (-0.344, P=0.001) and positively correlated to the realism of speed on curves (0.394, P=0.000). This means that when subjects believe that the realism of speed on straights increases, then the realism and ease of controlling speed on curves decreases. This finding suggests that subjects have a different attitude relative to realism and ease of controlling the simulator between curved and straight road sections and each one affects negatively the other.

6.6. Profiles overview between subjective simulator data and real road data

The hypothesis that the increase of simulator face validity will increase simulator behavioural validity was tested here. This was achieved by relating drivers' subjective responses to the simulator and real road data. For the purpose of this study, the face validity of the simulator was defined as the realism (in terms of speed, lateral position, steering, braking, difficulty to focus on distant objects and engine noise) and ease of controlling the simulator. That is to say subjects' responses to questions 1 (a1, a2, b1, b2), 2 (a1, a2, b1, b2), 3 and 4 of the post-experiment questionnaire and subjects' comments relative to the realism of the engine noise and the difficulty in focusing on distant objects. Responses to questions 1a1 and 1b1 (speed control) were unified as well as 1a2 and 1b2 (lateral control). The same applied for responses to questions 2a1, 2b1 (speed realism) and 2a2, 2b2 (lateral realism). As mentioned before (section 6.3), a scale of 1 to 5 was used to rate subjects' responses to the post-experiment questionnaire. However, for the purpose of this exercise, responses were summarised into 3 categories. The first category included responses 1 and 2 (category 1), the second category response 3 (category 2) and the third category responses

4 and 5 (category 3). That is to say, the first one included responses being positive, the second one being neutral and the third one being negative to either simulator realism or ease of controlling it. Only the first and the third category were used for the comparison. Subjects of the first category are defined from now on as "good" subjects (they believe that the simulator is realistic and easy to control it) and of the third category as "poor" subjects (they believe that the simulator is not realistic and difficult to control it). Subjects who found the engine noise realistic were the "good" subjects and subjects who had difficulty in focusing on distant objects were the "poor" subjects.

"Good" and "poor" subjects' behaviour was investigated in terms of speed and lateral position (mean and standard deviation values). Two hypotheses were tested. For the first hypothesis, "good" and "poor" subjects' behaviour was compared to each other to test if it is the same or different. If no differences are observed between the two categories, it implies that whatsoever subjects believe for the realism and ease of controlling the simulator (face validity) they have the same driving behaviour in the simulator. If differences are observed between the two categories, this implies that subjects behave differently, i.e. a category of subjects may present more reliable behaviour compared to the other. Thus, a second hypothesis emerged. It was tested which of the two categories of subjects produce more reliable results compared to the real road data, i.e. which of the "good" or "poor" subjects behave more close to the rear road drivers' behaviour.

The independent two samples t-test was used to test if the two aforementioned hypotheses were true of false. The t ratio was calculated for all measurement points. The computed t ratio was compared against the critical value at the 0.05 (t_{crit}= 1.96) significance level. If the t ratio was less than the critical value, then the null hypothesis was accepted; if it was equal or greater than the critical value then the null hypothesis was rejected. Only the statistically significant results at the 0.05 significance level will be presented in the following sections. The equality of variances was tested using the Levene test. It is a homogeneity-of-variance test, less dependent on the assumptions of normality than most tests. It is obtained by computing, for each case the absolute difference from its cell mean and performing a one-way ANOVA on these differences. If the two-tailed significance (from now on and in all following tables of this section it will be written "Levene") is small, e.g. Levene<0.05 then the null hypothesis that variances are equal is rejected (Norusis, 1993).

6.6.1. Realism of the simulator

"Good" and "poor" subjects' behaviour was tested in terms of speed and lateral position realism. Figures 6-7 and 6-8 show the mean and standard deviation speed profiles for the "good" and "poor" subjects' speed compared to the real road drivers respective profiles. As it can be seen from Figure 6-7 both "good" and "poor" subjects drove at almost the same mean speed for each of the 21 data points of the investigated road section. Slight differences seemed to appear on the first straight section. The independent two samples t-test for the two categories of subjects showed no statistical significant difference for any of the 21 points. Differences between the subjective data and the real road data appeared mainly on the straight road sections. The independent two samples t-test showed that both categories of subjects behaved differently compared to their real road counterparts but the number of differences (N=8) were the same for both categories. This means that both "good" and "poor" subjects behave the same irrespective of their belief relative to the simulator speed realism.

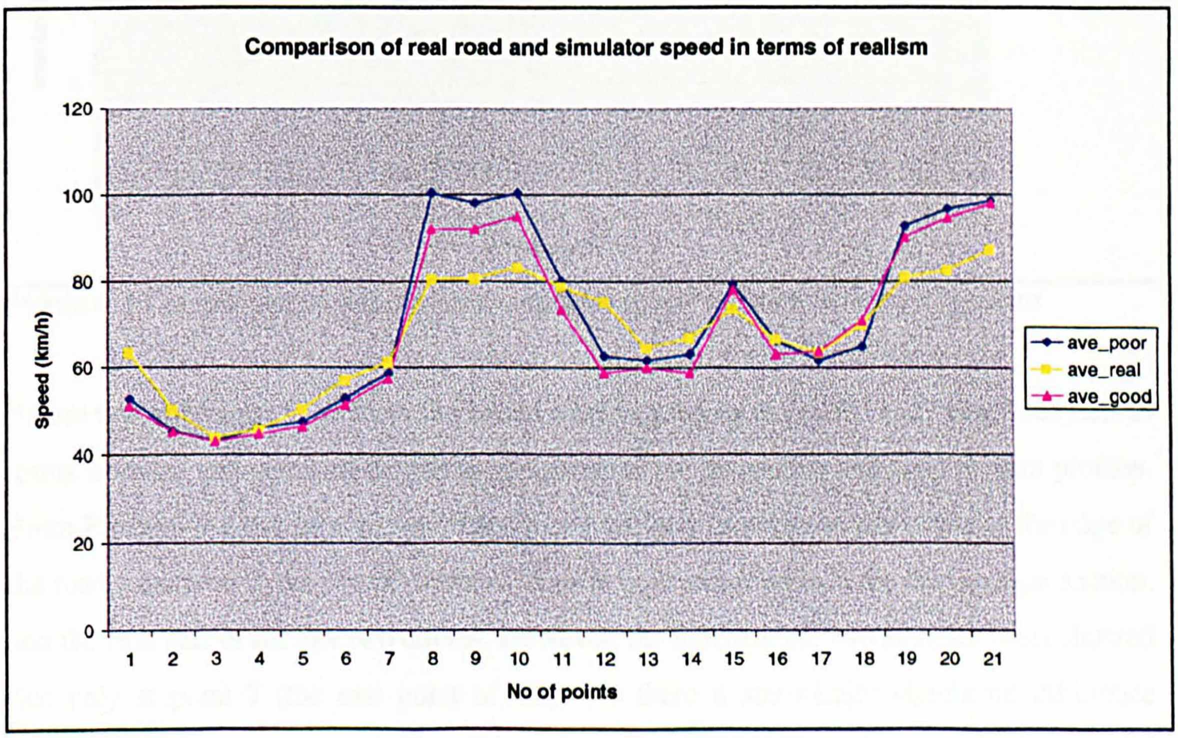


Figure 6-7 Comparison of real road and simulator speed in terms of realism

When looking at the speed variation (see Figure 6-8 below), it seems that subjects' speed variation differs significantly between the two categories of drivers. In particular "good" subjects seem to have smaller deviation than "poor" subjects, especially after the end of the "S" curve. However, the application of Levene's test showed that none of the observed differences were statistically significant. The "good" subjects speed variation profile was closer to the real road drivers' speed variation profile. Indeed, the independent two samples t-test showed that there was smaller number of statistically significant differences between the "good" subjects profiles (N=9) and the real road drivers compared to the "poor" subjects profile (N=12) and the real road drivers. These differences appeared in the last curve. The highest variability was observed in the first straight section (point 8) from the "poor" subjects and the lowest in the exit of the last curved sections by the "good" subjects.

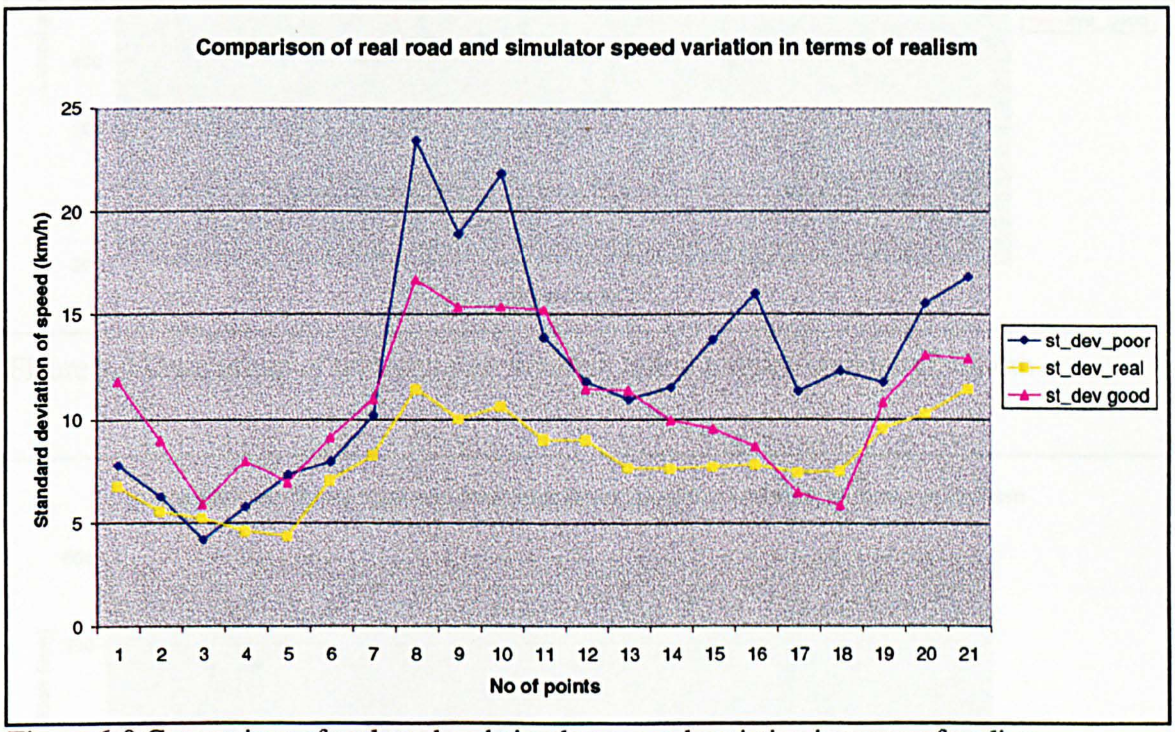


Figure 6-8 Comparison of real road and simulator speed variation in terms of realism

Figure 6-9 and Figure 6-10 show the lateral position profiles of "good" and "poor" subjects in terms of mean and standard deviation compared to the respective real road drivers profiles. From Figure 6-9 it can be observed that "good" subjects drove generally closer to the edge of the road compared to the "poor" subjects. This is quite observable in the first straight section, and the first part of the last two curves. However, the independent two samples t-test showed that only at point 7 (the exit point of C2) was there a statistically significant difference (t=2.07). This means that both "good" and "poor" subjects behave the same irrespective of what they believe relative to the simulator lateral position realism. As expected, the same number of statistically significant differences appeared between the two categories of subjects and the real road drivers (N=18 and N=19 for the "poor" and "good" subjects respectively).

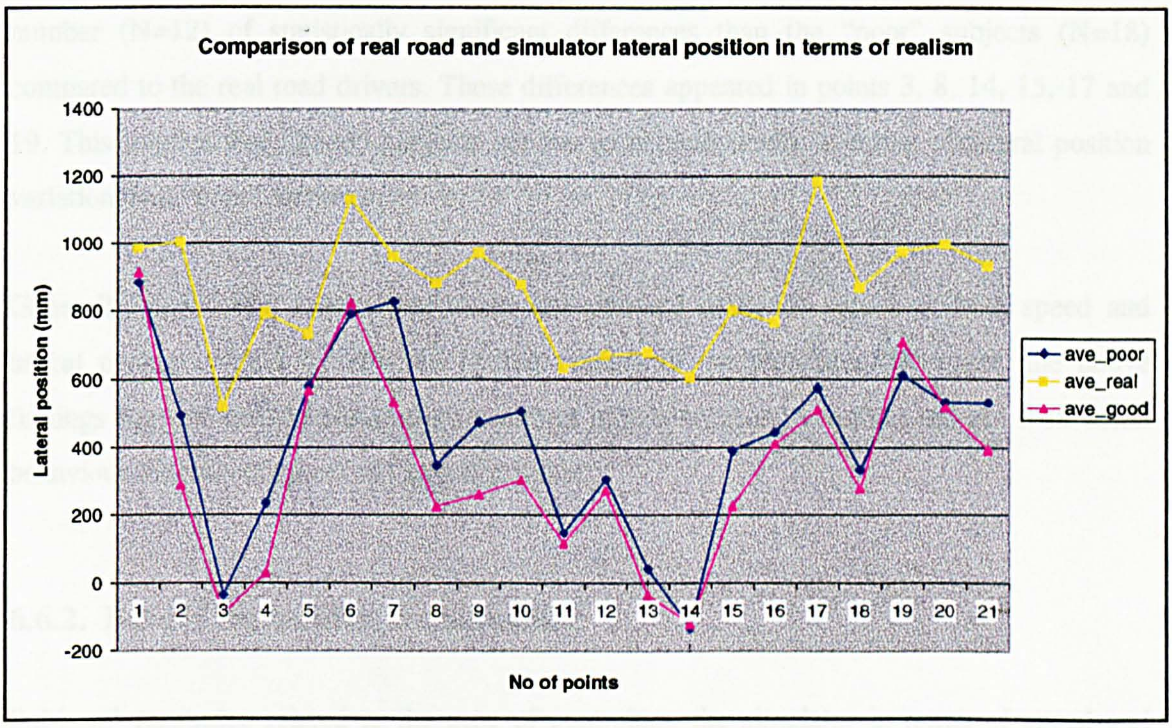


Figure 6-9 Comparison of real road and simulator lateral position in terms of realism

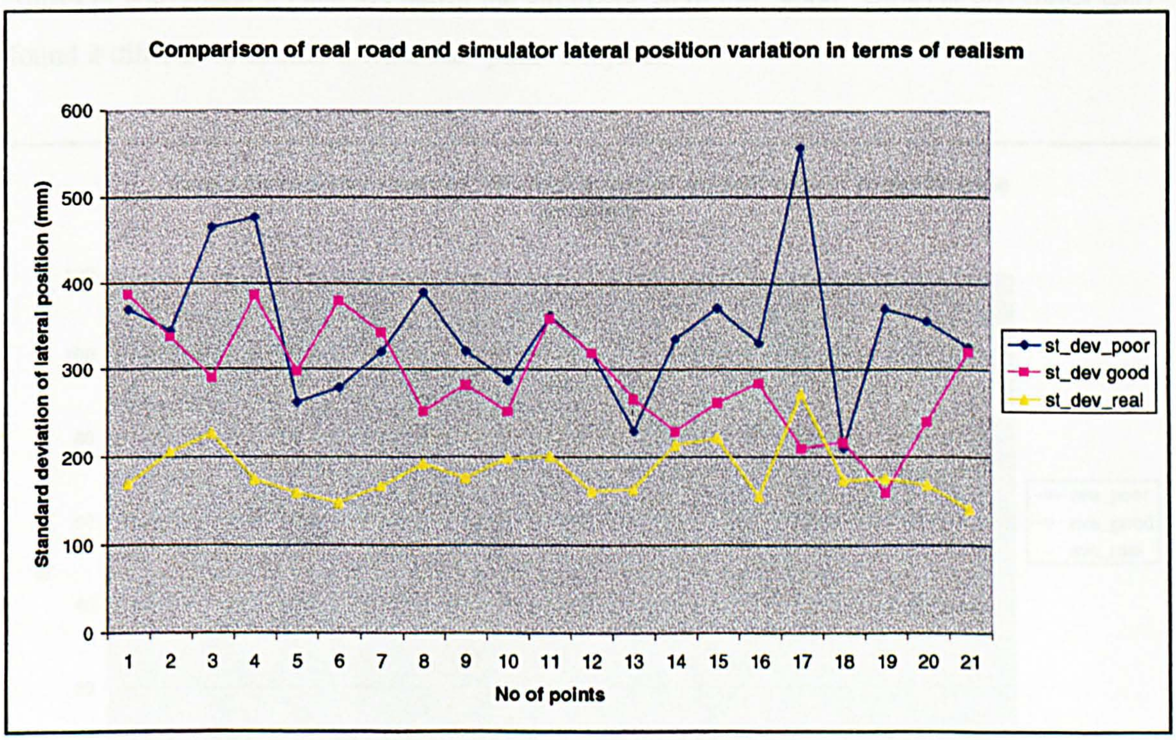


Figure 6-10 Comparison of real road and simulator lateral position variation in terms of realism

From Figure 6-10 above it can be observed that "good" subjects had less variability compared to "poor" subjects. However, the Levene Test showed that only at point 3 the difference was marginally statistically significant (F=4.394, p=0.049). The comparison of the two categories of subjects to the real road drives showed that "good" subjects had smaller number (N=12) of statistically significant differences than the "poor" subjects (N=18) compared to the real road drivers. These differences appeared in points 3, 8, 14, 15, 17 and 19. This implies that "good" subjects behave more realistically in terms of lateral position variation than "poor" subjects.

Generally, one would expect that mean and standard deviation values of both speed and lateral position would be affected by the realism of the simulator. However, the above findings suggest that simulator realism affects mostly subjects' variation and not their mean behaviour in terms of speed and lateral position.

6.6.2. Ease of controlling the simulator

Subjects' responses related to the ease of controlling the simulator in terms of speed and lateral position were compared to the simulator and real road speed and lateral position data. Subjects who found it easy to control the simulator were the "good" subjects and those who found it difficult to control it were the "poor" subjects.

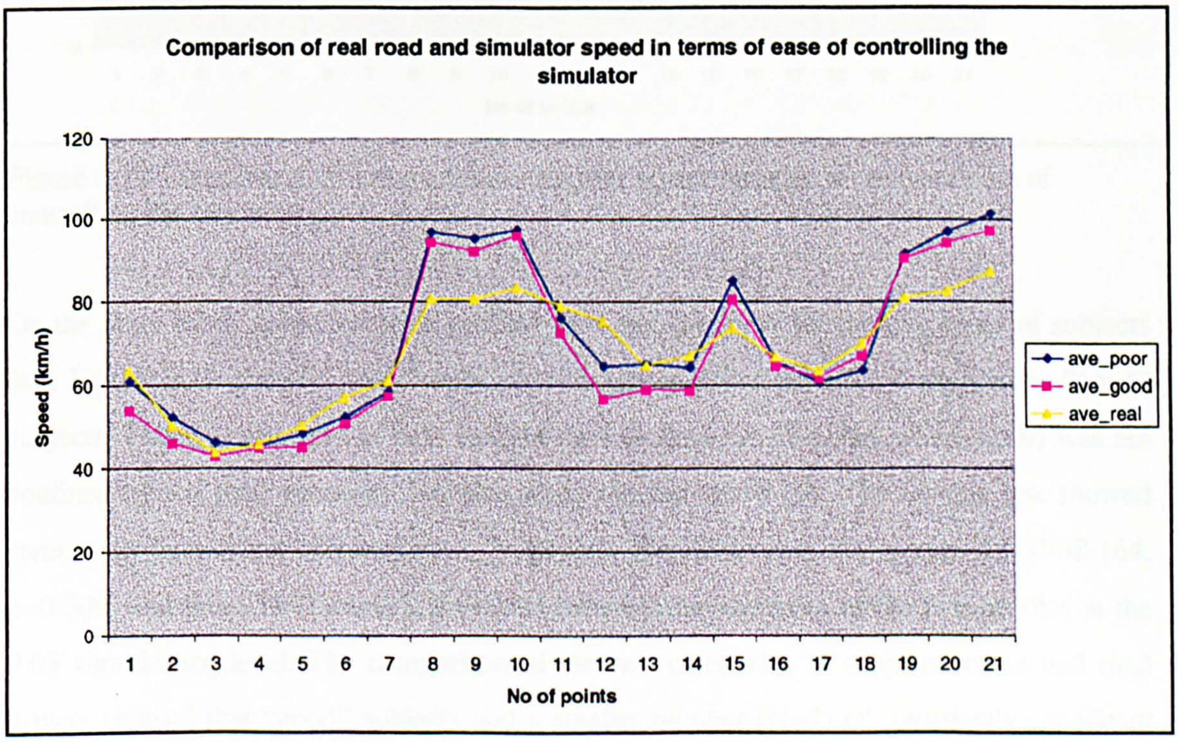


Figure 6-11 Comparison of real road and simulator speed in terms of ease of controlling the simulator

It was found that speed profiles were very similar whether subjects found the simulator easier or more difficult to control it (see Figure 6-11). Indeed, the independent two samples t-test showed that there are no statistical significant differences at any point. The comparison of the two categories of subjects to the real road data showed that "good" subjects (N=14) had almost the same number of statistically significant differences than "poor" subjects (N=15) compared to the real road drivers.

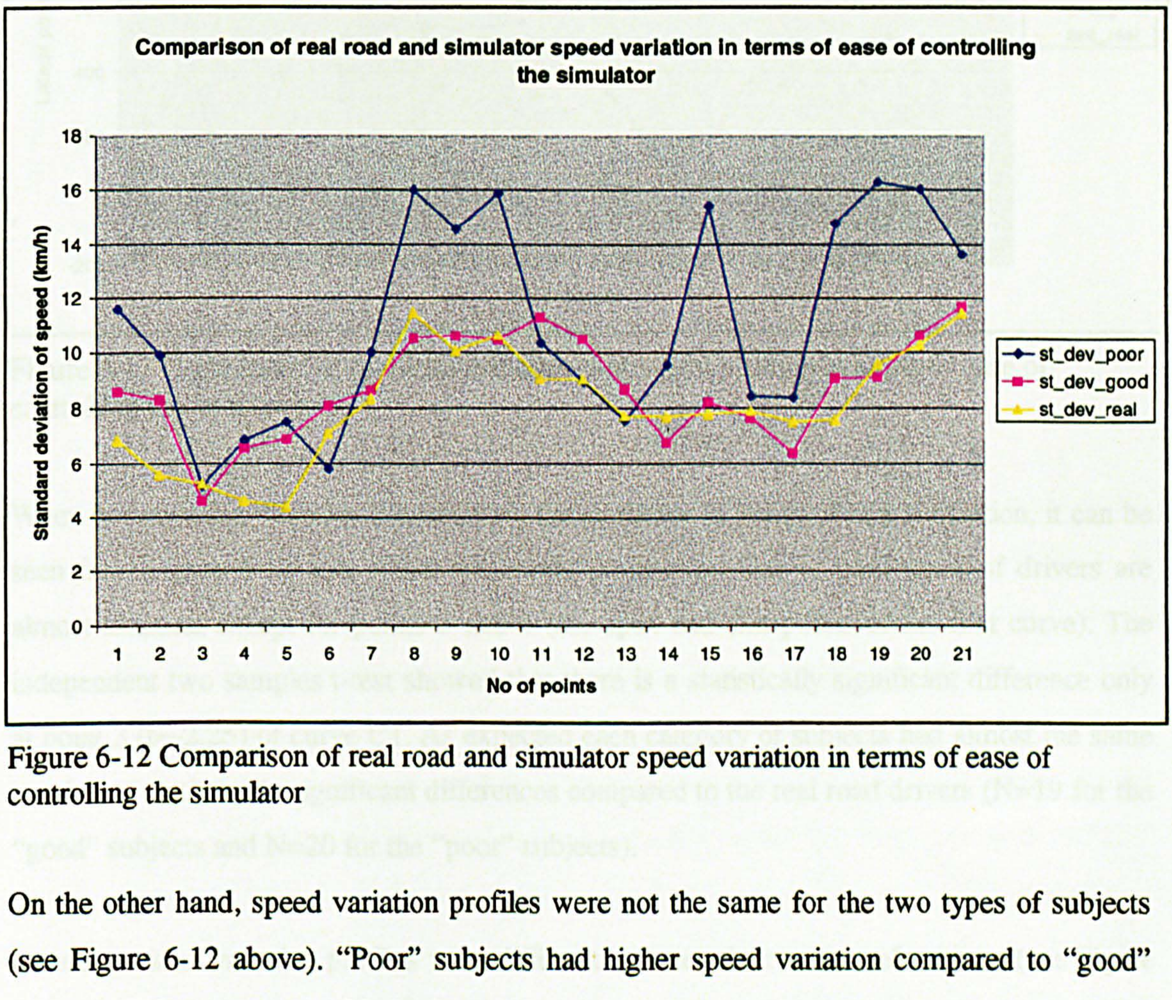


Figure 6-12 Comparison of real road and simulator speed variation in terms of ease of controlling the simulator

On the other hand, speed variation profiles were not the same for the two types of subjects (see Figure 6-12 above). "Poor" subjects had higher speed variation compared to "good" subjects. This was observed in both straight road sections, i.e. in points where speed was not confined by the road geometry but also along the last curve C4. The Levene test showed statistically significant differences at point 10 (F=5.360, p=0.031), point 15 (F=8.164, p=0.009) and point 19 (F=4.637, p=0.043) between the variances of the two profiles at the 0.05 significance level. The comparison of the two categories of subjects to the real road drivers showed that "good" subjects had a smaller number (N=2) of statistically significant differences than "poor" subjects (N=8) compared to the real road drivers. The differences appeared in points 1, 9, 10, 15, 18 and 19. This implies that "good" subjects behave closer to the real road drivers in terms of speed variation, especially on straight sections and in points of poor and/or restricted visibility.

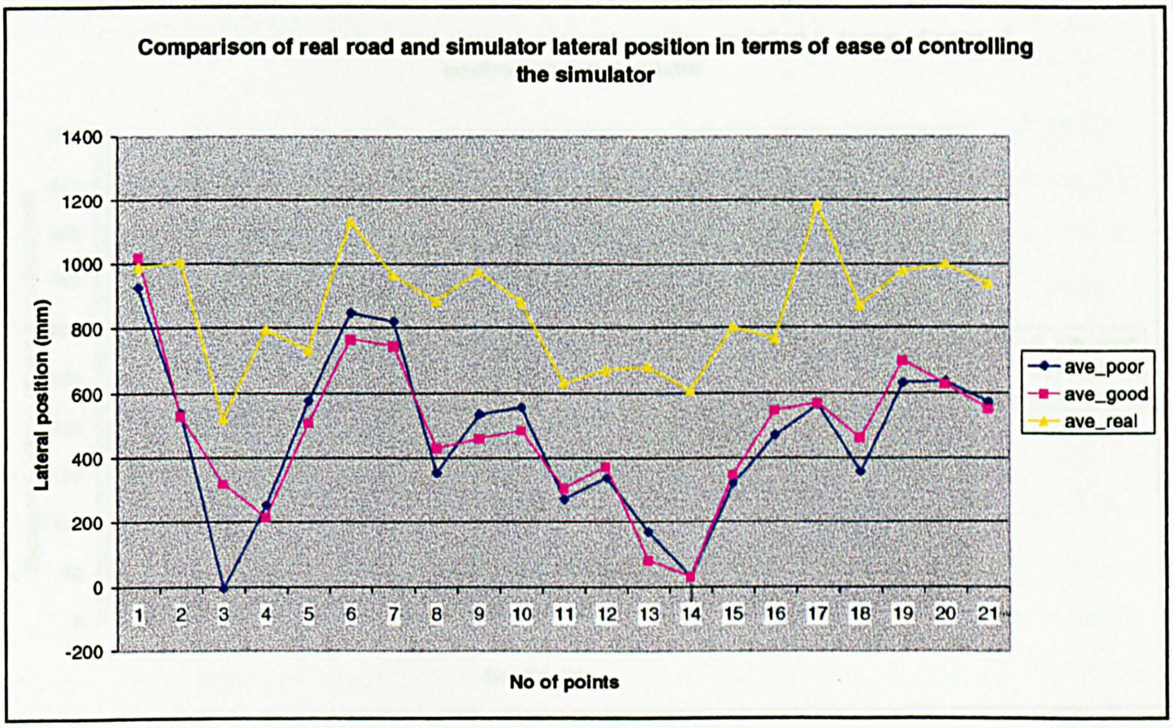


Figure 6-13 Comparison of real road and simulator lateral position in terms of ease of controlling the simulator

When investigating the ease of controlling the simulator in terms of lateral position, it can be seen from Figure 6-13 above that the lateral position profiles of both types of drivers are almost identical except for points 3 and 4 (the apex and exit points of the first curve). The independent two samples t-test showed that there is a statistically significant difference only at point 3 (t=-2.25) of curve C1. As expected each category of subjects had almost the same number of statistically significant differences compared to the real road drivers (N=19 for the "good" subjects and N=20 for the "poor" subjects).

Lateral position variation profiles were different between the two sets of subjects (see Figure 6-14 below). In particular, subjects who found it easier to control the lateral position of the simulator had lower variation compared to those who found it more difficult to control it. However, according to Levene's test these differences were not statistically significant. The comparison of the two categories of subjects to the real road drivers showed that "good" subjects had a smaller number (N=9) of statistically significant differences than "poor" subjects (N=17). These differences appeared in points 2, 8, 11, 12, 17, 18, 19 and 20. This suggests that "good" subjects will behave closer to real road drivers especially on straight road sections and points with restricted visibility and very poor road geometry.

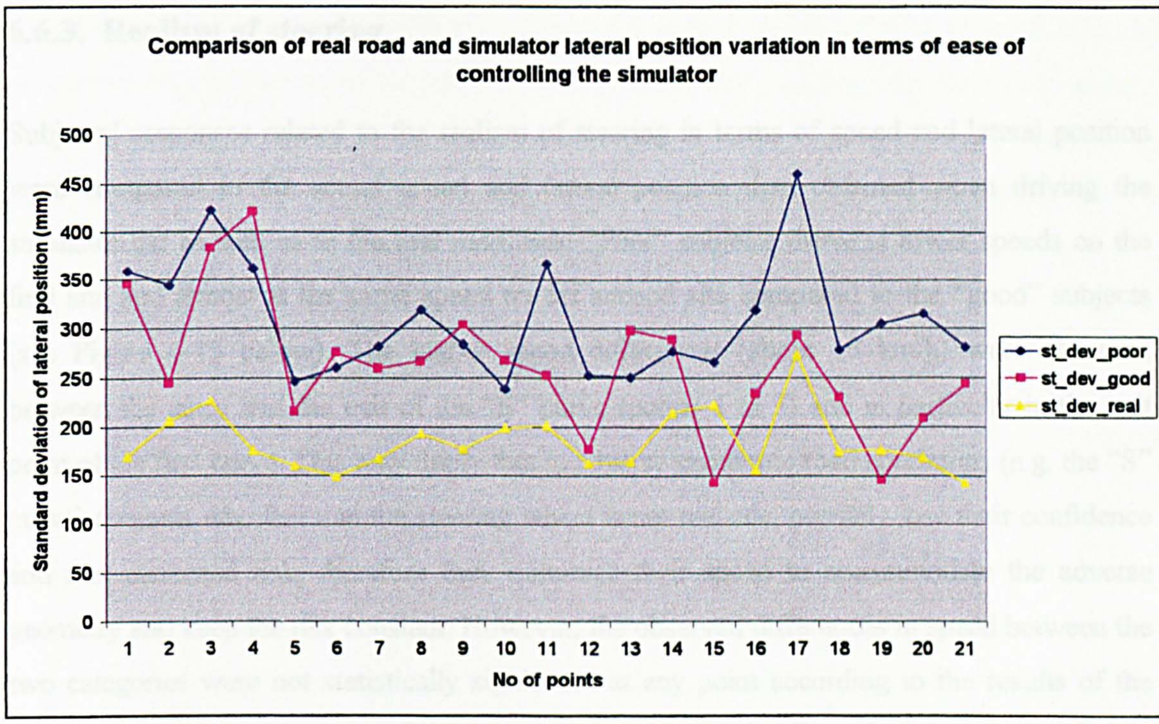


Figure 6-14 Comparison of real road and simulator lateral position variation in terms of ease of controlling the simulator

Overall, it could be argued that the ease of controlling the simulator does not significantly affects subjects' mean speed and lateral position but it does affect their respective variation. It is expected that "good" subjects will give more reliable results than "poor" subjects in terms of variation. For both variables, the effect was more distinct on the straight sections compared to the curved sections. One would expect that simulator control would be more difficult on the curved than the straight road sections but as it was proven, control was easier on the curved than the straight road sections. This suggests that where driver behaviour is confined by road geometry, control of the vehicle is better, besides at points where the geometry is really adverse. Subjects' responses to the post-experiment questionnaire relative to the speed and lateral control of the simulator (see section 6.3) showed that subjects believed that it was very easy to control speed on straights and more difficult to control lateral position on curves, i.e. opposite results to what was found above. This suggests that subjects do not actually behave according to what they think. This may mean that subjects do not have a clear perception of how they behave on the road. It could also mean that differences in driving behaviour between what subjects' think and what they actually do are so minor that cannot be easily quantified or qualified. This finding needs further investigation.

6.6.3. Realism of steering

Subjects' responses related to the realism of steering in terms of speed and lateral position were compared to the actual speed and lateral position data obtained when driving the simulator car as well as to the real road data. "Poor" subjects drove at lower speeds on the first site and almost at the same speed on the second site compared to the "good" subjects (see Figure 6-15 below). The higher speed differences (about 15 km/h) were observed between the entry and the exit of the "S" curve (points 1 to 7) and in particular in the exit point of the first curve. This may imply that in adverse geometric road conditions (e.g. the "S" curve) subjects who feel that the steering wheel is not realistic, possibly lose their confidence and feel increased risk, therefore they minimise their speed to accommodate the adverse geometry and keep the risk constant. However, the observed differences in speed between the two categories were not statistically significant at any point according to the results of the independent two samples t-test. The same test also showed that "poor" subjects had a slightly smaller number of statistically significant differences (N=15) than "good" (N=17) subjects and compared to the real road drivers.

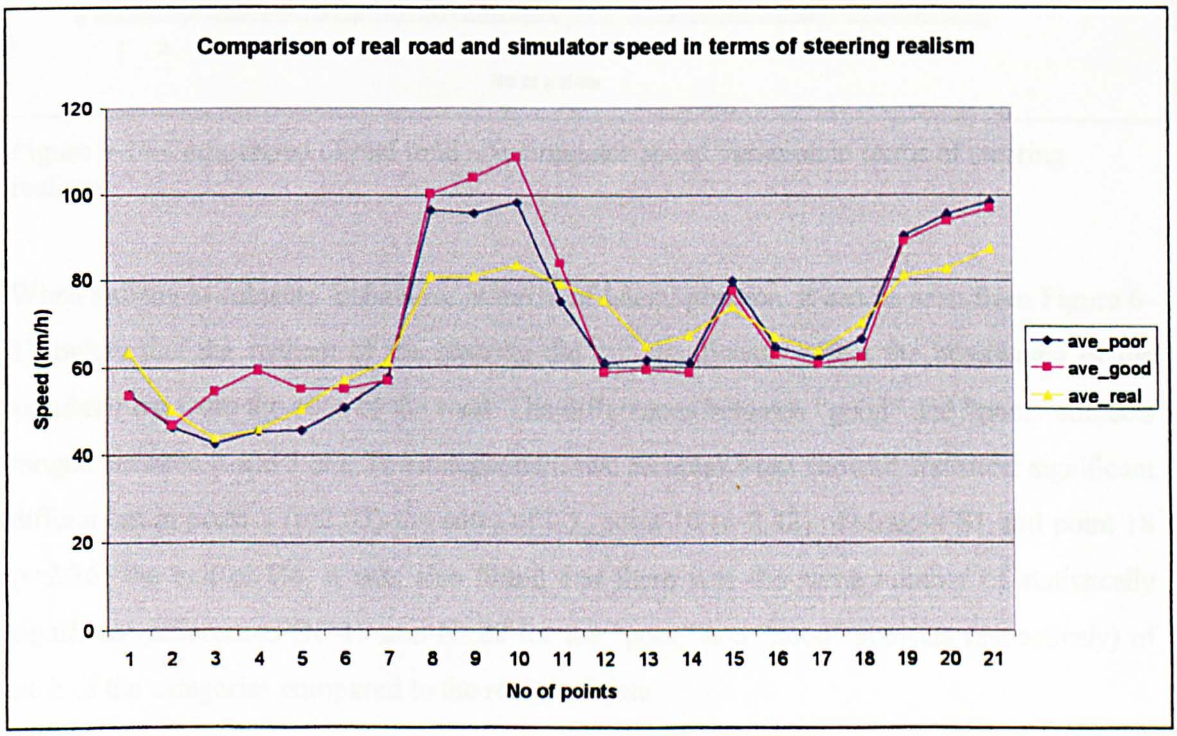


Figure 6-15 Comparison of real road and simulator speed in terms of steering realism

When looking at subjects' speed variation, it could be seen that "good" subjects had slightly higher variation on the first site and lower variation on the second site compared to "poor" subjects (see Figure 6-16 below). However, the Levene test showed marginal statistically significant difference between the two categories, only at point 7 (F=4.037, p=0.048). As expected, both categories of subjects' variation profiles differed from the real road variation profile. The independent two samples t-test showed that the number of statistically significant differences between each of the categories to the real road data was slightly smaller for the "good" subjects (N=6) than for the "poor" subjects (N=8).

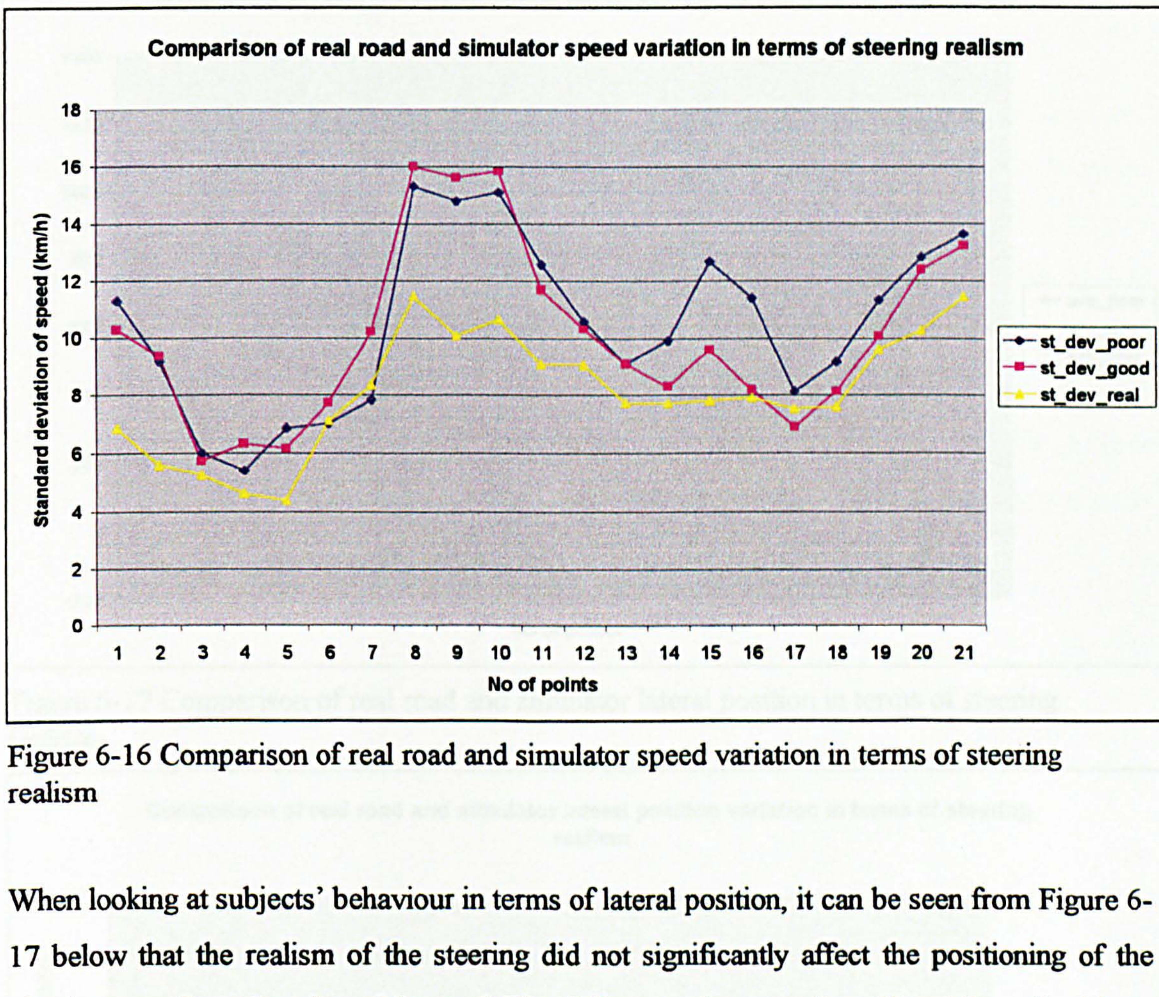


Figure 6-16 Comparison of real road and simulator speed variation in terms of steering realism

When looking at subjects' behaviour in terms of lateral position, it can be seen from Figure 6-17 below that the realism of the steering did not significantly affect the positioning of the simulator car from the edge of the road. The differences between "good" and "poor" subjects ranged between 0 and 5 cm. The independent two samples t-test showed statistical significant differences in point 2 (t=2.03) the entry of C1, point 10 (t=2.42) of straight S1 and point 18 (t=2.36) the exit of C4. It was also found that there was the same number of statistically significant differences (N=19 and N=20 for the "poor" and "good" subjects respectively) of each of the categories compared to the real road data.

"Good" subjects seemed to have smaller lateral position deviation than "poor" subjects (see Figure 6-18 below). Differences between the two categories were observed mainly after the end of the "S" curve, the highest in the apex of the last curve (60 percent more for those who found the steering behaviour less realistic). The highest difference in variation between the two categories of subjects was observed on the apex of the last curve. However, none of the observed differences were statistically significant according to the Levene's Test. The same test showed that "good" subjects had slightly better behaviour than "poor" subjects compared to the real road drivers since the number of statistically significant differences was N=16 and N=19 respectively.

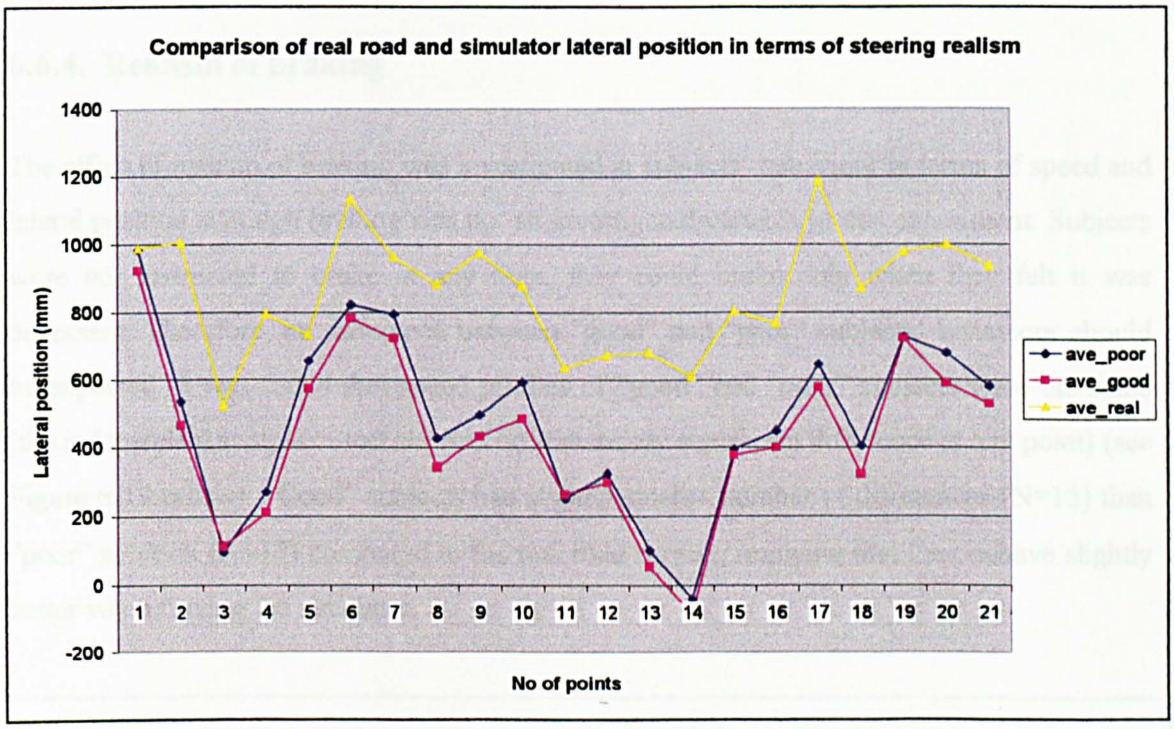


Figure 6-17 Comparison of real road and simulator lateral position in terms of steering realism

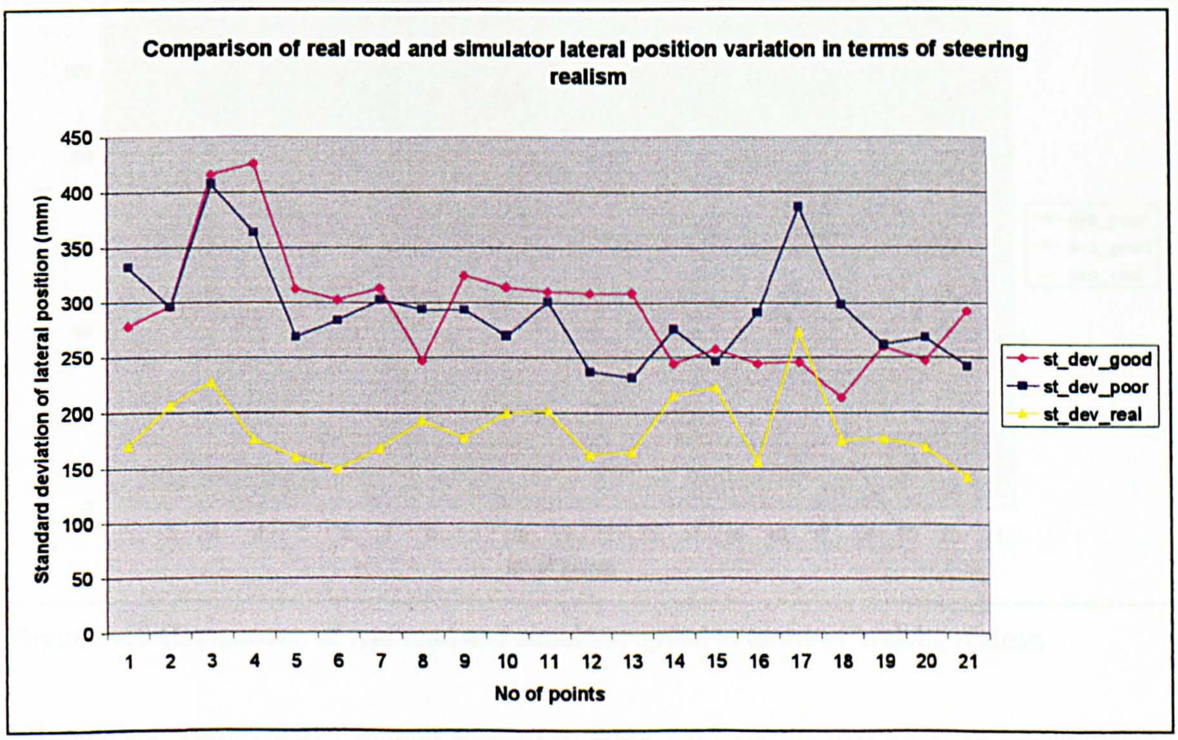


Figure 6-18 Comparison of real road and simulator lateral position variation in terms of steering realism

Overall, it could be argued that "good" and "poor" subjects behaved more or less the same in terms of speed and lateral position and "good" subjects behaved slightly better in terms of speed and lateral position variation. The majority of subjects commented that the feeling of the steering wheel was unrealistic (see also sections 6.3 and 6.4.1) however, as the above finding showed, subjects' perception did not affect their behaviour.

6.6.4. Realism of braking

The effect of realism of braking was investigated in subjects' behaviour in terms of speed and lateral position although braking was not an investigated variable in this experiment. Subjects were not instructed to brake at any time, they could brake only when they felt it was necessary. Therefore, no difference between "good" and "poor" subjects' behaviour should be expected. It was found that speed profiles of "good" and "poor" subjects were the same (the independent samples t-test showed no statistically significant difference at any point) (see Figure 6-19 below). "Good" subjects had slightly smaller number of differences (N=15) than "poor" subjects (N=17) compared to the real road drivers, implying that they behave slightly better when driving the simulator.

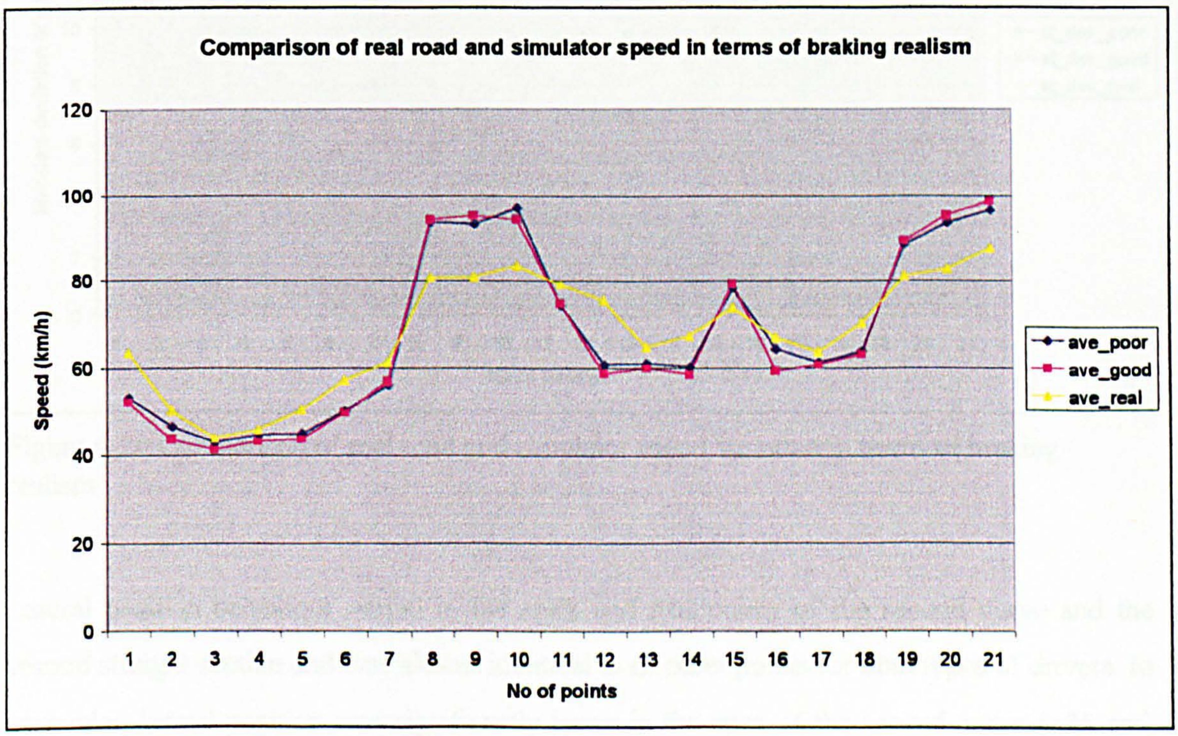


Figure 6-19 Comparison of real road and simulator speed in terms of braking realism

On the other hand, speed variation seemed to differ between the two types of subjects (see Figure 6-20 below). In particular, those who found braking more realistic had smaller speed variation in the majority of the points compared to those who found it less realistic. This difference was more observable in the first site compared to the second site. One possible explanation could be that the first site has more adverse geometry curved sections than the second site. The highest differences between the two categories of subjects were observed in the three points of the first straight section. Subjects knew that by the end of the road (i.e. by the end of the second straight section) they had to brake in order to stop the car, therefore no difference between the two categories of subjects would be expected at this straight. Therefore, if any differences were to be observed, they would be observed in the first straight section. However, the Levene test did not show any statistically significant difference between the two categories for any of the 21 points. It also showed that the number of statistically significant differences of each of the two categories and the real road data was the same (N=13 for both categories).

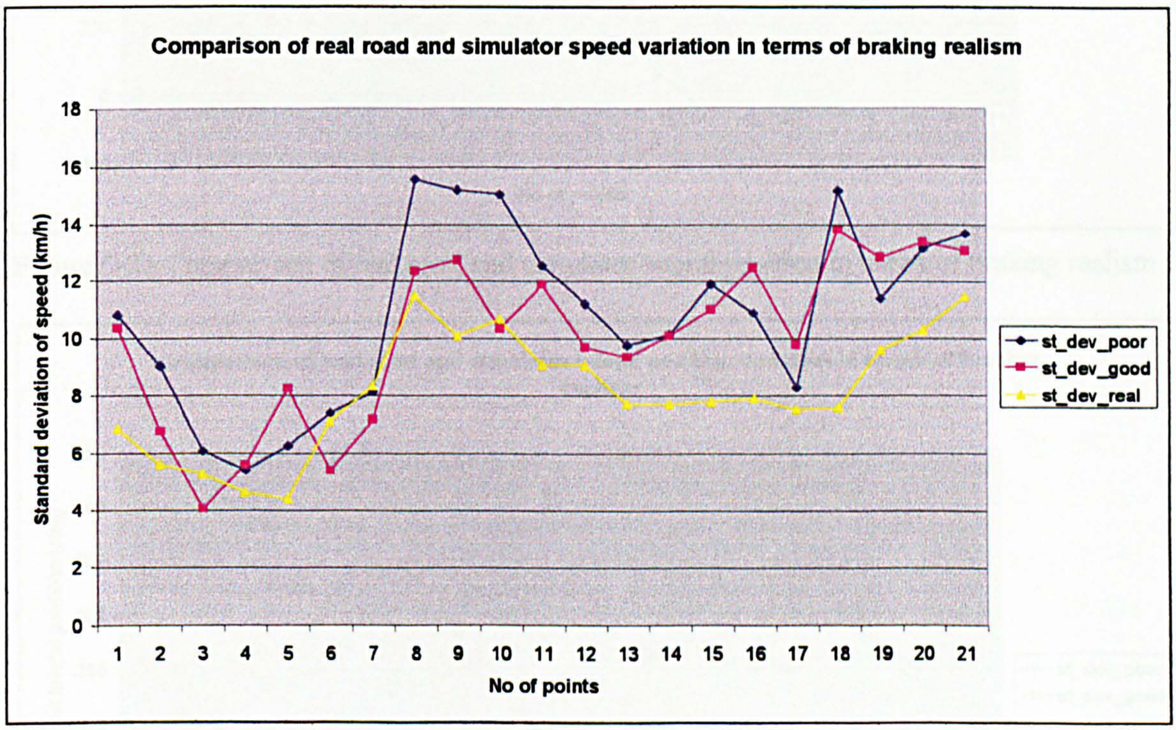


Figure 6-20 Comparison of real road and simulator speed variation in terms of braking realism

Lateral position behaviour varied in the apex and exit points of the second curve and the second straight section and was almost identical at all other points for both types of drivers. In particular, lateral position was significantly lower in the apex of the second curve (≅25 cm) and higher (≅10 cm) in the approach of curve C3 and the first point of S2 for "good" subjects (see Figure 6-21 below). The independent two samples t-test showed a statistically significant difference only at point 6 (t=2.51), the apex of C2 between the "good" and the "poor" subjects. The same test also showed that both "good" and "poor" subjects had the same number of statistically significant differences (N=20) compared to the real road drivers.

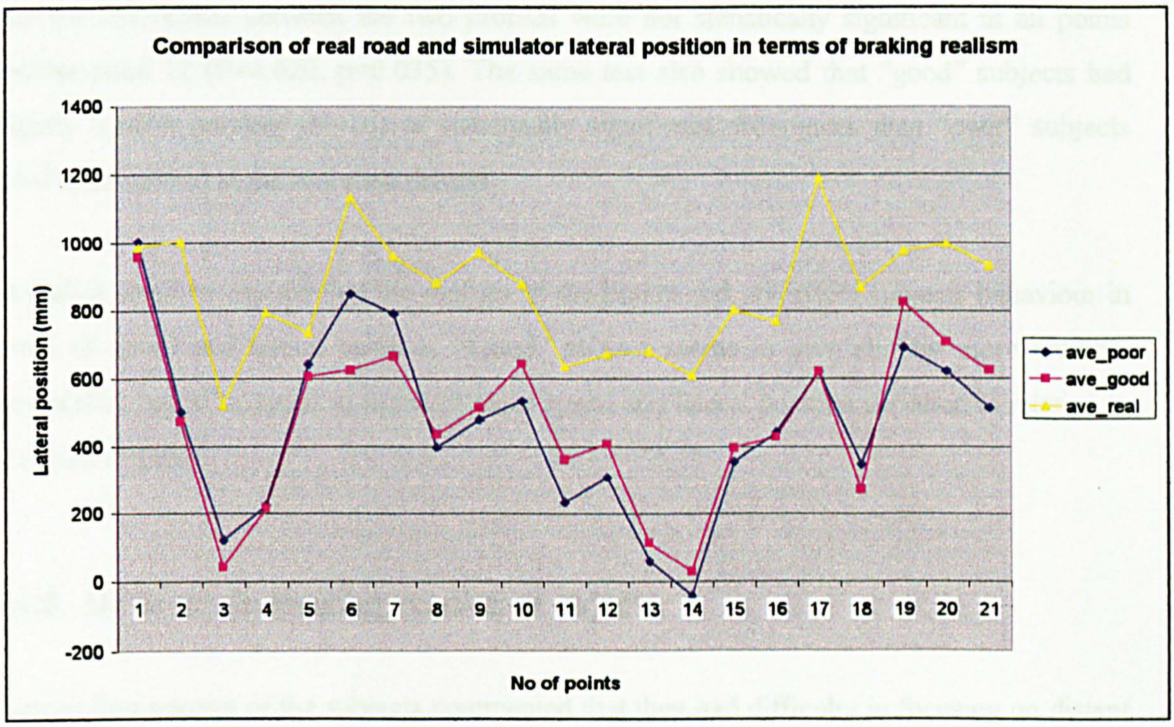


Figure 6-21 Comparison of real road and simulator lateral position in terms of braking realism

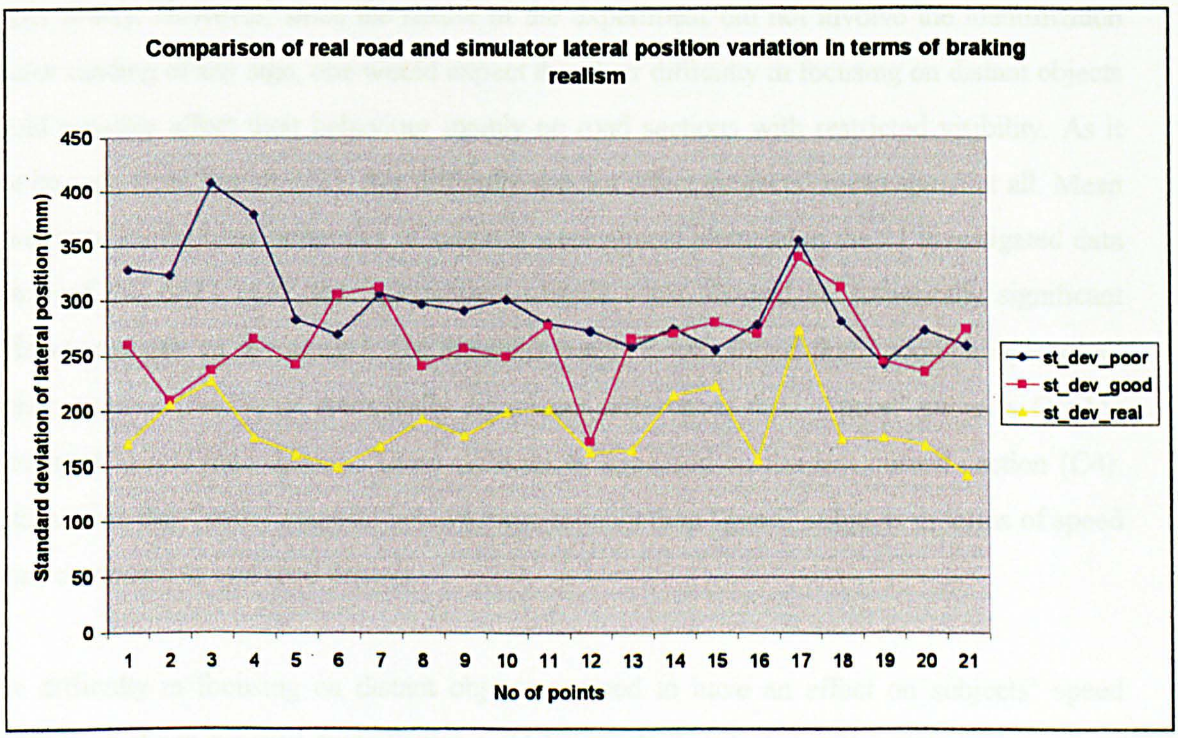


Figure 6-22 Comparison of real road and simulator lateral position variation in terms of braking realism

Lateral position variation profiles seemed different between the two categories of subjects especially for the first 12 points. Subjects who found the simulator more realistic in terms of braking, seemed to have smaller lateral position variation than those who found it less realistic. The highest differences were observed in the "S" curve and the entry point of the third curve (see Figure 6-22 above). However, the application of the Levene's test showed that the differences between the two profiles were not statistically significant in all points besides point 12 ($F=4.620$, $p=0.035$). The same test also showed that "good" subjects had slightly smaller number ($N=16$) of statistically significant differences than "poor" subjects ($N=18$) compared to the real road drivers.

Overall it could be argued that the realism of the brakes did not affect subjects behaviour in terms of speed and lateral position. "Good" subject seems to give slightly more credible results than "poor" subjects in terms of mean speed and lateral position variation in relation to real road drivers.

6.6.5. Difficulty in focusing on distant objects

Twenty-four percent of the subjects commented that they had difficulty in focusing on distant objects, i.e. they could not read from a far distance the traffic signs because the view was rather blurry. However, since the nature of the experiment did not involve the identification and/or reading of any sign, one would expect that their difficulty in focusing on distant objects could possibly affect their behaviour mainly on road sections with restricted visibility. As it can be seen from Figure 6-23, this difficulty did not affect subjects' mean speed at all. Mean speed profiles for both categories of subjects were almost identical in the 21 investigated data points of the A614 road (the independent sample t-test showed no statistically significant difference at any of the points). On the other hand, it was found that "good" subjects had higher number ($N=19$) of statistically significant differences than "poor" subjects ($N=15$) compared to real road drivers. These differences appeared on the last curved section (C4). This implies that "poor" subjects behave more reliably than "good" subjects in terms of speed when compared to real road drivers.

The difficulty in focusing on distant objects seemed to have an effect on subjects' speed variation as it can be seen from Figure 6-24 below. In 5 out of the 21 points both types of subjects had the same speed variation. The highest differences in speed variation were observed in the entrance of the first curve (approach and entry points) and the exit point of the last curve (C4). However, statistically significant differences between "good" and "poor" subjects were proved to be only the ones for point 2 (F=6.437, p=0.013) and point 4 (F=6.088, p=0.015).

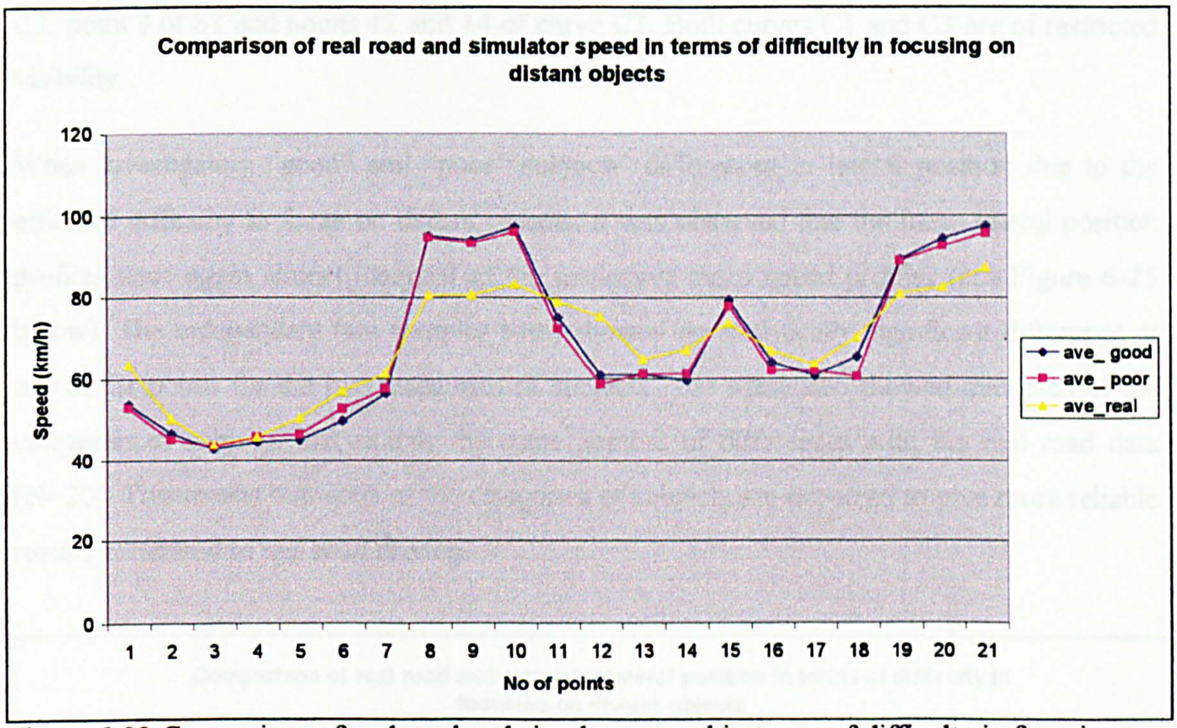


Figure 6-23 Comparison of real road and simulator speed in terms of difficulty in focusing on distant objects

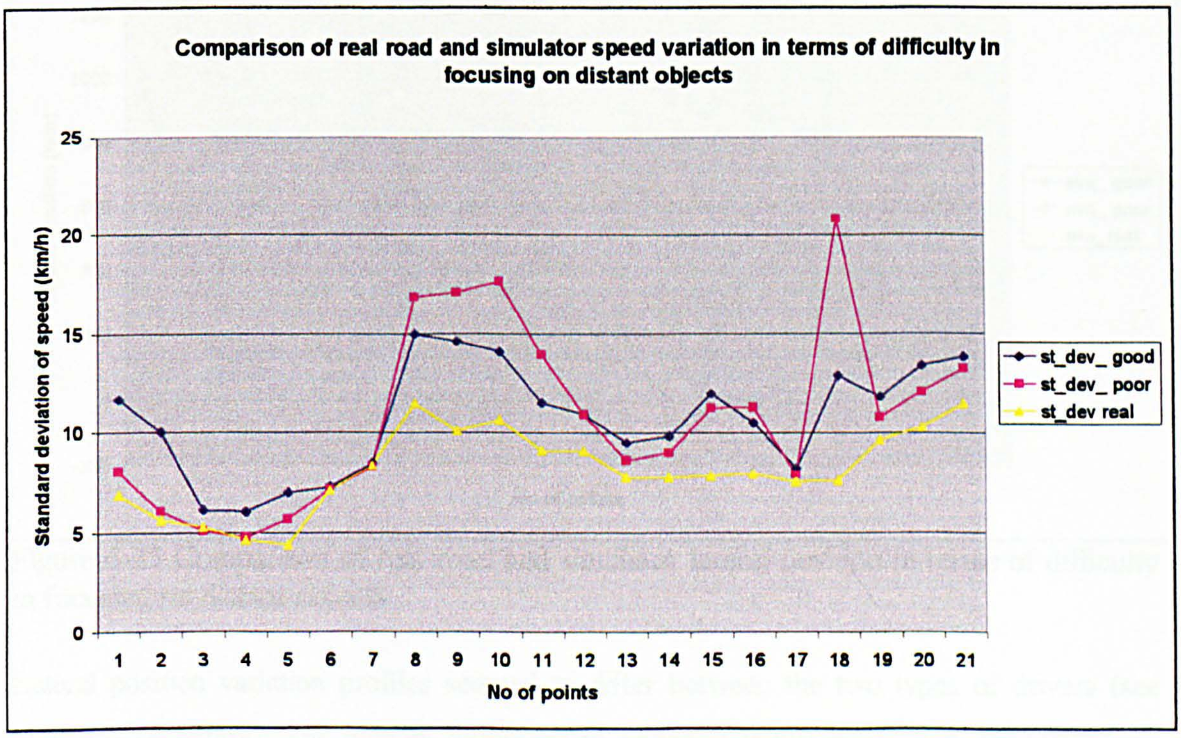


Figure 6-24 Comparison of real road and simulator speed variation in terms of difficulty in focusing on distant objects

The comparison of the two categories of subjects to the real road drivers showed that "poor" subjects had lower number (N=7) of statistically significant differences than "good" subjects (N=13) in terms of speed variation. These differences appeared in points 1, 2 and 4 of curve C1, point 8 of S1 and points 12 and 14 of curve C3. Both curves C1 and C3 are of restricted visibility.

When investigating "good" and "poor" subjects' differences in lateral position due to the effect of difficulty to focus on distant objects, it was observed that the mean lateral position profiles were again almost identical as the respective mean speed profiles (see Figure 6-25 below). The independent two samples t-test showed no statistically significant difference at any of the points for the two categories of subjects. The t-test also showed that each of the categories of subjects had exactly the same number of differences with the real road data (N=20). This means that none of the categories of subjects are expected to give more reliable results compared to real road driving.

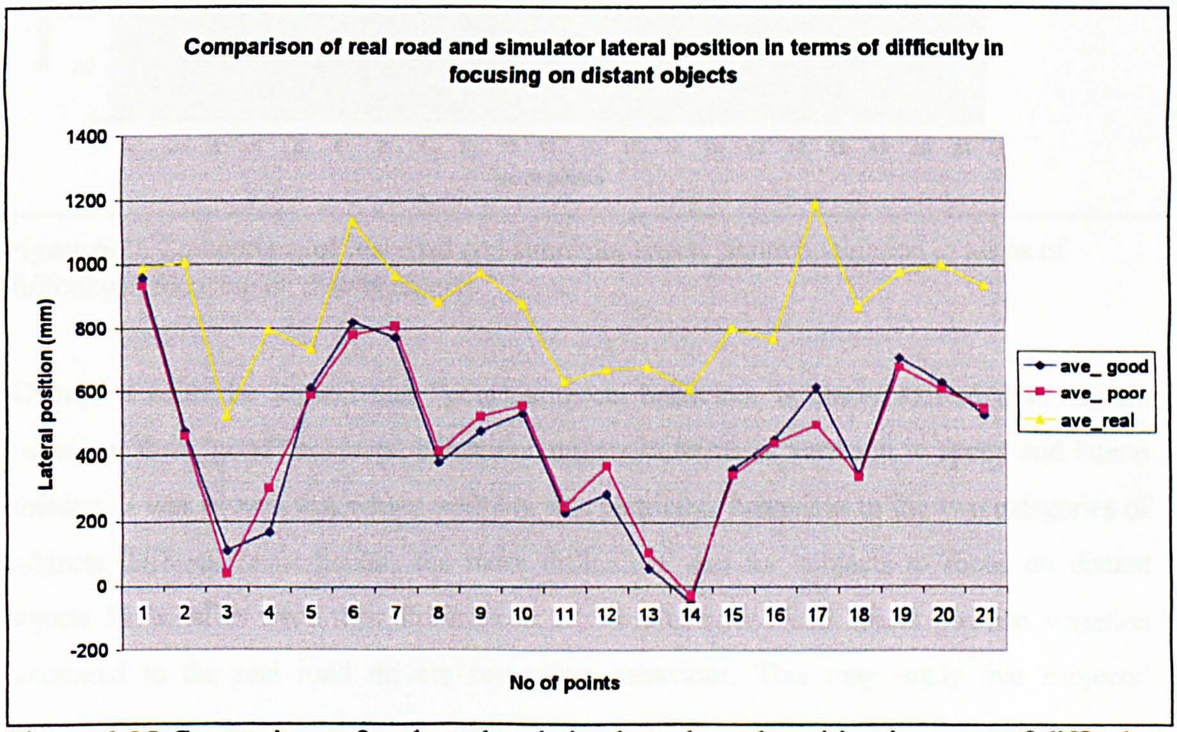


Figure 6-25 Comparison of real road and simulator lateral position in terms of difficulty in focusing on distant objects

Lateral position variation profiles seemed to differ between the two types of drivers (see Figure 6-26 below). The highest difference in variation between the two categories was observed in the entry of curve C4. However, marginally statistically significant differences were observed only in point 16 (F=3.983, p=0.049). "Poor" subjects had smaller number (N=13) of statistically significant differences than "good" subjects (N=19) compared to the real road drivers. These differences appeared in point 5 of curve C1, points 11, 13 and 14 of curve C3, and points 16 and 18 of cure C4. It seems that on sections where the visibility is restricted poor subjects minimise their lateral position variation to counterbalance the fact that they cannot see far ahead, therefore their behaviour is more close to the real road behaviour.

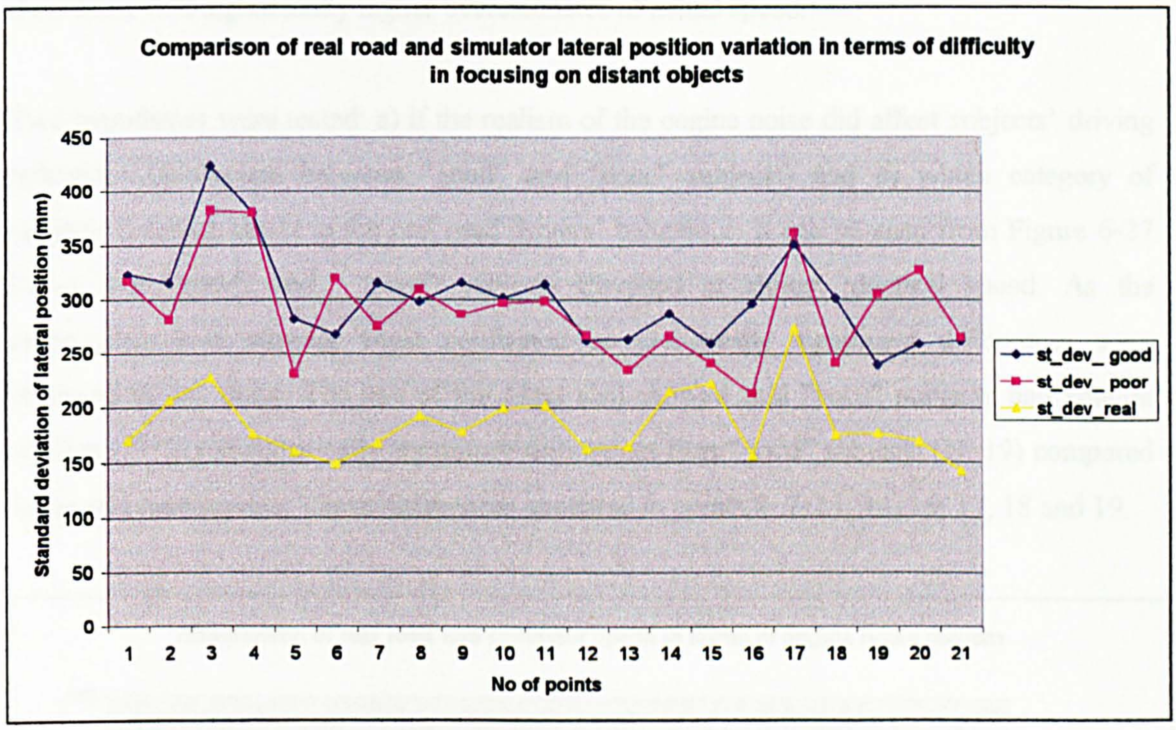


Figure 6-26 Comparison of real road and simulator lateral position variation in terms of difficulty in focusing on distant objects

Overall it could be argued that "poor" subjects behaviour is closer to real road drivers behaviour than "good" subjects' behaviour mainly in terms of variation in speed and lateral position. It was proven that where visibility was restricted, behaviour of the two categories of subjects differed. In particular, the more difficult it was for subjects to focus on distant objects the smaller were their differences in terms of speed and lateral position variation compared to the real road drivers respective behaviour. This may imply that subjects' difficulty to see clear ahead forces them to keep a more constant speed and to minimise the weaving of their vehicle.

6.6.6. Engine noise realism

Twenty percent of the subjects commented that the engine noise of the simulator car was unrealistic. The percentage of drivers who use the engine noise to adjust their driving speed and/or change gears is not exactly known. Simulator subjects commented that engine noise could be useful for estimating their driving speed (in addition to the use of the speedometer) and changing gears. In the speed and distance perception experiment carried out using the Leeds Advanced Driving Simulator (LADS) (Groeger et al, 1997) it was found that subjects do not perceive speed accurately and at lower speeds, the sound information alone was associated with significantly higher overestimates of actual speed.

Two hypotheses were tested: a) if the realism of the engine noise did affect subjects' driving behaviour (distinction between "good" and "poor" subjects) and b) which category of subjects behaved closer to the real road drivers' behaviour. It can be seen from Figure 6-27 below that "good" and "poor" subjects travelled at almost identical speed. As the independent two samples t-test confirmed no statistically significant differences were observed at any point. The use of the t-test also showed that "poor" subjects had smaller number (N=12) of statistically significant differences than "good" subjects (N=19) compared to the real road drivers. These differences appeared in points 2, 7, 11, 13, 16, 17, 18 and 19.

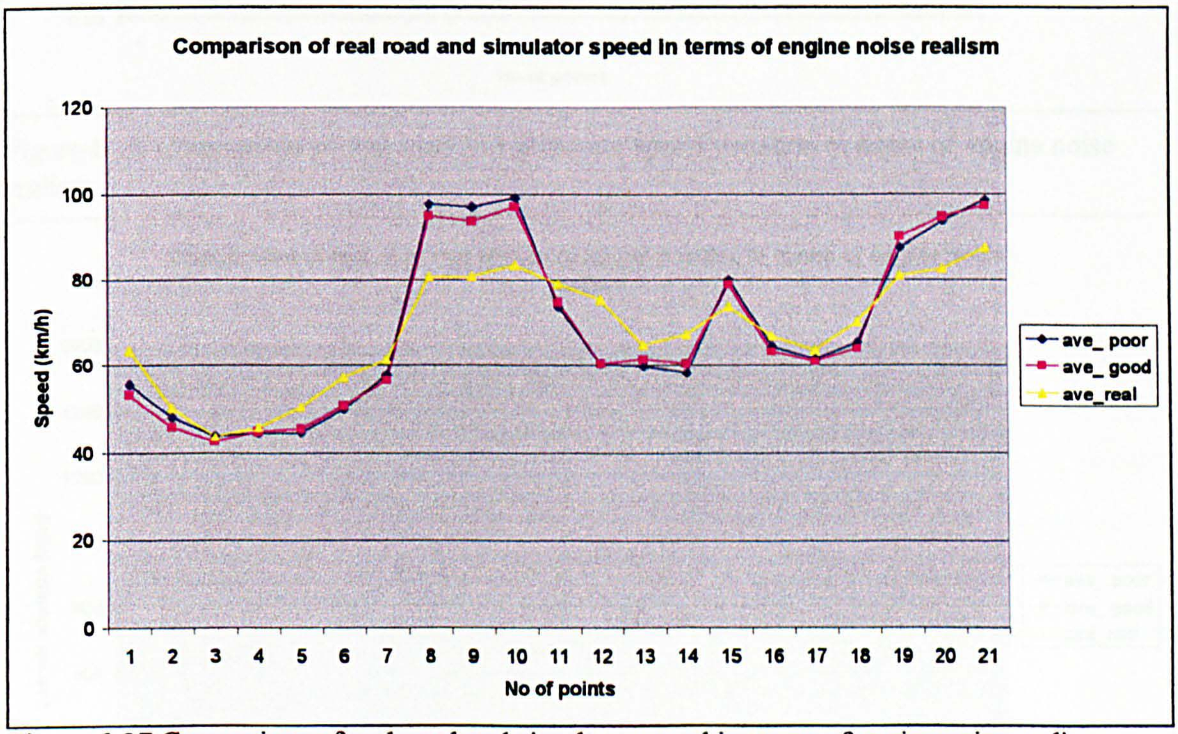


Figure 6-27 Comparison of real road and simulator speed in terms of engine noise realism

When investigating subjects speed variation, it can be seen from Figure 6-28 below that speed variation was lower in all points besides point 18 (the exit point of curve C4) for "good" subjects compared to "poor" subjects. Statistically significant differences were observed in point 19 ($F=6.649$, $p=0.011$), point 20 ($F=5.282$, $p=0.028$) and point 21 ($F=5.839$, $p=0.018$), i.e. the second straight section. The independent two sample t-test also showed that "good" subjects had smaller number (N=9) of statistically significant differences than "poor" subjects (N=17) compared to the real road drivers. These differences appeared in points 4, 8, 12, 13, 14, 16, 19, 20 and 21. Overall, it could be said that realistic engine noise decreases speed variation and behaviour becomes more realistic.

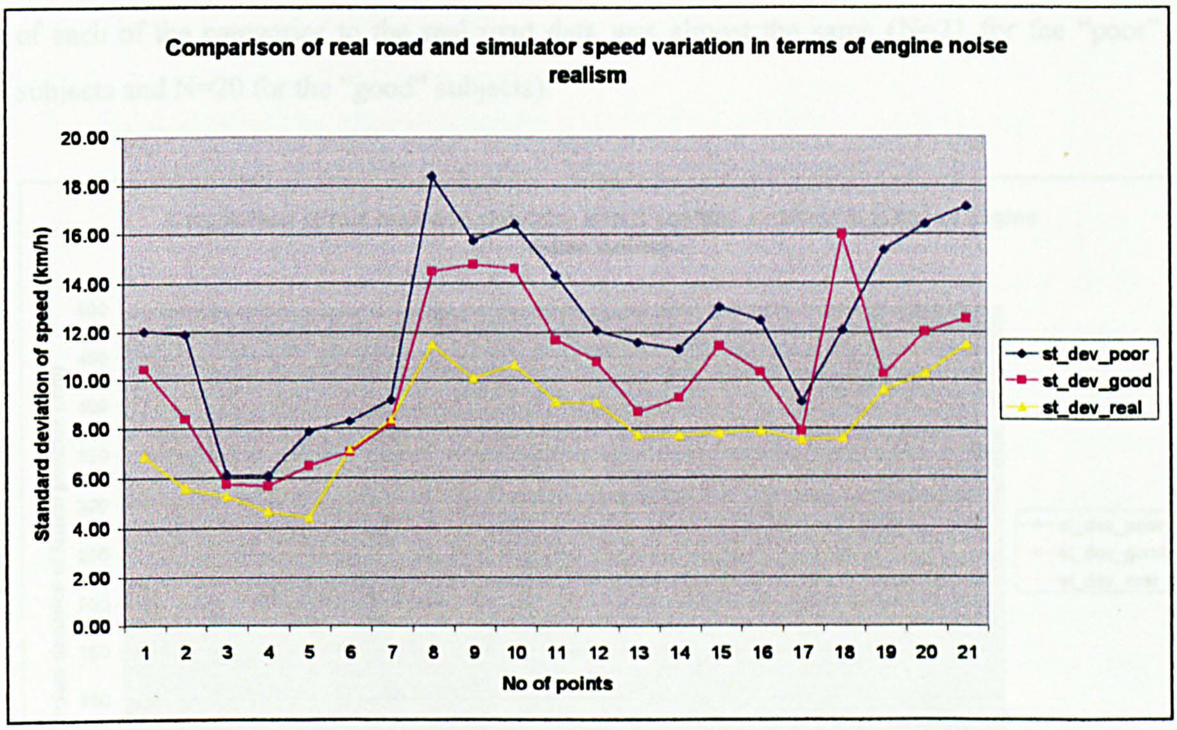


Figure 6-28 Comparison of real road and simulator speed variation in terms of engine noise realism

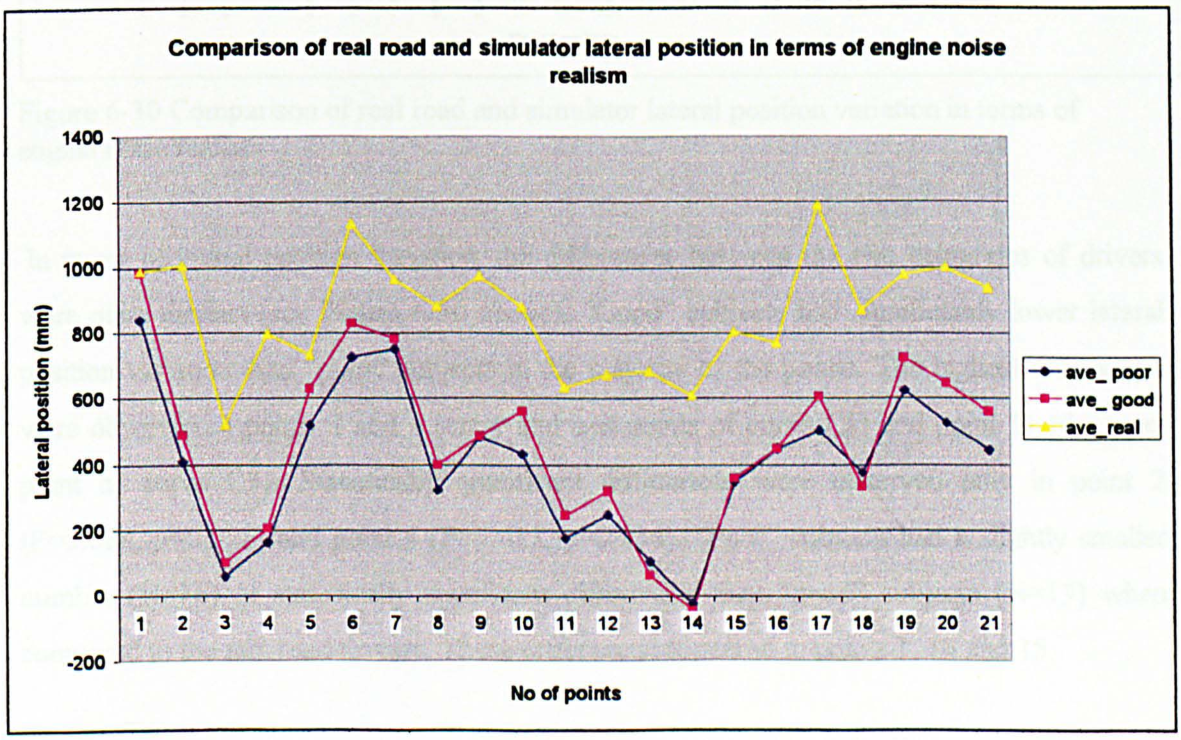


Figure 6-29 Comparison of real road and simulator lateral position in terms of engine noise realism

Subjects who found the engine noise realistic drove slightly closer to the centre of the road in all points besides points 13 and 18 (exit points of curves C3 and C4 respectively) compared to those who found it unrealistic (see Figure 6-29 above). However, the independent two samples t-test showed no statistically significant difference between the two categories at any of the points. The same test also showed that the number of statistically significant differences of each of the categories to the real road data was almost the same (N=21 for the "poor" subjects and N=20 for the "good" subjects).

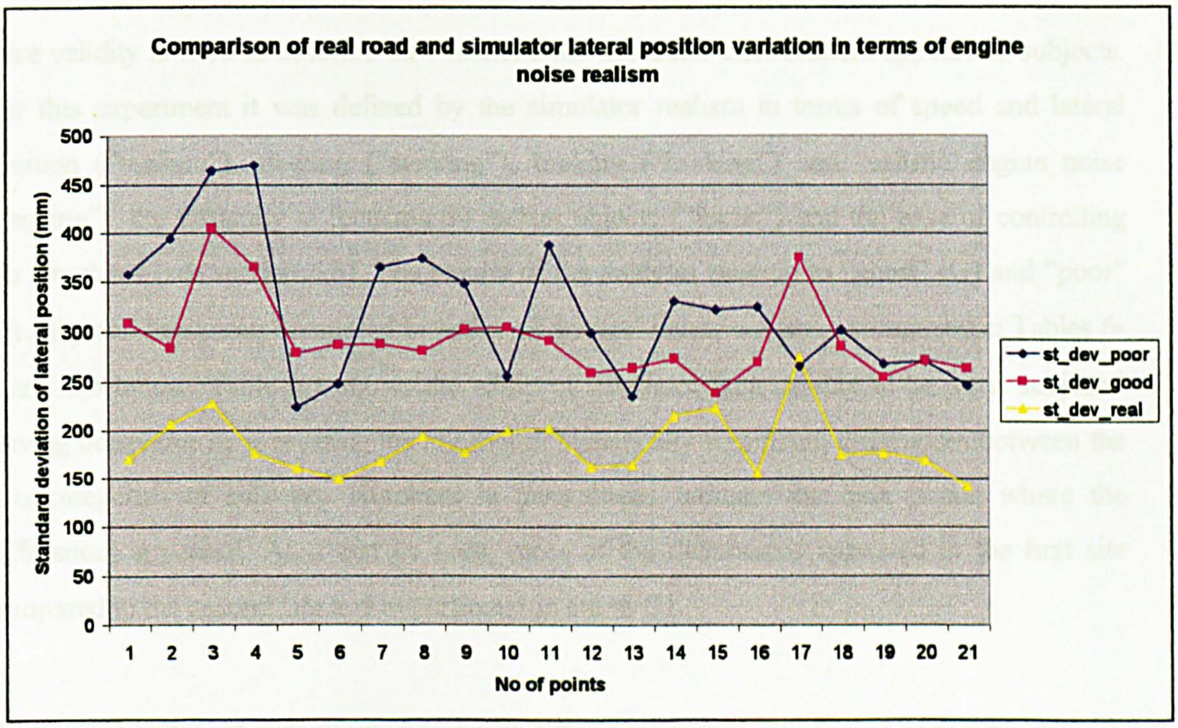


Figure 6-30 Comparison of real road and simulator lateral position variation in terms of engine noise realism

In terms of lateral position variation, the differences between the two categories of drivers were quite distinct (see Figure 6-30 above). "Good" subjects had significantly lower lateral position variation than "poor" subjects in the majority of the points. The highest differences were observed in points 2 and 4 (entry and exit points of curve C1) and point 11 (the apex point of curve C3). Statistically significant differences were observed only in point 2 (F=5.008, p=0.028) and point 4 (F=4.617, p=0.034). "Poor" subjects had a slightly smaller number (N=16) of statistically significant differences than "good" subjects (N=19) when compared to the real road drivers. These differences appeared in points 1, 14 and 15.

It could be argued that a realistic engine noise would have a more significant effect on subjects' speed than on their lateral position, especially when driving on straight road sections. The lack of speed perception as well as greater speeds developed on straights compared to curves when driving a simulator is already known. The above findings suggest that a realistic engine noise affects subjects' both speed and lateral position variation and in particular decreases the variation and the resulting subjects' behaviour is more close to the real road drivers' behaviour.

6.6.7. Summary of the effect of subjective data to subjects' behaviour

Face validity is used to describe how realistic the simulator environment appears to subjects. For this experiment it was defined by the simulator realism in terms of speed and lateral position ("realism"), steering ("steering"), braking ("braking") and realistic engine noise ("engine"); the difficulty in focusing on distant objects ("focus") and the ease of controlling the simulator (see section 6.6). The results of the analysis relating to "good" (G) and "poor" (P) subjects' behaviour compared to real road drivers' behaviour are summarised in Tables 6-4 and 6-5 below. Table 6-4 shows the effect of simulator face validity in-between subjects' driving behaviour by presenting the number of statistically significant differences between the two categories of subjects. Numbers in parentheses indicate the data points where the differences appeared. As it can be seen, most of the differences appeared in the first site compared to the second site and in particular in curve C1.

Table 6-4 Number of statistically significant differences between good and poor subjects

Face validity	Realism	Control	Steering	Braking	Focus	Engine
Speed	None	None	None	None	None	None
Speed variation	None	Three (10,15,19)	One (7)	None	Two (2,4)	Three (19,20,21)
Lateral position	One (7)	One (3)	Three (2,10,18)	One (6)	None	None
Lat. pos. variation	One (3)	None	None	One (12)	One (16)	Two (2,4)

From Table 6-4 the following conclusions could be drawn:

- Mean speed is a driving task that is not affected by drivers' opinion regarding simulator face validity. None of the parameters describing face validity affected subjects' speed behaviour

- Speed variation is not affected by the realism of speed itself and braking realism. It is mostly affected by the ease of controlling the speed in the simulator and the realism of the engine noise.
- Mean lateral position is slightly affected by the realism and ease of controlling the simulator in terms of lateral position as well as the realism of braking, mostly affected by the realism of steering and not at all affected by the realism of the engine noise and the difficulty in focusing on distant objects.
- Lateral position variation is not at all affected by the realism of steering and the ease of controlling the lateral position of the simulator (the opposite effect was observed in mean lateral position) and slightly affected by the other parameters that define simulator face validity.

Table 6-5 Number of differences between good and poor subjects compared to real road drivers

Face	Realism		Control		Steering		Braking		Focus		Engine	
validity	P	G	P	G	P	G	P	G	P	G	P	G
Speed	8	8	15	14	15	17	17	15	15	19	12	19
Speed variation	12	9	8	2	8	6	13	13	7	13	17	9
Lateral position	18	19	20	19	19	20	20	20	20	20	21	20
Lat. pos. variation	18	12	17	9	19	16	18	16	13	19	16	19

P="Poor" subjects, G="Good" subjects

Based on the results presented in Table 6-5, it could be argued that:

- Mean speed seems to be negatively affected by increased face validity of the simulator in terms of realistic engine noise and difficulty in focusing on distant objects. "Good" subjects had slightly worse behaviour than "poor" subjects when their behaviour was compared to real road driving besides when they believed that braking was realistic. Their behaviour was indifferent in terms of realism itself and ease of controlling the simulator (as it was also shown from Table 6.4).
- Speed variation was mostly positively affected by increased face validity. It was worse only in terms of difficulty in focusing on distant objects. It seems that "poor" subjects decrease their speed and speed variation to compensate the fact that they cannot see clear far ahead and therefore behave more close to the real road drivers. The ease of controlling

the simulator and the realism of steering were the two factors that had the greatest positive impact to speed variation;

- Lateral position was not affected by the face validity of the simulator. That is to say, subjects behave the same whatever they believe about the simulator realism or ease of controlling it. In this variable, the greater differences between any of the two categories of subjects and the real road drivers appeared, suggesting the lateral position is the variable that mostly lacks validity in the simulator;
- The weaving of the simulator vehicle was affected by face validity in a positive way. Increased face validity resulted in smaller weaving of the simulator car besides in terms of realistic engine noise and ability in focusing on distant objects. It seems that "poor" subjects due to their difficulty to see what is coming next at a long distance keep their vehicle at a steadier course compared to "good" subjects. The effect of the engine noise realism to lateral position variation was not expected. One possible explanation could be that the unrealistic engine noise confused subjects, made them feel unsafe and therefore forced them to keep the vehicle at a steadier course compared to subjects who found the engine noise realistic.

It was proven that "good" subjects are expected to give slightly more reliable results in terms of speed and lateral position variation, i.e. their driving behaviour will be closer to the real road driving behaviour. It is already known that higher differences between the real road and simulator environment appear mainly in terms of variation than in terms of mean values (Blaauw, 1982; Riemersma et al, 1990; Tenkink, 1990; Harms, 1993; Alm, 1995; Boulanger and Chevennement, 1995; Reed and Green, 1995; and Harms et al, 1996). Therefore it is suggested that "good" subjects should be preferred in future simulator experiments than "poor" subjects, because it expected that they would increase the reliability and validity of simulator results. Face validity should never be regarded as a substitute for objectively determined validity. As Harms et al (1996) concluded after the third behavioural validation study of the VTI driving simulator, "*increasing the face validity of the VTI simulator, it did not necessarily enhance the overall behavioural validity of the simulator*".

6.7. Chapter summary

This chapter summarised the data analysis of the simulator subjective data. Data was obtained from the pre- and post-experiment questionnaires (simulator realism data). Descriptive, inferential, qualitative and correlation analyses were used to analyse the pre- and post-experiment questionnaire data and subjects self-reported data.

It was found that subjects gender and age do not affect their performance in terms of speed and lateral position when driving the simulator car on a rural road in the presence of oncoming traffic and different geometric road features.

According to the post-experiment questionnaire, the least realistic feature of the simulator was braking followed by speed behaviour on curved sections. Subjects believe that speed control of the simulator vehicle was much easier on straight than curved road sections. The opposite applied for lateral control of the vehicle. About 15% of subjects claimed that oncoming traffic did not have any effect on their lateral position when driving on curved and straight road sections. A significant percentage (31%) said that oncoming traffic did not affect their speed at all when driving on straights whereas only 8% said that there was an effect when driving on curves.

According to male subjects' comments, the primary factor, which contributed negatively to the realism of the simulator was the feeling of the steering wheel, followed by the difficulty to focus on distant objects and the blurred or fuzzy screen. For female subjects the primary factor was the same as for male subjects, whereas the second was the unrealistic engine sound and the third the increased mental workload while driving the simulator as well as the difficulty to focus on distant objects. Although subjects commented that the least realistic feature of the driving simulator was braking, when specifically asked to comment on the realism of the simulator regarding the particular experiment, they replied that the least realistic feature was steering. This could be attributed to the fact that subjects did not feel that braking was an important task for the particular experiment (the experiment did not include any braking task) whereas steering was the primary task.

It was also proven that subjects who have a positive view relative to the face validity of the simulator give slightly more reliable results in terms of speed and lateral position variation compared to subjects who have a negative view. For both categories of subjects, face validity results in an indifferent behaviour in terms of lateral position.

7. CHAPTER SEVEN

COMPARISON OF REAL ROAD AND SIMULATOR DATA

7.1 Introduction

This chapter investigates the behavioural validity of the Leeds Advanced Driving Simulator (LADS) by comparing real road and simulator data using descriptive, inferential and correlation statistical analyses and where possible, relating the derived results with results from previous behavioural validation studies. It focuses on the quantitative and qualitative differences between the two environments by examining the effect of geometric features and different oncoming traffic conditions on driver behaviour in terms of speed and lateral position. It finally attempts to develop a model correlating the speed and lateral position data in the two environments.

7.2 Multiple parameters analysis

As mentioned before in section 5.4.3 in Chapter 5, it was decided to analyse the simulator road data of runs 2 and 3 both for medium and heavy oncoming traffic conditions. Because some subjects had appeared twice in that set of data, it was decided that for these particular subjects, the average of the two values should be taken as the final value. The aforementioned simulator data were compared to the real road data. Both sets of data were tested for their normality. If data were normally distributed, then parametric tests could be used.

The Kolmogorov-Smirnov Goodness of Fit Test was used to test the normality of data. This test is non-parametric and compares the observed cumulative distribution functions for a variable with a specified theoretical distribution, which is normal. The Kolmogorov-Smirnov test is computed from the largest difference (in absolute value) between the observed and theoretical distribution functions and the two-tail probability level is based on the Smirnov

(1948) formula (Norusis, 1993). When the two-tailed probability function is lower than 0.05, then data is not normally distributed –once the chosen significance level is 95%.

The results from the application of the test for both the real and simulator data in terms of speed and lateral position showed that both variables of both environments for all 21 measurement points were normally distributed. Therefore parametric tests and analysis of variance could be applied to test the differences in means and variances between the two environments.

Multivariate Analysis of Variance (MANOVA) was used to test the effect of different geometric features (factors) on speed and lateral position when these two dependent variables were examined combined. The factors were environment (simulator v. real road), degree of curve (varied according to the radius of the curves), site (site 1 and site 2) and type of road section (straight, "approaching a curve" straight section, left and right curves).

The following null hypotheses were tested and accepted or rejected according to the F statistic of MANOVA:

1. The null hypothesis that there was no "environment-by-type of road-by-site" interaction was rejected (Pillais trace: F=0.10; p=0.000) and all factors jointly contributed to the overall differences in the dependent variables ($F_{1,4119}$=44.76; p=0.000 for speed and $F_{1,4119}$=71.53; p=0.000 for lateral position);
2. The null hypothesis that there was no "type of road-by-site" interaction was rejected (Pillais trace: F=0.15; p=0.000) and all factors jointly contributed to the overall differences in the dependent variables ($F_{1,4119}$=285.44; p=0.000 for speed and $F_{1,4119}$=395.69; p=0.000 for lateral position);
3. The null hypothesis that there was no "environment-by-site" interaction was rejected (Pillais trace: F=0.01; p=0.000) and all factors jointly contributed to the overall differences in the dependent variables ($F_{1,4119}$=26.56; p=0.000 for speed and $F_{1,4119}$=10.85; p=0.000 for lateral position);
4. The null hypothesis that there was no "environment-by-degree of curve" interaction was rejected (Pillais trace: F=0.02; p=0.000) and all factors jointly contributed to the overall differences in the dependent variables ($F_{1,4119}$=74.41; p=0.000 for speed and $F_{1,4119}$=39.96; p=0.000 for lateral position);
5. The null hypothesis that there was no "environment-by-degree of curve-by-site" interaction was rejected (Pillais trace: F=0.05; p=0.000) and all factors jointly contributed to the

overall differences in the dependent variables ($F_{1,4119}$=33.87; p=0.000 for speed and $F_{1,4119}$=33.07; p=0.000 for lateral position);

6. The null hypothesis that there was no "degree of curve-by-site" interaction was rejected (Pillais trace: F=0.11; p=0.000) and all factors jointly contributed to the overall differences in the dependent variables ($F_{1,4119}$=158.22; p=0.000 for speed and $F_{1,4119}$=290.16; p=0.000 for lateral position);
7. The null hypothesis that there was no effect of the degree of curve on the dependent variables was rejected (Pillais trace: F=0.13; p=0.000) and this factor affected both dependent variables ($F_{1,4119}$=142.84; p=0.000 for speed and $F_{1,4119}$=141.13; p=0.000 for lateral position);
8. The null hypothesis that there was no effect of site on the dependent variables was rejected (Pillais trace: F=0.05; p=0.000) and this factor affected both dependent variables ($F_{1,4119}$=28.57; p=0.000 for speed and $F_{1,4119}$=175.31; p=0.000 for lateral position);
9. The null hypothesis that there was no effect of type of road on the dependent variables degree was rejected (Pillais trace: F=0.45; p=0.000) and this factor affected both dependent variables ($F_{1,4119}$=540.16; p=0.000 for speed and $F_{1,4119}$=271.11; p=0.000 for lateral position);
10. The null hypothesis that there was no effect of the environment on the dependent variables degree was rejected (Pillais trace: F=0.04; p=0.000) and this factor affected both dependent variables ($F_{1,4119}$=45.36; p=0.000 for speed and $F_{1,4119}$=139.07; p=0.000 for lateral position).

The results from the application of the MANOVA test showed that the effect of site, type of road and degree of curve does not apply the same in both the real road and the simulator environments which implies not so good relative validity. This suggests that simulator subjects and real road drivers perceive differently the geometric features of the road in the two environments. For example it is already known that the perception of distance is different in the simulator compared to real life (Groeger et al, 1997). The results suggest that neither the two sites nor the curved and straight road sections should be investigated together. It also suggests that the different radii curves should be analysed separately since there was an interaction of degree of curve by site as well as an effect of degree of curve to speed and lateral position.

Further investigation using analysis of variance when the dependent variables (speed and lateral position) were examined separately and not combined showed that all the aforementioned factors affect the dependent variables except for the degree of curve which did not affect lateral position (F=2.54, p=0.128). This implies that the radius of curve does not play such an important role in vehicle trajectory along the road. Using one-way analysis of variance the effect of different type of roads to speed and lateral position was examined. It was found that speed differed between left and right curves and between straight and curved road sections and between straight sections and "approaching a curve" straight sections. This implies that speeds adopted on straight sections, which are independent of precedent or following curved sections differ from those speeds adopted on the approach to a curve. Lateral position on straight sections and right curves differed to both lateral position on approaching sections and left curves and lateral position on approaching sections and left curves differed to each other. It seems that drivers positioned their vehicle at the same distance from the edge of the road on the approach of a curve and generally on a right curve, which was further away from the edge of the road compared to all other cases.

Based on the above results, it was decided to compare driver behaviour on real road and in the simulator, in terms of speed and lateral position for curved and straight road sections separately, for left- and right-hand curves separately as well as at characteristic points on the curve.

7.3 Effect of road geometry on driver behaviour

The following subsections will present the effect of road geometry on driver behaviour (in terms of speed and lateral position) when driving on curved versus straight road sections; when driving on left- versus right-hand curves and along the characteristic points of a curve (i.e., the approach, entry, apex and exit points of a curve).

7.3.1 Curved versus straight road sections

The mean and standard deviation of speed and lateral position, in terms of absolute values, for the real road and simulator data when driving on curved and straight road sections were calculated and tested for their statistically significant difference using relevant statistical tests. If there was no statistically significant difference, then the simulator could be characterised as "absolutely" valid according to Blaauw's (1982) absolute validity criterion. The mean speed and lateral position for the 21 measurement points of the two environments were also plotted against the whole length of the investigated road (see Table 7-1). The aim was to test if the observed differences between the two environments when driving on curved and straight road sections under the presence of oncoming traffic were of the same direction. If they were of the same direction then the simulator could be characterised as "relatively" valid according to Blaauw's (1982) relative validity criterion.

Table 7-1 Chainage between the points of sites 1 and 2

Points of site 1	Chainage	Points of site 2	Chainage
1 (approach C1)	17.50	11 (approach C3)	4249.45
2 (entry C1)	118.59	12 (entry C3)	4311.95
3 (apex C1)	151.58	13 (apex C3)	4386.72
4 (exit C1/approach C2)	184.57	14 (exit C3)	4461.49
5 (entry C2)	252.57	15 (approach C4)	4765.69
6 (apex C2)	309.25	16 (entry C4)	4865.69
7 (exit C2)	365.93	17 (apex C4)	4922.88
8 (Straight S1)	1830.65	18 (exit C4)	4984.32
9 (Straight S1)	1930.65	19 (Straight S2)	5457.41
10 (Straight S1)	2274.65	20 (Straight S2)	5537.41
		21 (Straight S2)	5617.41

7.3.1.1 Speed

From Table 7-2 below, it can be seen that the average difference in speed for all curved sections was 4.47 km/h. Standard deviation of speed was higher in the simulator compared to the real road for all measurement points on average by 2.44 km/h. Mean speed was higher on real road compared to the simulator for all points except for point 15 (approach point of curve C4). Due to the length of the tangent preceding point 15 (approximately 300 m) simulator drivers were not confined by the road geometry, therefore adopted a high speed, similar to the one they would adopt on a straight section. The smallest differences between the two environments were observed in the apex and exit points of curve C1 and were almost zero (points where drivers were mostly confined by road geometry).

Speeds adopted on straight sections in the simulator were higher compared to those adopted on the real road, both in terms of mean and standard deviation values (see Table 7-3 below). On average, subjects drove by ≈12 km/h faster in the simulator compared to real life. The average difference for standard deviation was 3.74 km/h higher in the simulator compared to real life.

Summarising, it was found that speeds in the simulator were lower on curves and higher on straights than those on the real road. The same effect has already been observed in a previous study in LADS (Pyne et al, 1995) where the same road alignment and environment had been used for a different study. This "verification" of results between previous and recent studies in LADS, increases the reliability of results obtained from the simulator. Soma et al (1996), using a moving-base driving simulator also observed lower speeds in the simulator compared to real life irrespective of whether the motion system was "on" or "off". However the observed differences between the simulator speed and the field speed were significantly smaller when the motion system was on. The "real road" experiment was conducted on a test track. On the other hand, Kaptein et al (1996) and Tenkink and van der Horst (1991) have found that speeds adopted on curved sections in the simulator were much higher than those adopted in real life. Harms (1993), Alm (1995) and Harms et al (1996) observed higher speeds in the simulator compared to real life both for driving on curved and straight road sections (a moving-base simulator was used for the simulator experiment). Duncan (1995) using a fixed-base simulator (with very limited motion system) has also observed higher speeds in the simulator. The "real road experiment" was conducted on a test track. Speed differences were also observed by Alicandri et al (1986).

Table 7-2 Descriptive statistics of observed driver and subject speed for curves only

Speed (km/h) - Curves						
Points	Mean			Standard Deviation		
Site 1						
	Real	Sim	Differ.	Real	Sim	Differ.
1 (approach C1)	63.40	54.00	9.40	7.94	10.82	-2.88
2 (entry C1)	50.26	46.51	3.75	6.83	9.40	-2.57
3 (apex C1)	43.75	42.90	0.85	6.06	6.21	-0.15
4 (exit C1/approach C2)	45.71	44.81	0.90	3.82	5.94	-2.12
5 (entry C2)	50.34	45.32	5.02	4.39	7.00	-2.61
6 (apex C2)	57.04	50.46	6.58	7.73	7.36	0.37
7 (exit C2)	61.15	56.57	4.58	10.30	9.05	1.25
Site 2						
11 (approach C3)	79.00	74.26	4.74	9.06	12.66	-3.60
12 (entry C3)	75.35	60.35	15.00	9.04	11.52	-2.48
13 (apex C3)	64.68	60.86	3.82	7.71	9.85	-2.14
14 (exit C3)	67.00	60.11	6.89	7.69	10.10	-2.41
15 (approach C4)	73.61	79.00	-5.39	7.77	12.32	-4.55
16 (entry C4)	66.74	63.75	2.99	7.88	11.57	-3.69
17 (apex C4)	63.53	61.25	2.28	7.50	8.54	-1.04
18 (exit C4)	70.00	64.31	5.69	7.57	16.76	-9.19
Mean	**61.54**	**57.06**	**4.47**	**7.38**	**9.82**	**-2.44**

Table 7-3 Descriptive statistics of observed driver and subject speed for straights only

Speed (km/h) - Straights						
Points	Mean			Standard Deviation		
Site 1						
	Real	Sim	Differ.	Real	Sim	Differ.
8 (S1)	80.68	95.08	-14.40	8.38	14.90	-6.52
9 (S1)	80.73	94.31	-13.58	10.14	14.62	-4.48
10 (S1)	83.35	97.37	-14.02	10.35	15.07	-4.72
Site 2						
19 (S2)	81.00	89.78	-8.78	9.59	11.36	-1.77
20 (S2)	82.55	94.60	-12.05	10.29	13.08	-2.79
21 (S2)	87.39	97.48	-10.09	11.43	13.59	-2.16
Mean	**82.62**	**94.77**	**-12.16**	**10.03**	**13.77**	**-3.74**

The mean speed profile of free-flowing observed vehicles and the simulator car have been plotted for each measurement point along the whole length of the investigated road section of the A614 (see Figures 7-1). Speed change rates can be observed in the speed profile plot through the slope of the lines linking data points.

From Figure 7-1 below, it can be seen that for the "S" curve (curves C1 and C2) both sets of drivers followed a very similar behaviour. They both decelerated until the apex of curve C1 and then continued acceleration until the exit of curve C2. The acceleration and deceleration rates of the real road drivers were steeper compared to their simulator counterparts.

Driver behaviour when traversing curve C3 was quite distinct between the two sets of drivers. Curve C3 is of very poor visibility on real road conditions. That is to say, from the approach until the apex of the curve, the visibility is extremely poor thus the driver is completely unaware of what is coming next or what is in front of him. Observed drivers decelerated from the approach until the apex point of the curve and after that started accelerating, whereas simulator subjects kept a constant speed at the circular arc of the curve. A probable explanation for the observed difference could be the way subjects perceive the layout (i.e. how long they think the curve is) and the appearance (i.e. what subjects think about the visibility) of curve C3 in the simulator. It seems that subjects and observed drivers perceive at a different moment the hazard of the curve and consequently adapt their speed. It seems that subjects perceived the hazard (poor visibility) earlier in the simulator (or the hazard was revealed earlier in the simulator) but it took them more time to counterbalance the counter-effect (speed reduction) compared to the real road.

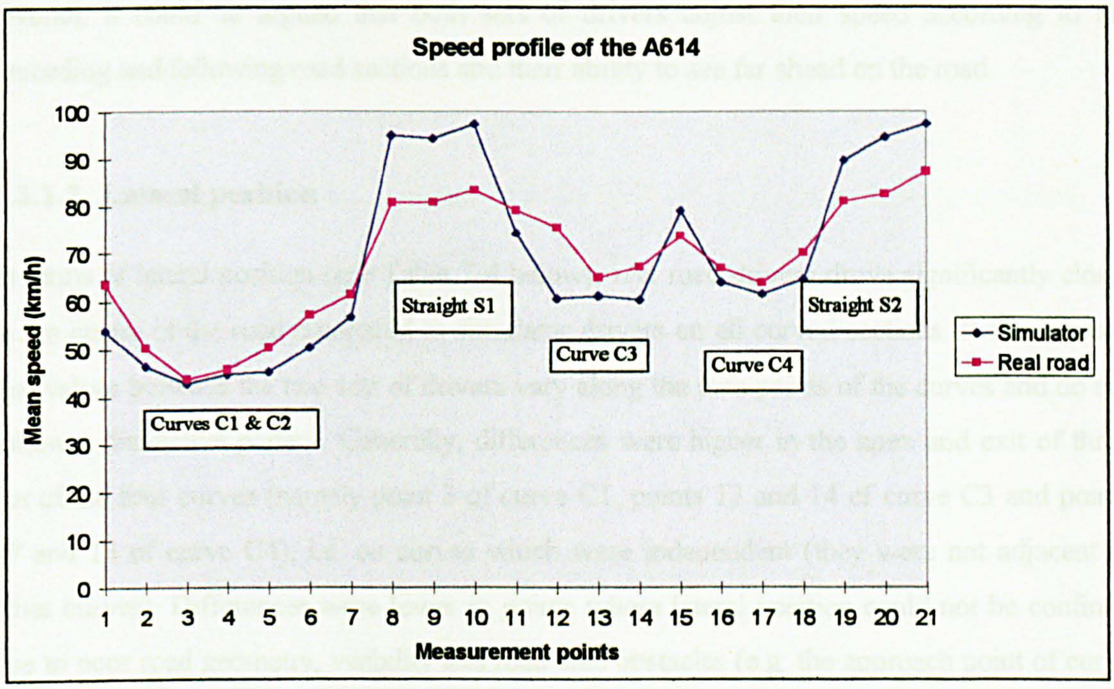


Figure 7-1 Comparison of the real road and simulator speed profiles for the whole length of the road

Relative to curve C4, it can be seen that for the approach until the apex of the curve, both sets of drivers decelerated; however, the deceleration rate of real road drivers was lower than the respective rate of the simulator subjects, especially between the approach and entry points. Simulator drivers approached the curve at a higher speed (this was also observed in Table 7-2), therefore they had to lower their speed very quickly to accommodate the curve successfully. For the second half of the arc, both sets of drivers accelerated; this time the acceleration rate of both drivers was almost the same.

Relative to the straight sections of the investigated road, both sets of drivers kept an almost constant speed along the whole length of the straight sections; however drivers on the real road drove slower than their simulator counterparts. Relative to the first straight, both sets of drivers slightly increased their speed from the first data point till the last data point. The same behaviour was observed in the second straight too; however the increase of speed in the second part of this straight was higher compared to the increase of speed in the respective part of the first straight. This could be explained by the fact that after the last data point of the first straight a curved section follows in about 500m (which is visible to the driver). On the other hand, after the last data point of the second straight the straight continues for at least another kilometre, therefore drivers of the second straight have no reason to decrease their speed.

Overall, it could be argued that both sets of drivers adjust their speed according to the preceding and following road sections and their ability to see far ahead on the road.

7.3.1.2 Lateral position

In terms of lateral position (see Table 7-4 below), real road drivers drove significantly closer to the centre of the road compared to simulator drivers on all curved sections. It can be seen that values between the two sets of drivers vary along the data points of the curves and do not follow a distinctive pattern. Generally, differences were higher in the apex and exit of three out of the four curves (namely point 3 of curve C1, points 13 and 14 of curve C3 and points 17 and 18 of curve C4), i.e. on curves which were independent (they were not adjacent to other curves). Differences were lower in points where lateral position could not be confined due to poor road geometry, visibility and road side obstacles (e.g. the approach point of curve C1, the entry point of curve C2 and the entry point of curve C4 respectively).

Table 7-4 Descriptive statistics of observed driver and subject lateral position for curves only

Lateral position (mm)- Curves				
Points	Mean		St Dev.	
	Site 1			
	Real	Sim	Real	Sim
1 (approach C1)	987	934	169	359
2 (entry C1)	1005	438	133	332
3 (apex C1)	521	74	182	483
4 (exit C1/approach C2)	795	194	174	391
5 (entry C2)	733	595	174	273
6 (apex C2)	1132	787	122	299
7 (exit C2)	963	758	156	312
	Site 2			
11 (approach C3)	633	224	201	330
12 (entry C3)	671	284	162	293
13 (apex C3)	680	66	164	261
14 (exit C3)	608	-33	214	300
15 (approach C4)	802	351	222	271
16 (entry C4)	767	436	155	284
17 (apex C4)	1187	573	273	368
18 (exit C4)	869	334	174	315
Mean	**838**	**410**	**177**	**326**

As it can be seen from Table 7-5 below, real road drivers positioned their vehicle significantly closer to the centre of the road compared to their simulator counterparts on the straight sections. The average of standard deviation for all measurement points was about twice in the simulator compared to the real road (382 mm and 190 mm respectively).

Table 7-5 Descriptive statistics of observed driver and subject lateral position for straights only

Lateral position (mm) - straights				
Points	Mean		St Dev.	
Site 1				
	Real	Sim	Real	Sim
8 (S1)	882	370	245	312
9 (S1)	973	466	203	331
10 (S1)	879	532	203	813
Site 2				
19 (S2)	977	698	176	281
20 (S2)	999	620	168	277
21 (S2)	935	534	141	275
Mean	**940**	**536**	**190**	**382**

Overall, subjects drove closer to the edge of the road by about 40 cm, compared to their real road counterparts whether they drove on curved and/or straight road sections. The same behaviour (i.e. driving closer to the edge of the road in the simulator) has been observed by Alm (1995), (the second VTI behavioural validation study) but the opposite behaviour had been observed in the first VTI behavioural validation study (Harms, 1993). Standard deviation of speed and lateral position was greater in the simulator compared to real life whether subjects drove on curved and/or straight sections. Differences between the real road and the simulator environment in terms of lateral position have been observed in most of the simulator studies, not necessarily behavioural validation studies (see Blaauw, 1982; Tenkink, 1989; Harms, 1993; Alm, 1995; Duncan, 1995; Harms et al, 1996).

Figure 7-2 shows the mean lateral position profiles of simulator subjects and real road drivers along the whole length of the investigated road section of the A614. The width of the road for each curve and straight road section is represented with two lines. The first line, which is the left line of the road coincides with the x-axis and the second line, which is the middle white line of the road is always located on the bottom of the mean lateral position profile line. This particular way of representing the lane width and vehicle path along the length of the curve reverses the natural way of looking at lateral position (i.e. it is suitable for driving on the left in England). On the other hand, the reader should bear in mind that the "sign" used so far to represent the vehicle placement on the road (positive when the vehicle was located on the right of the left white line and negative otherwise) is now reversed.

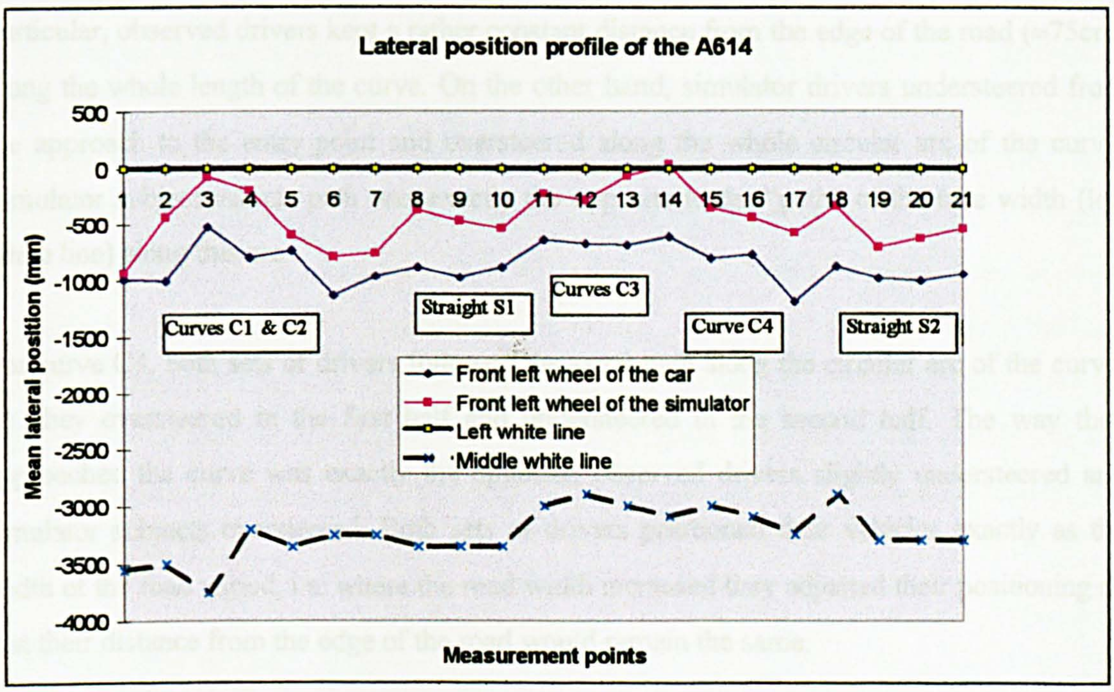


Figure 7-2 Comparison of the real road and simulator lateral position profiles for the whole length of the road

As it can be seen from Figure 7-2, for curve C1 both sets of drivers followed a very similar driving behaviour in terms of lateral position on the circular arc of the curve. In particular, from the entry until the apex of the curve, drivers from both environments oversteered and then from the apex until the exit of the curve understeered. The path of their vehicle along the length of the circular arc was exactly the opposite to the "path" of the lane width (left white line) along this arc. In other words, at the apex of the curve where the lane was wider, they moved even closer to the edge of the road. The only difference in their behaviour was the way they approached the curve. Observed drivers kept their vehicle a constant distance from the edge of the road (≈ 1m), whereas simulator subjects oversteered by about half a metre.

For curve C2 both sets of drivers followed a rather similar behaviour besides along the approach to the curve. That is to say, from the approach until the entry points of the curve, observed drivers understeered whereas simulator subjects oversteered. Along the circular arc of the curve both sets of drivers followed a similar behaviour, i.e. in the first half they oversteered and in the second half they understeered. It seems that observed drivers were not so much affected by the preceding curve whereas simulator drivers were indeed affected and their vehicle's lateral path along the "S" curve followed exactly the path of the "S" curve.

For curve C3, drivers in the two environments followed a different driving behaviour. In particular, observed drivers kept a rather constant distance from the edge of the road (≈75cm) along the whole length of the curve. On the other hand, simulator drivers understeered from the approach to the entry point and oversteered along the whole circular arc of the curve. Simulator subject vehicle path was exactly the opposite to the "path" of the lane width (left white line) along this arc.

For curve C4, both sets of drivers followed the same path along the circular arc of the curve, i.e. they oversteered in the first half and understeered in the second half. The way they approached the curve was exactly the opposite, observed drivers slightly understeered and simulator subjects oversteered. Both sets of drivers positioned their vehicles exactly as the width of the road varied, i.e. where the road width increased they adjusted their positioning so that their distance from the edge of the road would remain the same.

With regard to their lateral position on straight sections, the two sets of drivers had a different behaviour. In particular, relative to the first straight, simulator subjects constantly moved towards the centre of the lane, whereas observed drivers kept a rather constant distance from the edge of the road. Relative to the second straight, it can be seen that simulator subjects constantly move towards the edge of the road, whereas observed drivers kept a rather constant distant from the edge of the road. This aforementioned observed deviation in lateral placement of the vehicle between the two investigated road straight sections is not believed to be perceivable by any set of drivers. Both sets of drivers on both straights positioned their vehicle at a fixed distance from the edge of the road, namely ≈1m for the observed drivers and ≈60cm for the simulator subjects.

Overall, it could be argued that:

a) the direction of change was the same for the circular arcs of curves C1, C2 and C4 but different for curve C3 between the two environments;
b) the direction of change was different for the approach of curves C1, C2 and C3 but the same for curve C4 between the two environments;
c) the direction of change on the two straight sections was different between the two environments.

7.3.1.3 Testing the effect of road geometry on driver behaviour

The independent samples t-test was used to test the null hypothesis that the means of the two environments in terms of speed and lateral position were the same. The computed t ratio was compared against the critical values at the 0.05 (t_{crit}= 1.96) and 0.01 (t_{crit}= 2.58) significance levels. If the t ratio was less than the critical value, then the null hypothesis was accepted; if it was equal or greater than the critical value then the null hypothesis was rejected. The Levene's test was used to test the equality of variances of the two environments. If variances were equal, then the separated-variance t value was used – which resulted in an observed significance level somewhat larger than it should be. If variances were not equal then the pooled-variance t value was used – in this case the probability case associated with the statistic may be in error; the amount of error depends on the inequality of the sample size and of the variances (Norusis, 1993). However, for large samples, the discrepancy between the two methods is small.

The results showed that:

1. The null hypothesis that mean speed on curves between the real road and the simulator is equal to each other was rejected (t=9.29) at the 0.05 significance level, variances were unequal (F=12.603, p=0.000);
2. The null hypothesis that mean lateral position on curves between the real road and the simulator is equal to each other was rejected (t=31.89) at the 0.05 significance level, variances were unequal (F=207.236, p=0.000);
3. The null hypothesis that mean speed on straights between the real road and the simulator is equal to each other was rejected (t=-16.37), at the 0.05 significance level, variances were unequal (F=24.541, p=0.000);
4. The null hypothesis that mean lateral position on straights between the real road and the simulator is equal to each other was rejected (t=27.47), at the 0.05 significance level, variances were unequal (F=109.130, p=0.000).

The results of the above tests showed that the numerical differences between the two environments when driving on curved and straight road sections in terms of speed and lateral position, both for mean and standard deviation values were statistically significant. Therefore, according to Blaauw's (1982) absolute validity criterion (as defined in section 3.3.3 in

Chapter 3), LADS cannot be characterised as absolutely valid in terms of speed and lateral position when driving on curved and straight road sections.

7.3.2 Left-hand versus right-hand curves

Out of the four investigated curves, two of them were right-hand and the other two left-hand. These were curves C2 and C4 and curves C1 and C3 respectively. Table 7-6 and Table 7-7 summarise the descriptive statistics relative to the effect of direction of curves on driving behaviour when the real road environment is compared to the simulator environment in terms of speed and lateral position respectively.

Table 7-6 Differences in speed when driving on different direction curves between the two environments

Speed (km/h)				
Variables	Left Curves		Right Curves	
	Real	Sim	Real	Sim
Mean	61.02	58.18	61.14	55.48
St Dev	7.12	9.82	7.27	9.56

In terms of speed (see Table7-6 above), simulator drivers drove slower than their real road counterparts, whether they were moving on left or right curves. Observed drivers traversed the left and right-hand curves at the same speed, whereas simulator drivers drove at higher speed (by ≈3 km/h) on the right- compared to the left-hand curves. Standard deviation for both sets of drivers was almost the same level whether drivers where traversing a left or right-hand curve, however it was higher (by ≈2.5 km/h) in the simulator compared to real life.

It can also be observed that real road drivers drove slightly faster on the right curves compared to the left curves whereas simulator subjects did exactly the opposite (the difference in speed was much higher in this case).

In terms of lateral position, drivers of both environments drove further away from the edgeline on the left curves compared to the right curves (by 22% the observed drivers and 84% the simulator subjects). Simulator subjects drove generally closer to the left edge of the road compared to their real road counterparts (see Table 7-7 below). Differences between the left- and right-hand curves in terms of speed and lateral position were expected as the multivariate analysis of variance in section 7.2 had already shown.

Table 7-7 Differences in lateral position when driving on different direction curves between the two environments

Lateral position (mm)				
Variables	Left Curves		Right Curves	
	Real	Sim	Real	Sim
Mean	906	503	738	273
St Dev	181	314	175	344

The independent two samples t-test was used to test the hypothesis that the means of speed and mean lateral position when driving on left and right-hand curves were the same between the two environments. The t ratio was calculated for the 8 points of the left and right curved sections respectively in terms of speed and lateral position.

The results showed that:

1. The null hypothesis that mean speed on left curves between the real road and the simulator environment is equal to each other was rejected at both significance levels (t=8.978);
2. The null hypothesis that mean speed on right curves between the real road and the simulator environment is equal to each other was rejected at both significance levels (t=16.090);
3. The null hypothesis that mean lateral position on left curves between the real road and the simulator environment is equal to each other was rejected at both significance levels (t=42.574);
4. The null hypothesis that mean lateral position on right curves between the real road and the simulator environment is equal to each other was rejected at both significance levels (t=36.736);

Overall, it could be concluded that driver behaviour in the simulator differs from the respective behaviour on the real road when driving on different direction curves in terms of the absolute validity criterion.

7.3.3 Characteristic points of a curve

In addition to the effect of driving on curves versus on straights on driver behaviour, the effect of the characteristic points of the curve (namely the approach, the entry, the apex and the exit points) on driver behaviour between the two environments was also investigated. Table 7-8 gives the speed values for the real road and the simulator environment, relative to the effect of the characteristic points of a curve to each curve.

Table 7-8 Comparison of real road and simulator data relative to the effect of the characteristic points of a curve

Mean Speed (km/h)								
Curves	Approach		Entry		Apex		Exit	
	Real	Sim	Real	Sim	Real	Sim	Real	Sim
All curves	65.43	63.02	60.67	53.98	57.20	53.87	60.97	56.45
Curve C1	63.40	54.00	50.26	46.51	43.75	42.60	45.71	44.81
Curve C2	45.71	44.81	50.34	45.32	57.04	50.46	61.15	56.57
Curve C3	79.00	74.26	75.35	60.35	64.68	60.86	67.00	60.11
Curve C4	73.61	79.00	66.74	63.75	63.53	61.26	69.99	64.31

When comparing the characteristic points of each curve separately for the two environments, it can be observed that:

a) for curves C1, C2 and C4, speed behaviour was very similar along the points for the two environments but differed in absolute values;

b) for curve C3, speed behaviour was different both in absolute and relative terms between the two environments; the highest differences between the characteristic points between the two environments were observed in this curve compared to all other curves.

It could be concluded that in absolute values, speed varies significantly along the length of each curve between the two environments and there is not a distinctive pattern in terms of speed differentiation between the characteristic points of a curve for either real road or simulator driving.

Table 7-9 shows lateral position values on curves on the real road and the simulator. It can be seen that when comparing all curves, simulator subjects drove closer to the edge of the road regardless of the curve direction and at all curve points compared to their real road counterparts. The smallest difference appeared in the entry point of the curve (356mm). It can also be observed that for the majority of the curves (three out of four) the smallest difference between the two environments was at the entry of the curve. Generally greater differences between the two environments appeared in the apex and exit points of the curves.

Table 7-9 Comparison of real road and simulator data relative to the effect of the characteristic points of a curve on driver behaviour with regards to lateral position

Comparison of mean lateral position (mm)								
Curves	Approach		Entry		Apex		Exit	
	Real	Sim	Real	Sim	Real	Sim	Real	Sim
All curves	804	426	794	438	880	375	809	313
Curve C1	987	934	1005	438	521	74	795	194
Curve C2	795	194	733	595	1132	787	963	758
Curve C3	633	224	671	284	680	66	608	-33
Curve C4	802	351	767	436	1187	573	869	334

7.4 Effect of oncoming traffic on driver behaviour

The following paragraphs compare the real road and simulator data under different oncoming traffic conditions. It has been proven in Chapter 5, section 5.4.3.1 that subject behaviour is affected by the overall presence of traffic in the opposing lane but subjects cannot distinguish between medium and heavy oncoming traffic. This section investigates driver behaviour when the oncoming vehicle(s) is in the near vicinity of the investigated data point, i.e. vehicles travelling in the oncoming direction within a distance of 20 m on the curved sections and 50 m on the straight sections.

Table 7-10 below summarises the descriptive statistics relative to the difference between the two environments in terms of speed on curved road sections with and without oncoming traffic. It can be seen that speed in both environments decreased with the presence of oncoming traffic, however the decrease was almost insignificant (less than 2 km/h in both environments). It could be concluded that oncoming traffic had the same effect on both sets of drivers, i.e. it did not affect their speed on curves. Generally, observed drivers drove faster than their simulator counterparts on average by 5 km/h irrespective of the presence of oncoming traffic in the near vicinity or not. Standard deviation difference was almost the same in the two environments with or without the presence of oncoming traffic. Generally, standard deviation was smaller in the real road (by about 2.5 km/h) compared to the simulator environment.

Table 7-10 Summary of comparison of real road and simulator data in terms of speed with and without oncoming traffic when driving on curves

Speed on curves (km/h)				
Variables	with		without	
	Real	Sim	Real	Sim
Mean	60.24	55.12	61.77	56.92
St Dev	7.25	9.56	7.04	9.71

Table 7-11 summarises the descriptive statistics relative to the difference between the two environments in terms of lateral position on curved road sections with and without oncoming traffic. It can be seen that drivers of both environments moved slightly closer to the edge of the road (about 10cm) when there was oncoming traffic. That is to say, the effect of oncoming traffic was the same between the two environments. However, in terms of absolute values, simulator drivers positioned their vehicle about 45cm closer to the edge of the road compared to their real road counterparts.

Table 7-11 Summary of comparison of real road and simulator data in terms of lateral position with and without oncoming traffic when driving on curves

Lateral position on curves (mm)				
Variables	with		without	
	Real	Sim	Real	Sim
Mean	736	298	842	397
St Dev	189	270	181	332

Table 7-12 Summary of comparison of real road and simulator data with and without oncoming traffic when driving on straights

Speed on straights (km/h)				
Variables	with		without	
	Real	Sim	Real	Sim
Mean	83.64	92.50	82.35	93.56
St Dev	10.62	12.35	10.58	10.58

Table 7-12 above summarises the descriptive statistics relative to the difference in terms of speed on straight road sections with and without oncoming traffic between the two environments. It can be seen that the presence of oncoming traffic had a minimal effect on speed in both environments (about 1km/h). However, in terms of absolute values, observed drivers drove slower than their simulator counterparts by ≈10 km/h on the straight sections. Standard deviation was higher in the simulator compared to real life whatever the conditions of oncoming traffic. However it decreased with the presence of oncoming traffic in the simulator whereas on the real road there was no such effect.

Table 7-13 below summarises the descriptive statistics relative to lateral position on straight road sections with and without oncoming traffic between the two environments. It can be seen that only observed drivers moved slightly closer to the edge of the road (about 7cm) when there was oncoming traffic whereas simulator subjects did not change their vehicle position at all. On absolute values, the mean of simulator drivers was positioned 40 cm closer to the edge of the road compared to their real road counterparts irrespective of the presence of oncoming traffic. Standard deviation was higher in the simulator whatever the oncoming traffic conditions compared to the real road.

Table 7-13 Summary of comparison of real road and simulator data in terms of lateral position with and without oncoming traffic when driving on straights

Lateral position on straights (mm)				
Variables	with		without	
	Real	Sim	Real	Sim
Mean	880	540	952	539
St Dev	147	253	175	301

7.4.1 Testing the effect of oncoming traffic on driver behaviour

The two samples independent t-test was used to test if the differences observed in driving behaviour in terms of mean speed and mean lateral position when driving with and without oncoming traffic between the two environments were statistically significant. The t ratio was calculated for the 15 points of the curved sections and the 6 points of the straight sections. The computed t ratio was compared against the critical values at the 0.05 (t_{crit}= 1.96) and 0.01 (t_{crit}= 2.58) probability levels. If the t ratio was less than the critical value, then the null hypothesis was accepted; if it were equal or greater than the critical value then the null hypothesis was rejected.

The results showed that:

1. The null hypothesis that <u>mean speed</u> on <u>curves</u> <u>with oncoming traffic</u> on the real road and in the simulator was equal to each other was rejected at both significance levels (t=15.680);
2. The null hypothesis that mean speed on curves <u>without oncoming traffic</u> on the real road and in the simulator was equal to each other was rejected at both significance levels (t=15.505);

3. The null hypothesis that mean lateral position on curves with oncoming traffic on the real road and in the simulator was equal to each other was rejected at both significance levels (t=49.009);
4. The null hypothesis that mean lateral position on curves without oncoming traffic on the real road and in the simulator was equal to each other was rejected at both significance levels (t=45.044);
5. The null hypothesis that mean speed on straights with oncoming traffic on the real road and in the simulator was equal to each other was rejected at both significance levels (t=-13.207);
6. The null hypothesis that mean speed on straights without oncoming traffic on the real road and in the simulator was equal to each other was rejected at both significance levels (t=-18.212);
7. The null hypothesis that mean lateral position on straights with oncoming traffic on the real road and in the simulator was equal to each other was rejected at both significance levels (t=28.139);
8. The null hypothesis that mean lateral position on straights without oncoming traffic on the real road and in the simulator was equal to each other was rejected at both significance levels (t=28.725).

Overall, it could be concluded that the presence of oncoming traffic in the near vicinity (20m for the curved sections and 50m for the straight sections) did not affect driver behaviour in terms of speed and lateral position in neither of the environments. However, the absolute values of the two variables were statistically significantly different between the two environments.

7.5 Horizontal profiles analysis

This section compares the longitudinal behaviour of observed and simulator drivers at different speed categories. As was mentioned in section 4.4 (Chapter 4) one of the innovations of this study was that for the first time on a real road, behaviour of the same driver was observed along a series of characteristic points on either a curved and/or straight road section. This type of observation enables the investigation of vehicle trajectory of different categories of drivers (e.g. according to their speed or lateral position) along a stretch of a road.

Individuals' vehicle trajectory could not be studied and compared between the two environments for the whole length of the investigated road section (i.e. for all 21 data points simultaneously) for two reasons:

a) the field study has been conducted in two sites, i.e. two sets of 100 observed drivers has been recorded (see section 5.3.2 in Chapter 5). The first site included the "S" curve (curves C1 and C2) and straight S1 and the second one curves C3 and C4 and straight S2;
b) the analysis of variance showed that drivers of both environments behave differently on the two sites and also between curved and straight road sections (see section 7.2).

For each driver, the average speed and lateral position was calculated along the number of the investigated data points for the curved and straight road sections separately (e.g. 7 points for the "S" curve, 8 points for curves C3 and C4 and 3 points for each straight section). Then, the minimum and maximum average speed values defined the lower and upper limit of the speed range across the investigated data points. The whole speed range was divided to 10 km/h categories. The number of speed categories was not necessarily the same between the two environments. However, only the common speed categories between the two environments were compared in this study. Each driver was allocated to one of these categories. The mean lateral position of each driver along the whole length of each investigated section was calculated and allocated to the respective speed category.

7.5.1 Curved sections

Figures 7-3 and 7-4 compare the longitudinal profiles of real road and simulator drivers for the "S" curve and curves C3, C4 respectively, for various speed categories. For the "S" curve only two common speed categories of drivers were formed: those driving between 40-50 km/h and those driving between 50-60 km/h. As it can be seen from Figure 7-3 simulator subjects positioned their vehicle closer to the edge of the road compared to observed drivers for the whole length of the "S" curve regardless of speed category (something that has already been observed before for the mean lateral position of all drivers, see section 7.3.1.2). It can also be seen that simulator drivers kept the same trajectory along the "S" curve irrespective of their driving speed. On the other hand, observed drivers moved closer to the centre of the road as their speed increased. A possible explanation for the observed differences in the lateral position profiles between the two environments could be the lack of speed perception in the simulator and therefore the lack of correct speed estimation, assuming that the lateral position is highly correlated to driving speed.

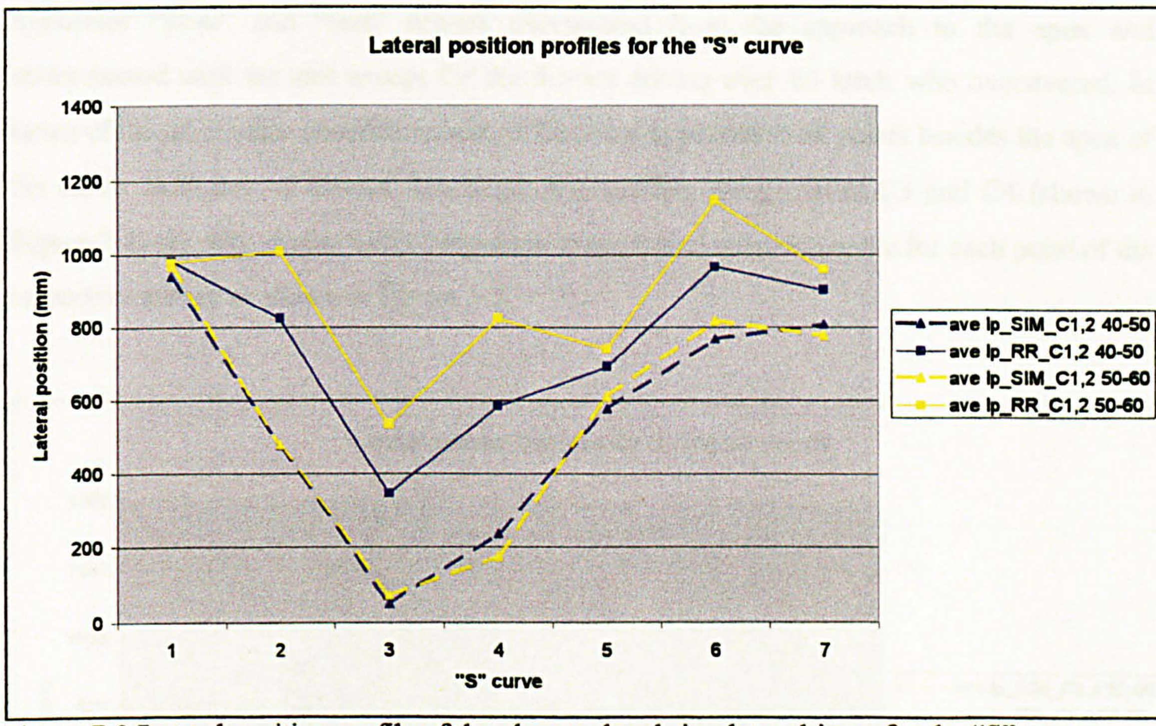


Figure 7-3 Lateral position profile of the observed and simulator drivers for the "S" curve

Figure 7-4 below shows the lateral position profiles of both sets of drivers when moved along curves C3 and C4. Four speed categories were defined ranging between 50 and 90 km/h. As "slow" drivers were defined those driving less than 70 km/h and as "fast" drivers those driving over 70 km/h. Once again simulator subjects positioned their vehicle closer to the edge of the road compared to the observed drivers irrespective of their driving speed along the whole length of the investigated curves. For curve C3, observed "slow" and "fast" drivers had a different behaviour at the circular arc of the curve. "Slow" drivers understeered and then oversteered whereas "fast" drivers did exactly the opposite. However the differences between the two categories were marginal. On the other hand, simulator "slow" and "fast" drivers had the same behaviour at the circular arc of the curve (understeered at the whole length of the arc) however the absolute values of lateral position altered slightly according to the driving speed. At the approach point, simulator "slow" drivers approached the curve at a distance of about 25-35 cm from the edge of the road, whereas "fast" drivers positioned their vehicle at about 10cm from the edge of the road.

For curve C4, simulator and observed drivers followed a different behaviour along the curve. Observed "slow" and "fast" drivers followed the same behaviour along the curve (understeered from the approach to the entry, oversteered from the entry to the apex and understeered from the apex to the exit of the curve). In addition they had the same lateral position in terms of absolute values besides for the very slow drivers at the apex of the curve. Simulator "slow" and "fast" drivers oversteered from the approach to the apex and understeered until the exit except for the drivers driving over 80 km/h who oversteered. In terms of lateral position absolute values, differences appeared in all points besides the apex of the curve. Both sets of drivers' lateral position profiles along curves C3 and C4 (shown in Figure 7-4) are very similar to the respective mean lateral position profile for each point of the respective curves as shown in Figure 7-2.

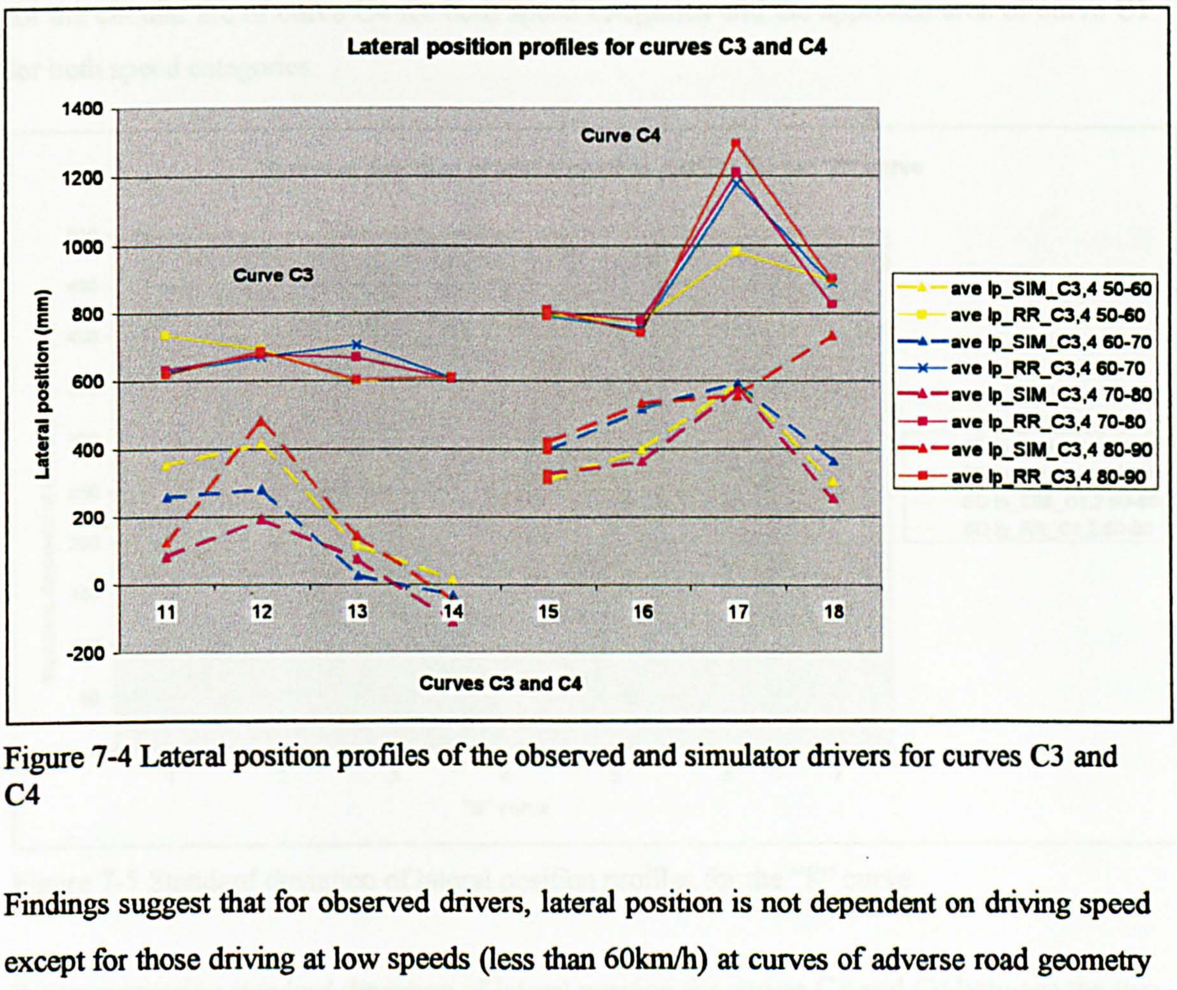


Figure 7-4 Lateral position profiles of the observed and simulator drivers for curves C3 and C4

Findings suggest that for observed drivers, lateral position is not dependent on driving speed except for those driving at low speeds (less than 60km/h) at curves of adverse road geometry whereas for the simulator drivers the opposite applies. For the "S" curve, simulator lateral position profiles were parallel to the real road profile of 40-50 km/h. On the other hand, this observation does not apply for curves C3 and C4, i.e. real road and simulator profiles were not parallel to each other for most of the length of the investigated curved sections. Possible explanations could be that subjects could not perceive the lower speed categories (less than 60 km/h), therefore there was no response in terms of lateral position; or that the risk they felt when entering the "S" curve was so high that they preferred to keep the same lateral position irrespective of their speed. The differences between curves C1 (the first 4 points of the "S" curve) and C3 which are both left curves could be attributed to the different road width (the road width of C1 is about 1m more than the road width of C3) and the very poor visibility of C3 from the approach until the entry of the curve.

In terms of lateral position standard deviation for the "S" curve (see Figure 7-5 below), it can be observed that for both sets of drivers their deviation increased as their speed increased. The effect was more pronounced for the real road drivers. The highest differences between the two real road profiles appeared in points 3 and 4 (≈15cm). Real road and simulator profiles moved parallel for each speed category for the whole length of the "S" curve except for the circular arc of curve C4 for both speed categories and the approach area of curve C1 for both speed categories.

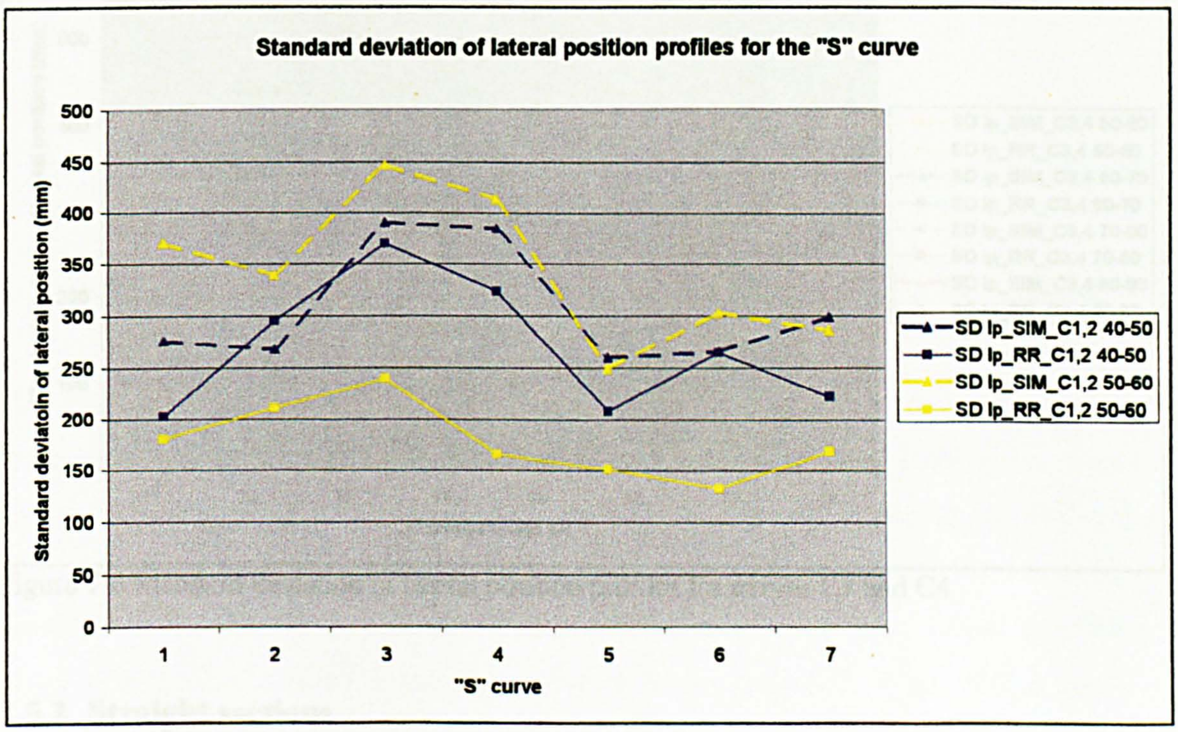


Figure 7-5 Standard deviation of lateral position profiles for the "S" curve

When comparing standard deviation of lateral position for curves C3 and C4 between the two environments, it can be seen from Figure 7-6 below that it was the slowest and fastest drivers that deviated the most in both environments, especially on curve C4. For the observed drivers and curve C3 (points 11 to 14), drivers driving between 60-80 km/h had almost the same standard deviation from the approach until the apex of the curve, whereas differences appeared from the apex to the exit of the curve between these drivers and drivers driving at the lower and upper speed categories. For curve C4, standard deviation increased as speed increased for the whole length of the curve, except for the lowest speed category of drivers. Those drivers had the highest deviation of all speed categories along the circular arc of the curve. For simulator drivers, standard deviation profiles did not follow a specific trend according to the driving speed. It could be said that as speed increased, standard deviation of lateral position increased too but not in a proportionate way between the speed categories for both curves C3 and C4. The fastest simulator drivers had the highest lateral position deviation compared to all other drivers of both environments and all speed categories. The minimum differences between the two environments and all speed categories appeared in the exit point of curve C4.

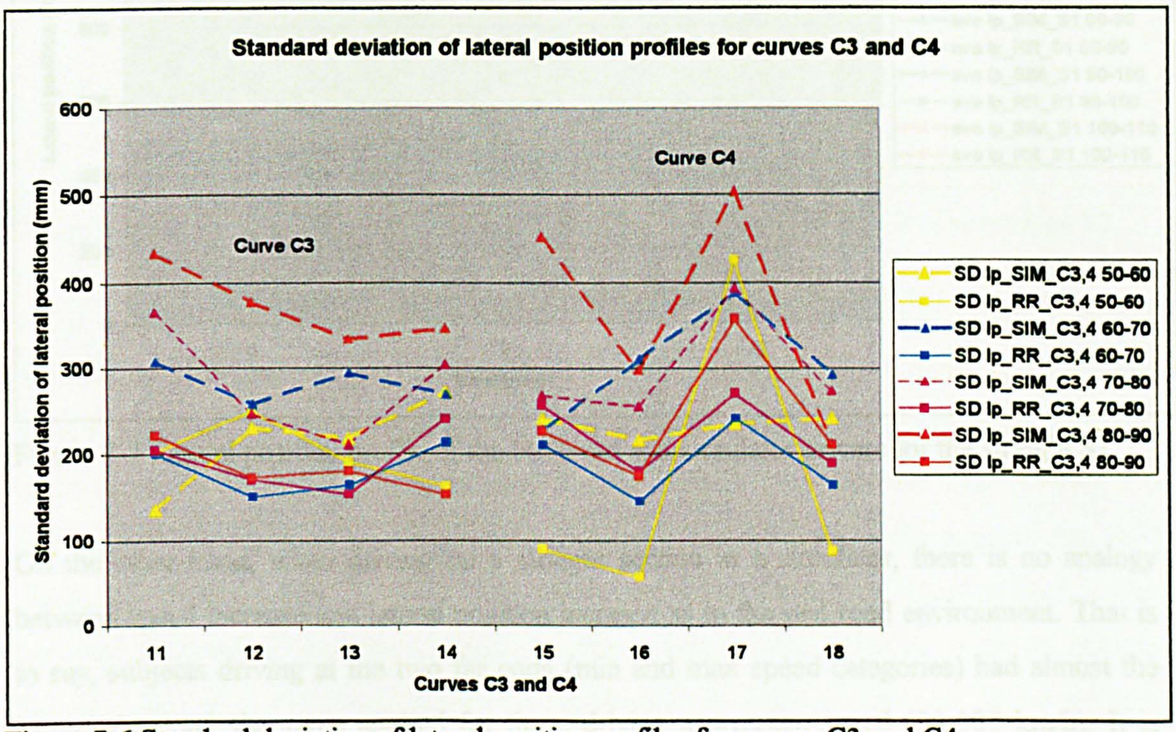


Figure 7-6 Standard deviation of lateral position profiles for curves C3 and C4

7.5.2 Straight sections

Figures 7-7 and Figure 7-8 show the lateral position profiles of different speed categories for straight sections S1 and S2 respectively for both environments. Speeds ranged between 70 and 110 km/h in both straight sections. As it can be seen from Figure 7-7, observed drivers increased their distance from the edge of the road as their speed increased (drivers driving between 80 and 100 km/h had the same standard deviation) when traversing straight S1.

This could imply that as speed increases drivers feel unsafe, therefore they move closer to the centre of the road. The anticipatory characteristic of the driving activity given by Hirschenberg and Miedel (1980, quoted by Bartmann, Spijkers and Hess, 1991) where as speed increases the peripheral field of view drastically decreases is already known. Therefore drivers driving at high speeds are expected to move closer to the centre of the road compared to those driving at low speeds.

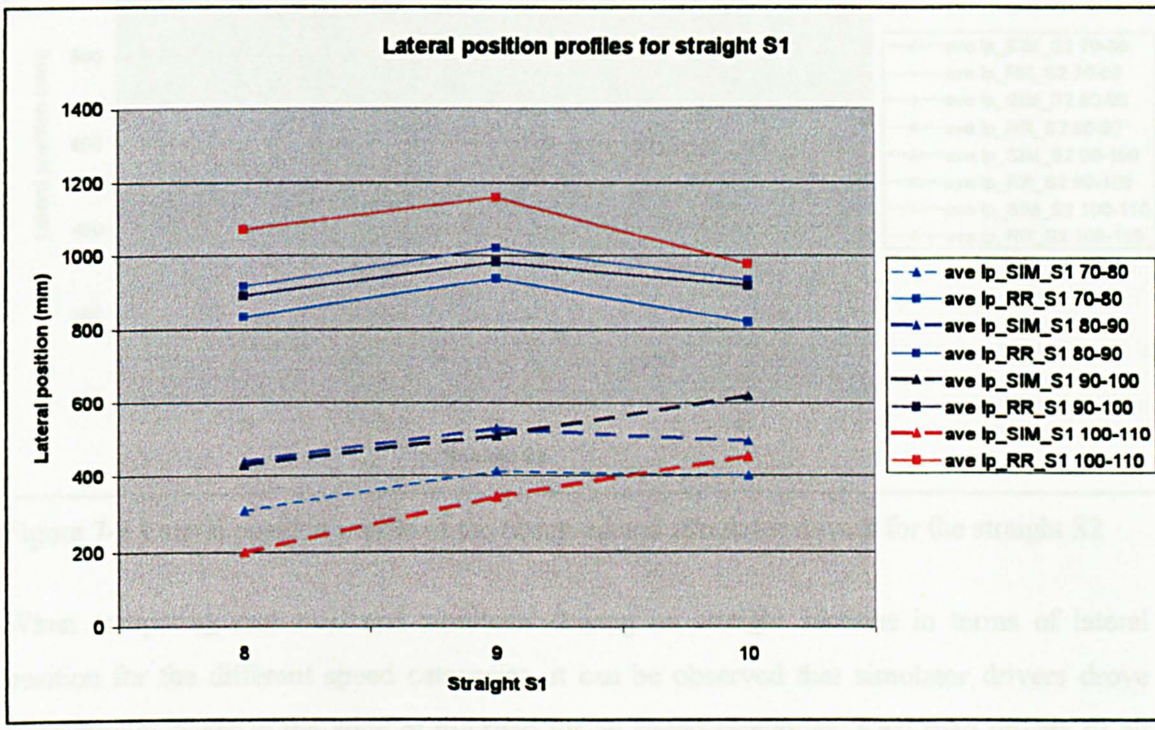


Figure 7-7 Lateral position profile of the observed and simulator drivers for the straight S1

On the other hand, when driving on a straight section in a simulator, there is no analogy between speed increase and lateral position increase as in the real road environment. That is to say, subjects driving at the two far ends (min and max speed categories) had almost the same behaviour; the same applied for those driving at average speed (80-100 km/h). It is possible that the anticipatory behaviour does not apply when driving the simulator. In addition the inherent lack of risk in the simulator prevents drivers' behaviour to be affected by their fears and expectations (e.g. that something unexpectedly may appear from the roadside environment and it is a possible cause for a road accident). Lateral position behaviour on straight S2 differs from behaviour on straight S1 (see Figure 7-8). The fastest real road drivers move closer to the middle of the road compared to all other drivers' categories that kept the same lateral position. Simulator drivers had the same lateral displacement irrespective of their speed and generally they all moved closer to the edge of the road as they traversed the straight section.

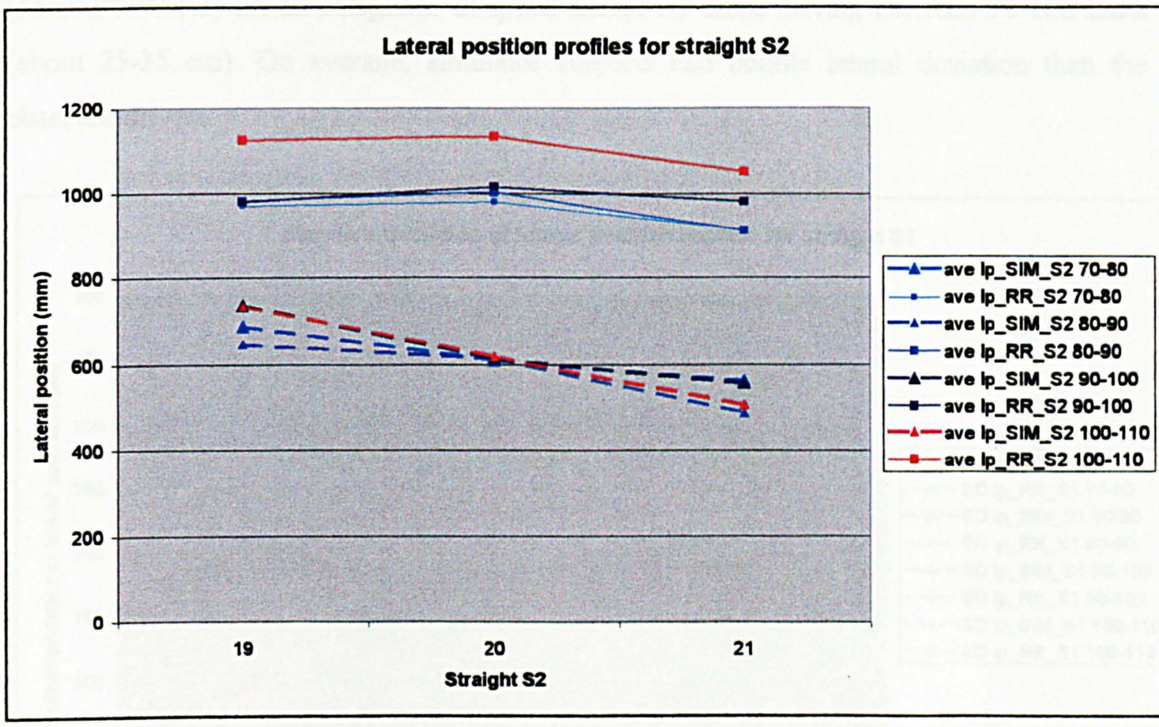


Figure 7-8 Lateral position profile of the observed and simulator drivers for the straight S2

When comparing real road and simulator driving on straight sections in terms of lateral position for the different speed categories, it can be observed that simulator drivers drove substantially closer to the edge of the road for all speed categories. Real road drivers of all speed categories except for the fastest one followed a rather similar behaviour between the two straight sections (i.e. positioned their vehicles around 1m from the edge of the road whereas the fastest ones at 1.2 m). On the other hand, simulator drivers lateral position varied between 20cm and 60 cm from the edge line for straight S1 and 70cm to 50 cm for straight S2 depending on their driving speed. The differences in simulator drivers' lateral position between the two straights cannot be explained easily since both straights had the same road width. Their main differences were the total length of the straights (the length of S1 was significantly smaller than the length of S2) and the roadside environment (straight S1 had roadside developments whereas straight S2 did not). It seems that the combination of these two differences affected simulator drivers' lateral behaviour (although they did not affect real road drivers' behaviour).

Standard deviation of lateral position profiles of straight S1 for both real road and simulator drivers are shown in Figure 7-9. It can be observed that real road drivers had more or less the same deviation irrespective of their driving speed (about 15-20 cm), except for the fastest category (those driving more than 100 km/h) whose standard deviation was started from 10 cm and increased to 30cm. For the simulator drivers, standard deviation was almost the same (about 25-30 cm) for all categories of speed except for those driving between 90-100 km/h (about 25-35 cm). On average, simulator subjects had double lateral deviation than the observed drivers.

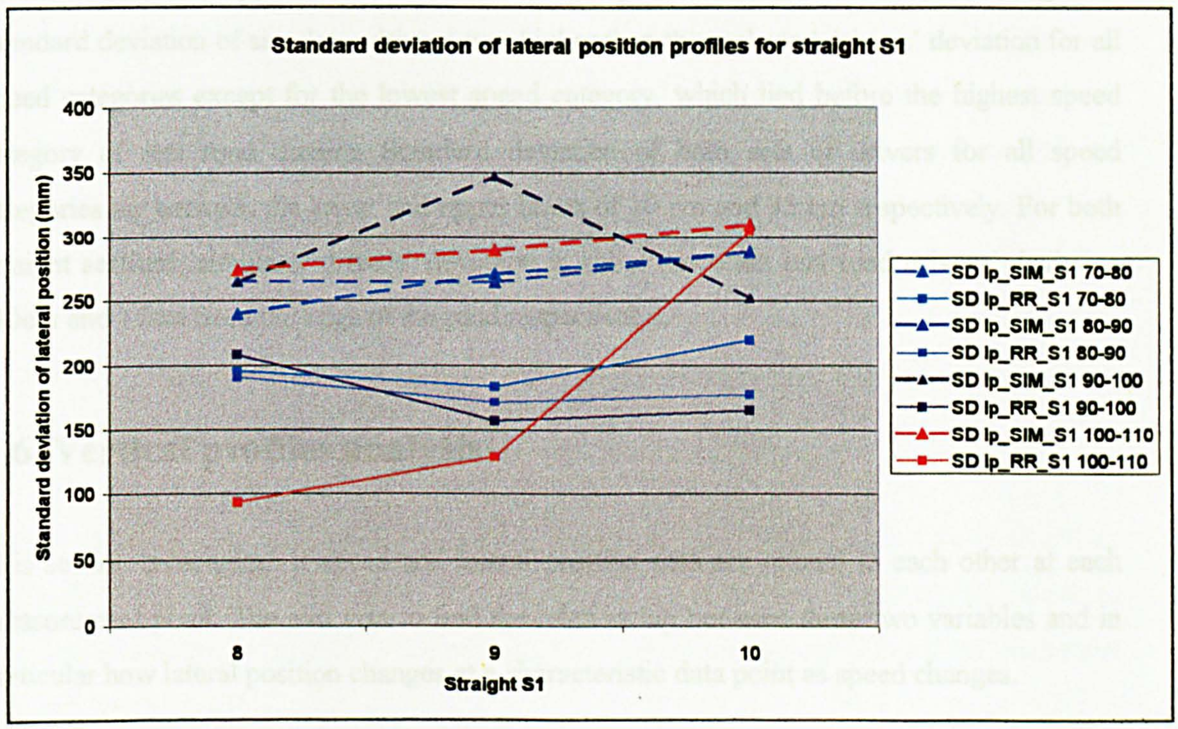


Figure 7-9 Standard deviation of lateral position profiles for straight S1

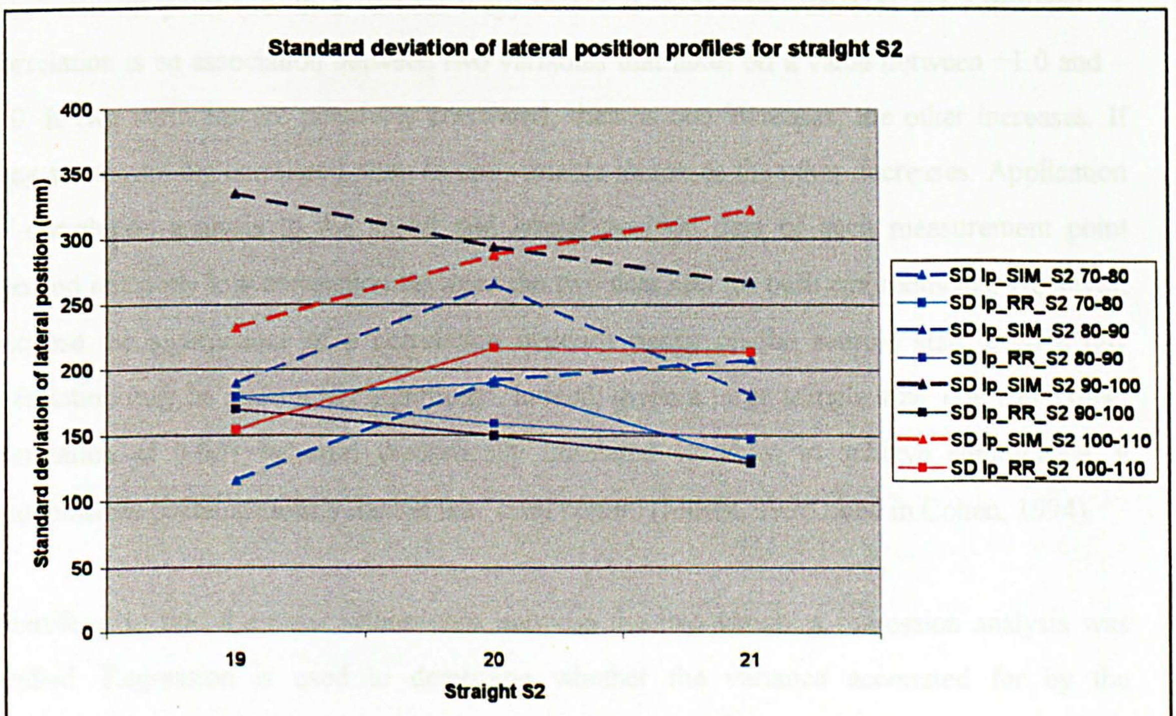


Figure 7-10 Standard deviation of lateral position profiles for straight S2

Standard deviation of lateral position profiles of straight S2 for both observed and simulator drivers are shown in Figure 7-10 above. It can be observed that as speed increased, standard deviation increased too except for the lowest speed category of real road drivers. For simulator drivers it applied the same as above except for the last two fast speed categories. Standard deviation of simulator drivers was higher than the real road drivers' deviation for all speed categories except for the lowest speed category, which lied before the highest speed category of real road drivers. Standard deviation of both sets of drivers for all speed categories lay between the lower and upper limits of 10 cm and 35 cm respectively. For both straight sections, simulator drivers' deviation is about twice the real road drivers' deviation (30cm and 15cm from the edge of the road respectively).

7.6 Vertical profiles analysis

This section investigates if speed and lateral position data are related to each other at each measurement point. The aim was to find the relationship between these two variables and in particular how lateral position changes at a characteristic data point as speed changes.

As a first step, correlation analysis was applied to the speed and lateral position data of each measurement point (i.e. in a vertical way) to see if these two variables are correlated. A correlation is an association between two variables that takes on a value between +1.0 and –1.0. If two variables are positively correlated, then as one increases, the other increases. If they are negatively correlated, then as one variable increases the other decreases. Application of correlation analysis to the speed and lateral position data of each measurement point showed relatively low correlation between the two data sets for both environments. However, because the significance of a correlation depends partly on the sample size, even a tiny correlation may be statistically significant. Indeed, given a large sample size, one can expect correlation of 0.001 between theoretically unrelated variables to achieve significance, a phenomenon contemptuously named the "crud factor" (Meehl, 1990 cited in Cohen, 1994).

Therefore, to find the exact relationship between the two variables regression analysis was applied. Regression is used to determine whether the variance accounted for by the continuous independent variable in the dependent variable is significant. To do this one finds the square of the correlation between them (the R^2) and tests whether it is significantly different from zero. The regression analysis provides some index of the magnitude of the association between the independent and the dependent variable (Leong and Austin, 1996). Regression typically involves creating a linear equation to predict scores on a dependent variable. The equation represents the line that fits best through a scatter plot of points describing the relationship between the dependent variable and one or more independent variables. The beta weight, or coefficients on the independent variables in the equation, provides information about the relationships between the independent variables and the dependent variable. For one dependent and one independent variable (as it is the case here), the slope of the best fit line will be the beta weight and will represent the changes in the value of the dependent variable that are associated with each change of one unit in the independent variable. However, for this particular set of data, the equation was not linear. Therefore, curve fit was used.

Curve estimation fits various types of mathematical functions to data. It can easily fit linear, quadratic, and cubic models. Based on these results it can be seen which of the models is adequate to summarise the data. The analysis was carried out by using the SPSS Statistical Package (Norusis, 1993).

7.6.1 Curved sections

The best-fit line for the investigated curved road sections was the quadratic line. The quadratic model fitted has the form:

$$Y = b_0 + b_1 * x + b_2 * x^2$$

where Y = the dependent variable

x = the specified independent variable

b_0, b_1 and b_2 = coefficients

The derived quadratic equations for the curved road sections, based on the above model, are given in Tables 7-14 and 7-15 (where Y = lateral position in mm, x = speed in km/h and X = speed range in km/h). It can be seen that for all investigated points on the curves, the correlation coefficients were higher than 0.60.

Table 7-14 Curve estimation and correlation coefficients for the curved sections of site 1

Measurement Points	Equations for real road	Equations for simulator
1 (approach C1)	$Y=-0.1865*x^2+27.568*x+10.212$ $R^2=0.9807$ X=40-80	$Y=0.5211*x^2-46.831*x+1935.1$ $R^2=0.6012$ X=25-85
2 (entry C1)	$Y=-0.4894*x^2+45.026*x+37.706$ $R^2=0.8947$ X=30-70	$Y=0.2629*x^2-14.744*x+582.31$ $R^2=0.6918$ X=25-75
3 (apex C1)	$Y=-0.6834*x^2+54.985*x-568.49$ $R^2=0.8554$ X=25-60	$Y=2.0952*x^2-161.06*x+3076.9$ $R^2=0.7133$ X=25-60
4 (exit C1/ approach C2)	$Y=-1.5471*x^2+143.29*x-2455$ $R^2=0.7311$ X=35-60	$Y=-2.0452*x^2+182.96*x-3828$ $R^2=0.7934$ X=35-60
5 (entry C2)	$Y=-0.4606*x^2+47.931*x-496.75$ $R^2=0.7669$ X=40-65	$Y=1.049*x^2-92.069*x+2589$ $R^2=0.9448$ X=30-50
6 (apex C2)	$Y=0.1973*x^2-19.919*x+1628.3$ $R^2=0.7015$ X=45-80	$Y=1.0689*x^2-99.377*x+3041.5$ $R^2=0.7018$ X=35-70
7 (exit C2)	$Y=-0.3187*x^2+44.014*x-519.48$ $R^2=0.6837$ X=45-90	$Y=-0.3133*x^2+34.502*x-148.05$ $R^2=0.7393$ X=40-75

Table 7-15 Curve estimation and correlation coefficients for the curved sections of site 2

Measurement Points	Equations for real road	Equations for simulator
11 (approach C3)	$Y=0.4837*x^2-80.012*x+3909.1$ $R^2=0.5412$ X=65-105	$Y=-0.4391*x^2+50.891*x-1096.4$ $R^2=0.8176$ X=45-100
12 (entry C3)	$Y=-0.1463*x^2+23.145*x-226.76$ $R^2=0.2499$ X=60-100	$Y=0.8686*x^2-115.67*x+4055$ $R^2=0.8889$ X=35-90
13 (apex C3)	$Y=0.2117*x^2-33.389*x+1961.3$ $R^2=0.6787$ X=50-80	$Y=0.9674*x^2-119.98*x+3712.8$ $R^2=0.7145$ X=35-80
14 (exit C3)	$Y=-0.0405*x^2+4.1844*x+508.21$ $R^2=0.1345$ X=50-85	$Y=0.7222*x^2-86.819*x+2528.9$ $R^2=0.9145$ X=35-85
15 (approach C4)	$Y=1.3322*x^2-189.16*x+7477.4$ $R^2=0.9378$ X=60-100	$Y=0.2869*x^2-40.892*x+1761.4$ $R^2=0.7299$ X=55-105
16 (entry C4)	$Y=-0.3471*x^2+48.718*x-918.73$ $R^2=0.8741$ X=45-85	$Y=-0.4179*x^2+52.033*x-1116.2$ $R^2=0.33$ X=35-95
17 (apex C4)	$Y=1.3306*x^2-171.25*x+6587.4$ $R^2=0.6944$ X=45-85	$Y=-0.7571*x^2+90.233*x-2042$ $R^2=0.7477$ X=40-80
18 (exit C4)	$Y=-0.4942*x^2+61.544*x-996.31$ $R^2=0.6287$ X=50-90	$Y=0.7514*x^2-92.565*x+3101.1$ $R^2=0.5941$ X=30-85

The lateral position profiles for all curved sections for the real road and simulator environment presented in Figures 7-11 and 7-12 respectively were based on the equations given in Tables 7-14 and 7-15 above.

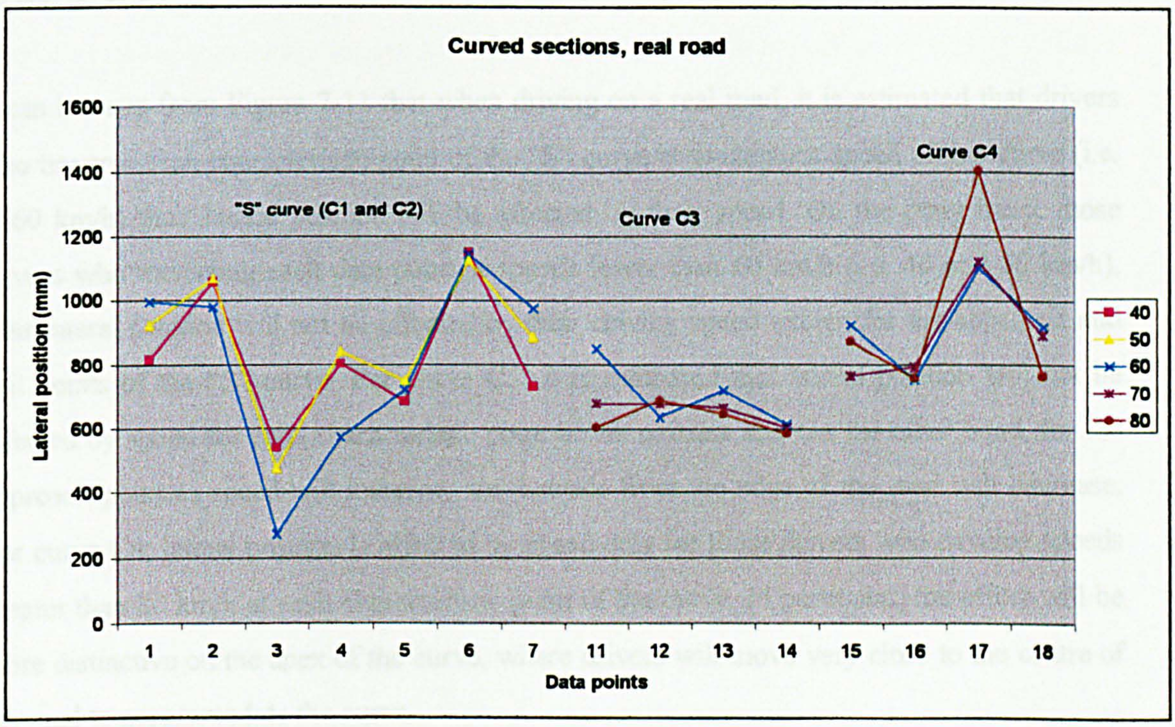


Figure 7-11 Lateral position profiles of the curved sections for the real road drivers

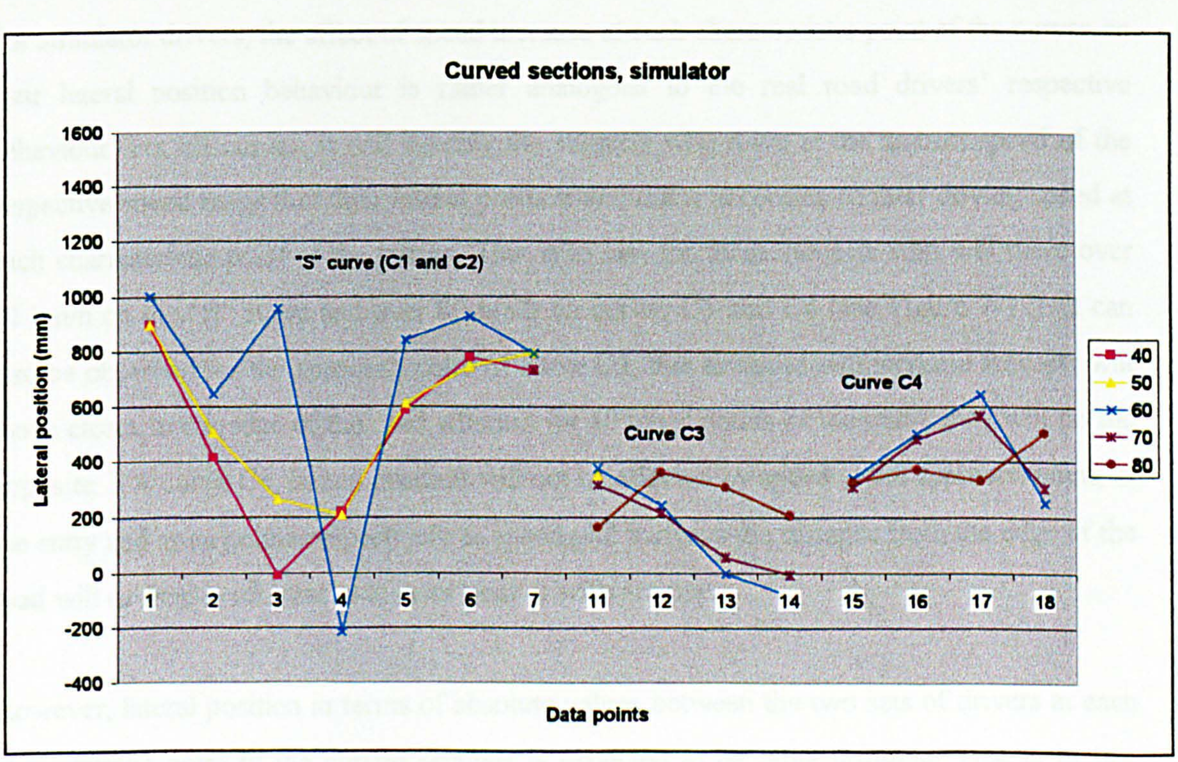


Figure 7-12 Lateral position profiles of the curved sections for the simulator drivers

The speed categories used for each of the figures are those applicable for all respective data points of each curved section. The upper and lower limits of these categories were based on the common speed ranges adopted in both environments, along each of the four curves of the investigated road (based on Tables 7-14 and 7-15). The speed categories applicable to both environments for the "S" curve were 40, 50 and 60 km/h and for curves C3 and C4 were 60, 70 and 80 km/h.

It can be seen from Figure 7-11 that when driving on a real road, it is estimated that drivers who traverse each characteristic point of the "S" curve at the highest speed of this curve (i.e. at 60 km/h) their lateral position will be affected by their speed. On the other hand, those drivers who traversing each data point at speeds lower than 60 km/h (i.e. 40 and 50 km/h), their lateral position will not be affected by their driving speed except for the approach and exit points of the "S" curve. For curve C3, it is estimated that lateral position will not be affected by speed for each characteristic point of the circular arc. On the other hand, for the approach point as speed will increase, the distance from the edge of the road will decrease. For curve C4, lateral position is affected by speed only for those drivers who develop speeds greater than 80 km/h at each characteristic point of the curve. In particular, the effect will be more distinctive on the apex of the curve, where drivers will move very close to the centre of the road to accommodate the curve.

For simulator drivers, the effect of speed increase at each characteristic point of the curves on their lateral position behaviour is rather analogous to the real road drivers' respective behaviour. For all curves, it will be only the subjects who drive at the highest speed of the respective speed range that their lateral position will differ according to their driving speed at each characteristic point of the curves. That is to say, for those subjects who will drive over 60 km/h on the "S" curve and over 80 km/h on curves C3 and C4 (see Figure 7-12). It can also be observed for the approach point of curve C3, that as speed will increase subjects will move closer to the edge of the road whereas for all other points of the curve they will do the opposite. For curve C4, lateral position will not be affected by speed at the approach point; at the entry and apex points respectively as speed will increase the distance from the edge of the road will decrease, whereas at the exit point it will increase.

However, lateral position in terms of absolute values between the two sets of drivers at each characteristic point of the curved sections is expected to be quite different. That is to say, drivers who will traverse at the same speed any characteristic point of the curves are expected to have different displacement from the edge of the road between the two environments. This effect will be quite distinctive on curves C3 and C4, where simulator drivers are expected to drive closer to the edge of the road compared to their real road counterparts by ≈40cm. This estimation agrees with the observed differences between the two environments where the simulator drivers have driven on average 40cm closer to the edge of the road compared to their real road counterparts. When driving in the simulator environment on the "S" curve, edgeline encroachments are expected for points 3, 4 (apex and exit of curve C1) at 40 km/h and 60 km/h respectively. On the other hand, for observed drivers for the same points and driving at the same speeds, lateral distance will be approximately 60cm from the edge of the road. For curve C3, edgeline encroachments for simulator drivers are expected for points 13, 14 (apex and exit points) for those driving at 60 and 70 km/h. Again, the lateral distance of observed drivers will be approximately 60cm from the edge of the road. Very similar lateral distance from the edge of the road is expected to be only at the approach point of curve C1 between the two environments, that is to say ≈1m from the edge of the road. All the above estimated findings are partly validated from the existing mean lateral position profile (presented in section 7.3.1.2) where it can be observed that simulator drivers crossed the edgeline at points 3 and 14 as well as from the horizontal speed profiles where all different speed categories of drivers almost crossed the edgeline at point 3 and those driving over 60 km/h crossed the edge line at point 14. The findings are partly validated because the observed mean lateral position profile applies only to the mean lateral position at each data point and the horizontal profiles apply to a mean speed along all investigated data points.

Overall it could be said that for the real road environment the effect of speed on lateral position is expected to be more distinct on the apexes of curves C1 and C4, and less distinct on the approach and exit points of all curves. The same applies for the simulator environment. However, the lateral distance from the edge of the road in terms of absolute values will be different for the two environments for all speed categories and all characteristic points of the curves except for the approach point of curve C1. This suggests that the typical cues, which are used when approaching a curve on a real road, could not be used the same way when approaching a simulator curve. Curve perception and therefore curve negotiation seems to be different in the simulator. This problem has been also addressed by other researchers (Laya, 1991).

7.6.2 Straight sections

For all the straight sections on real road, the linear line was the best-fit line as well as the quadratic model. However, for the simulator data, the linear model could not be applied.

Therefore, it was decided to apply the quadratic line for the straight sections of both environments to be comparable to each other. The quadratic model fitted for the straight sections has the form:

$$Y = b_0 + b_1 * x + b_2 * x^2$$

where Y = the dependent variable

x = the specified independent variable

b_0, b_1 and b_2 = the coefficients

The derived quadratic equations for the straight road sections, based on the above model, are given in Table 7-16. It can be seen that for all investigated points on the straight sections, the correlation coefficients were higher than 0.75, besides point 3 on the real road and point 2 in the simulator. The equations were used to plot the lateral position

Table 7-16 Curve estimation and correlation coefficients for the straight sections of both environments

Straight S1	Equations for real road	Equations for simulator
8	$Y= 0.013*x^2+2.0469*x+637.92$ $R^2=0.6909$ X=50-105	$Y=-0.0434*x^2+7.903*x+32.923$ $R^2=0.2031$ X=65-140
9	$Y=-0.0802*x^2+18.487*x+10.105$ $R^2=0.6655$ X=55-105	$Y=0.3099*x^2-54.797*x+2798.5$ $R^2=0.6341$ X=60-130
10	$Y=-0.0638*x^2+16.065*x+18.767$ $R^2=0.9448$ X=60-110	$Y=0.7514*x^2-92.565*x+3101.1$ $R^2=0.5941$ X=65-140
Straight S2	**Equations for real road**	**Equations for simulator**
19	$Y=-0.0937*x^2+19.792*x-10.387$ $R^2=0.9657$ X=50-100	$Y=-0.1107*x^2+17.802*x-6.4574$ $R^2=0.8059$ X=50-110
20	$Y=-0.0785*x^2+18.321*x+25.538$ $R^2=0.8578$ X=50-110	$Y=0.1532*x^2-25.607*x+1637.6$ $R^2=0.4563$ X=55-115
21	$Y=-0.0474*x^2+11.047*x+345.31$ $R^2=0.4231$ X=50-120	$Y=-0.0037*x^2+5.9545*x+9.1971$ $R^2=0.7862$ X=60-125

Where Y = lateral position (mm), x = speed (km/h), X = speed range (km/h)

Based on the equations given in Table 7-16 and the common speed ranges between the real road and the simulator environments, the lateral position profiles were plotted for each data point of the two straight sections for each environments (see Figures 7-13 and 7-14 respectively). As it can be seen from Table 7-16, speeds ranged between 50 and 140 km/h in the two environments, however the common speed range applicable to both environments was 60 to 100 km/h and this one was used for the two figures.

It can be seen from Figure 7-13 below that when driving on real road straight sections, as speed increases the distance from the edge of the road is expected to increase too. This applies for all data points of both straight sections. It is also observed that there is a relationship between speed increase and lateral position increase. In particular, as speed increase from 60 to 100 km/h the speed change rate decreases and the same applies for lateral position change rate. That is to say, as speed will increase from 60 to 80 km/h (35%) lateral position will decrease by 17%; as speed will increase from 80 to 100 km/h (25%) lateral position will decrease by 8%. This applies for both straight sections on the real road but it does not apply for the simulator straight sections (see Figure 7-14 below).

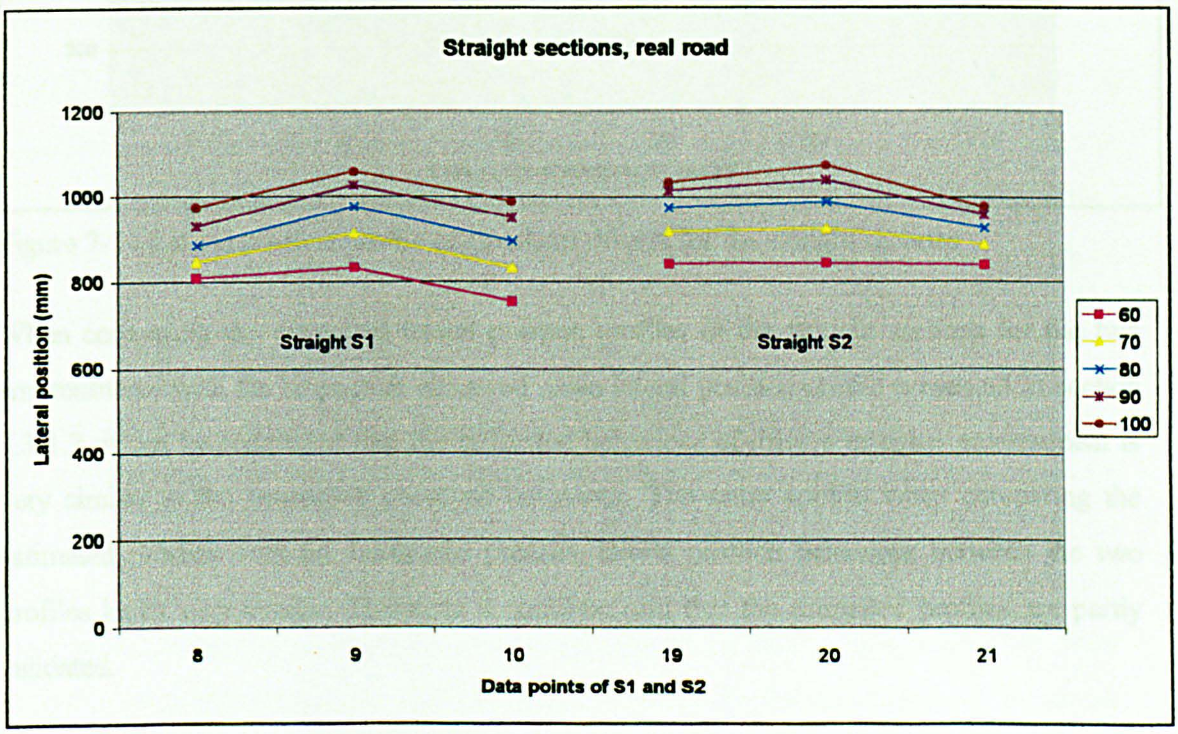


Figure 7-13 Lateral position profile of real road drivers for the straight sections

As it can be seen for the straight road sections in the simulator, lateral position at each data point of straight S1 differs a lot according to the driving speed. That is to say, at the first data point lateral position is the same irrespective of the driving speed; at the second data point (100m further down) as speed increases lateral position decreases for the lower speeds (60-70 km/h) and remain constant for the other speed categories and; for the last data point (344m further down) as speed increases lateral position remains the same for the lower speed and increases for the other speed categories. Lateral position behaviour on the second straight section is more comparable to the real road respective behaviour. For the first two data point lateral position will not be affected by speed, whereas for the last data points there will be a slight movement towards the centre of the road as speed increases.

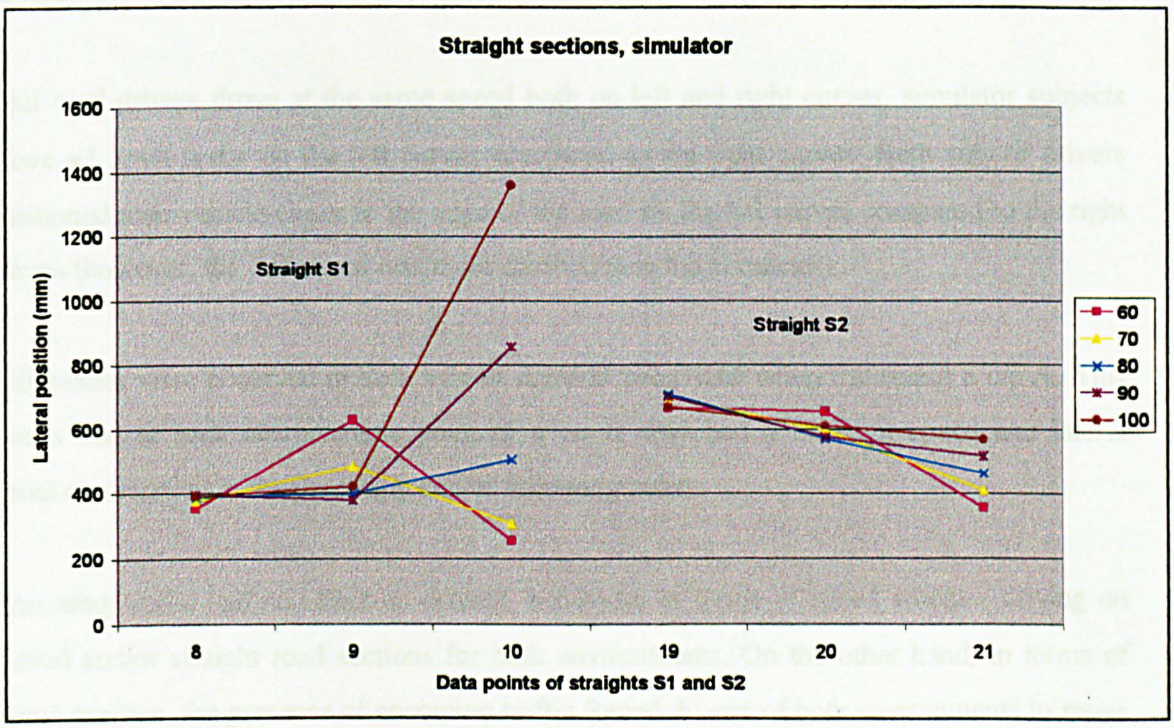


Figure 7-14 Lateral position profile of simulator drivers for the straight sections

When comparing the estimated lateral position profiles of the straight sections for the two environments with the respective observed mean lateral position profile presented in section 7.3.1.2, it can be concluded that the estimated behaviour of drivers in either environment is very similar to the respective observed behaviour. The same applies when comparing the estimated profiles with the horizontal profiles, lateral position behaviour between the two profiles looks very similar. Therefore it could be said that the estimated profiles are partly validated.

7.7 Chapter Summary

This chapter compared real road and simulator drivers' behaviour in terms of speed and lateral position.

Differences were observed between the real road and simulator environments both in terms of speed and lateral position. Simulator subjects drove slower on the curved sections and faster on the straight sections compared to their real road counterparts. In terms of lateral position, simulator subjects positioned their vehicle closer to the edge of the road compared to their real road counterparts (by about 40cm) irrespective of the road geometry (curved or straight road section). Standard deviation of speed and lateral position was higher in the simulator compared to real life irrespective of the geometry of the road.

Real road drivers drove at the same speed both on left and right curves, simulator subjects drove ≈3 km/h faster on the left curves compared to the right curves. Both sets of drivers positioned their vehicle closer to the edge of the road on the left curves compared to the right curves (however, the difference was more distinctive in the simulator).

Differences were observed in both sets of drivers' behaviour when traversing a curve. This means that at each characteristic point of a curve they had a different speed and lateral position compared to the preceding and/or following point.

Oncoming traffic had no effect on drivers' behaviour in terms of speed whether driving on curved and/or straight road sections for both environments. On the other hand, in terms of lateral position, the presence of oncoming traffic forced drivers of both environments to move closer to the edge of the road on the curved sections but had no effect on simulator drivers on straight sections.

The comparison of the horizontal (along data points) lateral position profiles showed that the two sets of drivers followed a different strategy in terms of positioning their vehicle from the edge of the road on a curve according to the speed they had developed when traversing the respective curve. When driving on straight road sections, lateral displacement was affected by driving speed for both sets of drivers. The comparison of the vertical (per data point) lateral position profiles showed that for each data point, it would be the upper limit of the speeds developed at the respective points that would produce the most awkward lateral displacements. It was also found that the approach and exit points of the curves would be those that they would be mostly affected by the driving speed. When investigating the data points on the straight sections, it was shown that the two sets of drivers were expected to have a different behaviour at each point according to the driving speed.

8. CHAPTER EIGHT

DISCUSSION OF RESULTS, SUMMARY AND CONCLUSIONS

8.1. Introduction

This chapter summarises the findings of this research study. The findings have been divided into two main areas: a) the face validity of LADS and b) the behavioural validity of LADS. Face validity has been obtained from the analysis of data concerning from drivers' subjective opinions and behavioural validity from the descriptive, inferential and correlation statistical analyses of driver behaviour data when compared between the real road and the simulator environments. Limitations and recommendations have been presented based on the above findings.

8.2. Face validity

The issues summarised in the following subsections are the main findings from the data analysis related to subjects' responses to the pre- and post-experiment questionnaires as presented in Chapter 6.

8.2.1. Subjects' opinions

It was found that the most realistic feature of the simulator was driving on straights both in terms of speed and lateral position. It was easier to control speed on straights than speed on curves. However the ease of controlling lateral position on straights and curves was the same. The least realistic feature of the simulator was braking followed by steering. The majority of subjects commented that the steering wheel oversteers. At the time of the experiment (in 1997) LADS simulator steering wheel was designed to slightly oversteer since it had been observed during previous experiments that subjects had the tendency to drive very close to the edge of the road and tend to leave the curve trajectory. Boulanger and Chevennement

(1995) had already proven that simulator vehicles that understeer are not proper for simulator driving.

One-third of the subjects stated that oncoming traffic did not affect their speed on straights at all. They believed that oncoming traffic affected their speed and lateral position about the same percentage whether they drove on curved and/or straight road sections. They also believed that the effect was greater on their lateral position than on their speed. Their opinion was wrong in terms of speed for both curved and straight road sections and correct in terms of lateral position for the curved sections only.

8.2.2. Subjects' comments

Subjects who had driven the simulator before commented that the wider field of view (the simulator used to have only one instead of three screens) made driving much easier and was less disorientating. However, it is not exactly known how this feeling improved their driving performance or if it has been improved at all. Male subjects rated the most problematic area of the simulator as being the steering, followed by their difficulty in focusing on distant objects; whereas the respective areas for the female subjects were steering and the unrealistic engine sound.

Regarding the practice run, it was shown that it is essential for subjects to get used to the simulator controls and it should at least last for 5-6 minutes. Preferably it should include features and conditions which subjects will encounter during the test runs.

8.2.3. Correlation analysis

One important finding was that there was no statistically significant correlation between subjects' age and gender to the realism and ease of controlling the simulator in terms of speed and lateral position when driving on curved and straight road sections. This means that neither gender nor age plays an important role in subjects' opinion regarding simulator realism. Both males and females can control the driving simulator in like manner irrespective of their age.

Subjects who had taken advanced lessons drive on average more miles annually and used both the door and interior mirrors of the simulator car more. Female subjects were more familiar with computer/arcade games compared to male subjects.

As the correlation analysis results showed, subjects who commented that the feeling of the steering was not realistic, could better control the lateral position of the car on curves than on straights. Subjects had a different attitude relative to realism and ease of controlling the simulator between curved and straight road sections and each one affected negatively the other.

8.2.4. "Good" and "poor" subjects behaviour

The correlation of subjects responses relative to the realism and ease of controlling the simulator to the simulator data have indicated that subjects who believe that the simulator is more realistic and find it easier to control have smaller speed and lateral position variation. Steering realism had a more pronounced effect on subjects' lateral position variation, whereas braking realism and realistic engine noise affected both speed and lateral position variations. The effects were more pronounced in areas of poor road geometry or generally of adverse road geometry.

It could be concluded that subjects who thought positively about the face validity of the simulator performed in a more uniform way compared to those who thought negatively. This finding suggests that the improvement of simulator face validity may reduce driver variation. It is well known that simulators produce significantly higher driver variation compared to the real road, irrespective of their kinaesthetic feedback (see for example studies conducted in the TNO fixed-base simulator and in the VTI moving-base simulator as described in Chapter 3). It was also found that subjects who believed that steering was more realistic found it easier to control their speed on curves and their lateral position on straights but found it more difficult to control their lateral position on curves. This means that there is an interrelation between speed and lateral position on curves (as correlation analysis also proved in Chapter 7).

8.3. Behavioural validity

It has been shown that there are no learning effects when simulator subjects are driving alone on the road with no external factors. On the other hand, when there is an external factor that may cause an effect on their behaviour (e.g. oncoming traffic), they need some time to get used to this factor. The findings suggest that overall, subjects need at least two runs to get used to the simulator controls. Thus if the experiment has only one run, the derived data may not be representative of simulator subjects' performance.

It has also been shown that the overall presence of oncoming traffic conditions in the simulator road network did affect subject behaviour. However, the intensity of oncoming traffic in the opposing lane did not have a statistically significant effect on their behaviour since subjects did not even perceive that the number of oncoming vehicles had been increased from the medium (M) condition to the heavy (H) condition by 20%.

The two samples independent t-test showed that both in terms of speed and lateral position, whether driving on curved and/or straight road sections, real road values were not the same as simulator values at the 0.05 significance level. The average difference in mean speed was 3.84 km/h higher in the simulator and in mean lateral position was 413 mm closer to the edge of the road in the simulator. The average standard deviation for speed was 3.31 km/h and for lateral position was 169 mm higher in the simulator. The findings suggest that LADS cannot be characterised as absolutely valid both in terms of speed and lateral position when using Blaauw's (1982) absolute validity criterion.

Results from the application of MANOVA showed that speed differs between the left and right curves, between the curved and straight road sections and between straight sections and straight sections adjacent to a curved section. The last finding suggests that drivers do perceive and are able to distinguish the difference between a straight section, and one which is independent of curved sections but adjacent to a curved section and accordingly adjust their driving strategy. The results from the MANOVA suggest that curved and straight road sections should be examined separately, as well as left and right curves.

8.3.1. Curved versus straight road sections

The effect of road geometry on driver behaviour was investigated according to the type of road (driving on curved versus straight road sections) direction of curves (left hand and right hand) and the characteristic points of a curve (namely the approach, the entry, the apex and the exit points).

Results showed that the simulator gives more valid results on curved than on straight road sections and more in terms of speed than in terms of lateral position. In particular, it was found that both sets of drivers drove more slowly on curves compared to straights (by ≈35% for observed drivers and by ≈65% for simulator subjects). Both sets of drivers moved closer to the edge of the road on curves compared to straights (by ≈14% for observed drivers and by ≈38% for simulator subjects). Standard deviation of both sets of drivers was lower on curves compared to straights, both in terms of speed and lateral position. Speed variation was 33% higher in the simulator compared to real road, both on curved and straight road sections. Lateral position variation was 84% on curves and 100% on straights, higher in the simulator compared to the real road conditions.

8.3.1.1. Speed

In terms of speed, mean speed varied between 50.78 km/h and 68.47 km/h on the real road and between 47.06 km/h and 67.08 km/h in the simulator for the curved sections. For the straight sections, mean speed varied between 80.68 km/h and 87.39 km/h on the real road and between 94.31 km/h and 97.48 km/h in the simulator. For both environments, the lowest mean speed was observed on the curve with the smallest radius (curve C1). On all curved sections subjects drove slower in the simulator compared to their real road counterparts. However, most researchers have observed higher speeds on curves in the simulator (Tenkink, 1990; Tenkink and van der Horst, 1991; Harms, 1993; Duncan, 1995; Kaptein et al, 1996). Only Blaauw (1982) has observed higher speeds on straight sections in the simulator compared to real life. It could be concluded that speeds adopted in LADS are significantly faster than those adopted on a real road at points where speeds are not constrained by the horizontal alignment of the road. Since the above mentioned finding is in accordance with the previous smaller scale validation study in LADS (Pyne et al, 1995), it means that LADS gives consistent results in terms of speed, regardless of the improvements that it went through over the years in terms of the visual system. This could lead to the conclusion that an enlarged front field of view and/or higher performance hardware does not seem to significantly improve driver perception and control of speed in the simulator environment for driving on two-lane rural roads under free-flowing conditions.

Differences in speed have been attributed to various reasons:

a) differences between the real road geometry/environment/layout/other road users (Tenkink, 1990; Riemersma et al, 1990; Alicandri et al, 1986; Reed and Green, 1995);

b) differences in face validity (size, capabilities, engine noise) of the instrumented vehicle and the simulator car (Tenkink, 1990; Alicandri et al, 1986; Reed and Green, 1995; Harms et al, 1996);

c) lack of acceleration forces for the fixed-base simulators and lack of visual information in the simulator (Tenkink, 1990);

d) different type of subjects used on the field study and in the simulator experiment and different instructions given for the simulator driving (Riemersma et al, 1990) and

e) different types of speedometers (Reed and Green, 1995).

LADS is a fixed-base simulator, therefore for this particular study the most applicable of the aforementioned reasons could be the lack of acceleration forces and lack of the appropriate visual information. Ritchie, McCoy and Welde (1968) concluded that the perceived lateral acceleration is under-estimated in a fixed-base simulator, where only visual stimuli are available, and lead to a lower perceived risk and a speed increase. Reymond, Kemeny, Droulez and Berthoz (1999) also reported that verbal reports of their subjects converged towards a general sensation of loss of intuitive speed references in the static simulator, which increased their need for speedometer reading and cognitive estimation built from the test laps. Further psychophysics experiments adapted to LADS set-up are necessary to measure the probable under-estimation of lateral accelerations under pure visual information (since it is a fixed-base simulator and no motion information can be provided anyhow).

Another possible reason for the observed differences in speed could be the limitations of the vehicle dynamics model of LADS, which could not simulate the forces due to road camber. As a consequence, it could be difficult to identify any driving behaviour variation due to the influence of the foregoing parameters or their combination with other road elements (e.g. radius).

As it was mentioned in Chapter 4, the road under investigation was almost flat (longitudinal grade no greater than 1%), and therefore this particular grade was not expected to affect driver behaviour (Lamm et al, 1991). On the other hand, the superelevation on the apex of all curves was 7% (in accordance with the Highway Link Design, 1989; TD 9/81, Table 3, page B5). The differentiation of vehicle motion equations due to superelevation is believed to have a significant effect on subjects' speed as the following paragraphs show.

In particular, in terms of speed, Table 8-1 shows the effect of absence of superelevation rate on curves of 55m and 200m respectively (i.e. the radii of curve C1 and curve C3 respectively), for extreme pavement conditions according to a dynamic model describing the vehicle motion on combined horizontal and vertical curvature (Mavromatis and Psarianos, 1998). Since the maximum friction factors exceed the sliding friction factor by 10%-45%, varying with the tyre and pavement types (Gauss, 1976), both these two extreme values were selected in order to describe the desired (45%) but also the undesired (10%) tyre-pavement conditions.

Table 8-1 Effect of superelevation on driver speed on curves

Max speed (km/h) for skidding						
Radius (m)	Poor condition pavement (1.10)			Good condition pavement (1.45)		
	S = 7%	S = 0%	Difference km/h (%)	S = 7%	S = 0%	Difference km/h (%)
55	54.3	49.3	5 (10)	59.6	54.7	4.9 (8)
200	95.5	85.5	10 (10.5)	104.8	95.5	9.3 (9)

The speed data shown in Table 8-1 apply for a medium sedan passenger car (Dixon, 1996). It can be seen that the lack of superelevation on a 55m radius curve results in a ≈5 km/h reduction of maximum speed and on a 200m radius curve in a ≈10 km/h reduction, i.e. about 5%-10% reduction of maximum speed whether driving on poor or good condition pavement. Therefore, the effect of superelevation on driver speed during curve negotiation should not be ignored totally.

Taking into account the effect of lack of superelevation when driving on curves, a number of differences observed between the two environments could be explained. For example, the smallest differences observed in the apex and exit points of curve C1 which were almost zero could be due to the fact that drivers were traversing a small radius curve (R= 55m).

8.3.1.2. Lateral position

The mean lateral position for the curved sections varied between 521 mm and 1187 mm on the real road and between –33 mm and 934 mm in the simulator. For the straight sections, the values varied between 879 mm and 999 mm for the real road and between 370 mm and 698 mm for the simulator. This means that subjects drove closer to the edge of the road by about 40 cm, compared to their real road counterparts whether they drove on curved and/or straight road sections. The same behaviour (i.e. driving closer to the edge of the road in the simulator) has been observed by Alm (1995), (the second VTI behavioural validation study) but the opposite behaviour had been observed in the first VTI behavioural validation study (Harms, 1993). Reed and Green (1995) found that there was a much larger range of values across subjects in lane-keeping, particularly because age had more pronounced effects on lane keeping than speed control.

The differences in lateral position behaviour between the two sets of drivers could be attributed to a number of reasons such as:

a) lack of perception of danger in simulator driving (see also Allen et al, 1991)
b) lack of perception of lateral distance (see also Groeger et al, 1997)
c) misuse of the respective cues that are used for real road driving and distance perception.

Possible ways of improving lateral position behaviour include the recruitment of subjects who have driven the simulator before and consider the simulator as being quite realistic. Other measures could include the introduction of vertical curvature in the graphics software; the readjustment of the vehicle dynamics model to better simulate the lateral acceleration (centrifugal) forces on curves and the introduction of oncoming traffic (especially on the straight road sections) which minimises the lateral position variation.

8.3.1.3. Speed and lateral position variation

Speed variation has been considered occasionally more important than driving speed for traffic safety because increase of speed variance leads to increase of traffic accidents (Solomon, 1964; Cirillo, 1968; Hauer, 1971; Blana, 1994). Most of the researchers have observed higher speed variation in the simulators compared to real life (Riemersma et al, 1990; Tenkink and van der Horst, 1991; Hogema, 1992; Harms, 1993; Duncan, 1995; Reed and Green, 1995; Alm, 1995; Boulanger and Chevennement, 1995; Harms et al, 1996). The same effect was observed in this study too.

Higher lateral position variation has been observed in the simulator compared to real life in this study and various other studies (McLane and Wierwille, 1975; Blaauw, 1982; Tenkink, 1988; Harms, 1993; Alm, 1995; Duncan, 1995; Harms et al, 1996). This means that simulator subjects cannot keep the car in a steady course and swerve more in their lane compared to their real-road counterparts. The consequence of this observation is that when the simulator is used for an experiment that is directly related to lateral position (e.g. the effect of alcohol and/or drug-induced sedation on drivers' path on the road) it cannot produce results that are valid in an absolute sense.

It has also been observed that the position of side objects affect subjects' lateral position (Harms et al, 1996). In particular, if objects are placed closer to the lane, speed and lateral position variation decreases (Tenkink, 1989; Tenkink, 1990; Tenkink and van der Horst, 1991). It has also been observed that oncoming traffic decreases lateral position variation (Alm, 1995) and as it was proven in this study it has a more pronounced effect on straight sections than curved sections. These findings could be used in the simulator driving as an artifice to normalise speed and lateral position distribution and decrease the respective variations. It has been proven that trying to produce a simulator environment to be exactly the same as the real road environment does not necessarily result in the desired effect and different artifices have to be employed to make the simulator driving more like that in the real world.

8.3.2. Left-hand versus right-hand curves

Left and right curves were investigated separately since it has been found that their contribution to accident rates is different (Smith, Purdy, McBee, Harwood, St John and Glennon, 1981; Highway Link Design, 1989). Results were based on two left and two right curves, so that it is not advisable to be generalise from them.

Higher speed differences were observed on the right curves compared to the left curves only in the simulator environment. Speed variation was the same for the two types of curves for both environments. Both sets of drivers positioned their vehicle closer to the edge of the road on right curves compared to the left curves. Lateral position variation was the same for both types of curves for both environments. No cutting-off the centreline behaviour on the right curves (driving on the left side of the road) was observed at any point as has been observed by Glennon et al (1985), Zeeger et al (1990) and Reinfurt, Zegeer, Shelton and Neuman (1991). Drivers' behaviour was affected by the radius of the curve and the visibility (results agree with McLean, 1974). There were some edgeline encroachments on the sharp left curve C1 (driving on the left side of the road, results agree with Emmerson, 1969; McLean, 1974, Johnston, 1983 and Reinfurt et al, 1991).

These findings provide a basis for the need of more real road studies, which should verify if indeed a different driving strategy is followed on different direction curves. Although a fixed-base driving simulator is not the most appropriate simulator for the investigation of driving on curves since it lacks the kinaesthetic feedback, results were based on two sets of 100 drivers and subjects, therefore it should not be neglected.

8.3.3. Characteristic points of a curve

The driving behaviour pattern across the characteristic points of each curve was not the same in the two environments. Observed drivers generally adapted their speed according to the road geometry. On the other hand, simulator subjects kept a steady speed when traversing the circular arc of a curve whether it had poor or good visibility. On curves with very small radius and length of curve, their speed varied from the beginning until the end of the curve. The highest difference for all curves (aggregated data) was observed at the entry point, whereas the minimum difference was observed at the approach point. In all points besides the approach point of curve C4, simulator subjects drove slower than their real road counterparts. Comparing the differences between the four curves, the smallest difference was observed on the approach point of curve C2 (0.9 km/h) and the highest at the entry point of curve C3 (15 km/h). Observed drivers did not ever cross the left white line, but the 50 percent of subjects crossed the left white line of the road on the exit point of curve C3.

Findings suggest that speed change along a curve may be influenced heavily by the preceding and following road sections relative to the investigated curve. The highest speed change was observed between the approach and all other points of each curve. Speed along the circular arc of each curve was never constant. Speed between the approach point and all other points varied between the four investigated curves and was influenced by the geometry of the particular curve (in terms of radius, length of curve and visibility). The highest speed change occurred on curve C1 (the one with the poorest road geometry compared to the other three curves) between the approach point and the apex point. The above findings apply to both environments. However higher speed change was observed on the real road compared to the simulator. Studies have shown strong association between adverse geometric elements and accident blackspots (Boughton, 1975; Jorgensen et al, 1978; and Federal Highway Administration, 1982). Small radius curves and narrow width sections of road have been shown to be over-represented among accident blackspots (as for curve C1 in real life). The literature review of speed on curved road sections (for more details see Appendix 4-1) showed that researchers do not exactly agree on how drivers perceive curves and consequently adapt their driving behaviour when traversing it (Taragin, 1954; Kneebone, 1964; Tharp and Harr, 1965; Emmerson, 1969; Holmquist, 1970; Neuhardt, Herrin and Rockwell, 1971; McLean, 1974; Glennon et al, 1985; Mintsis, 1988; Reinfurt et al, 1991). However, the results of this particular study tend to agree more with the findings of Glennon et al (1985), Mintsis (1988) and Reinfurt et al (1991). They all concluded that the factors most associated with speed changes by the drivers were the sharpness of the impending curve (as for example the speed change between curves C1 and C2 which were adjacent) and the level of curvature (e.g. curve C1).

In terms of lateral position, observed drivers' and simulator subjects' behaviour was the same in the circular arc of curves C1, C2 and C4 but different in their respective approach points. That is to say on curves C1, C2 and C4 both sets of drivers oversteered from the entry until the apex and understeered from the apex until the exit. Generally, it could be said that simulator subjects oversteered from the approach until the apex of these curves. On curve C3 the two sets of drivers followed a different behaviour. Observed drivers kept a steady distance from the edge of the road from the approaching to the exit of the curve, whereas the simulator subjects understeered in the approach area and oversteered along the circular arc of the curve. This could be attributed to the fact that curve C3 had very poor visibility and the two sets of drivers may perceive differently the lack of visibility in the two environments. On straight sections both sets of drivers kept a constant distance from the left edge of the road.

8.3.4. Effect of oncoming traffic

Oncoming traffic was defined as vehicles travelling in the oncoming direction within a distance of 20m on the curved sections and within 50m on the straight sections. Real road speed and lateral position were not the same as simulator speed and lateral position when driving under different oncoming traffic conditions on curved and/or straight sections at the 0.05 significance level.

There was no effect of oncoming traffic on drivers' mean speed whether driving on curved and/or straight sections for both environments. Speed variation decreased by 20% on straight sections in both environments due to oncoming traffic. Drivers positioned their vehicle closer to the edge of the road due to oncoming traffic (14% for the observed drivers and 33% for the simulator subjects) on curves. There was no effect on observed drivers lateral position variation but simulator subjects' variation decreased by 23%.

8.3.5. Horizontal profiles results

Although speed has been widely and rather thoroughly investigated by researchers both behaviourally and "physically", fewer researchers have addressed the issue of vehicle lateral displacement, and moreover its relation to speed. Lateral position statistics started to develop in 1980's and since then are repeatedly used by traffic psychologists in field tests for measuring effects of drugs (O'Hanlon et al, 1982; Brookhuis, Volkerts and O'Hanlon, 1990) and fatigue (Desmond and Matthews, 1996) on driving performance.

It is not clear whether a driver controls lateral position with regard to a certain desired value or just between two boundary values (Rashevsky, 1964). Rashevsky stated that the driver only controls the lateral position when it exceeds two imaginary boundaries set by himself. He claimed that the distribution of lateral position is uni-modal, rather than uniform or multi-modal pointing more to a certain desired control value.

The results of this study showed that lateral position depends on a combination of driving speed and specific road geometry. The driving path differs between the real road and the simulator environments as well as the driving strategy in terms of lateral displacement when traversing a curve. It was also found that results are specific to the investigated curved sections and cannot be easily generalised to other respective curves. On curves with very low visibility and poor road geometry (very small radius and length of curve), lateral position in the simulator was independent of speed whereas the opposite applied for the real road. This suggests that the two sets of drivers perceive the curvature and the visibility differently in the two environments and it is also possible that the safety margins in terms of lateral distance from the edge of the road are defined differently in the two environments. On better geometry curves, lateral position on the real road did not depend on the driving speed whereas the opposite applied for the simulator. The relation between speed and road geometry (in terms of curve radius and visibility) and lateral position needs further investigation. The range of speeds under or below which lateral position becomes affected by them also needs further exploitation. Differences in driving strategies between the two environments suggest that curves are recognised (and therefore the information provided to the driver about the nature of the curve) in a different way in the two environments. Because the investigated curves all had poor geometry and rather small radius and length, further investigation about curve negotiation in the simulator is needed using intermediate and large curves.

In terms of standard deviation of lateral position, it was found that deviation increased as the speed increased for all curves and both environments. However, this effect was more pronounced for the real road drivers. A parallel increase of speed and lateral position was more obvious on curves C1, C2 and C4; this effect did not apply for curve C3 (the curve with the poorest visibility).

The parallel increase of lateral position as speed increases was mostly apparent on the straight road sections and especially at the higher speeds (over 100 km/h). At these speeds real road drivers moved by ≈20 cm closer to the centre of the road. At lower speeds, drivers kept an almost constant distance from the edge of the road (≈1 m) irrespective of their driving speed (70 km/h to 100 km/h). This observation applied for both straight sections. However, this effect did not apply for the simulator drivers. Simulator subjects positioned their vehicle at different distances from the edge of the road on each straight road section. Lateral displacement was the same irrespective of the driving speed. It is possible that simulator subjects cannot distinguish between the different categories of driving speed and therefore their lateral position is not affected by their speed at all. The differences in lateral position between the two straight sections in simulator driving cannot be easily explained. One would expect that subjects would drive closer to the centre of the road along straight S1 since there was roadside development but the opposite was observed. The findings suggest that the driving strategy that subjects follow when traversing a straight road section in the simulator needs further investigation.

8.3.6. Vertical profiles results

The relation between speed and lateral position data at each measurement point was investigated. Correlation and regression analyses (in terms of best-fit line) were used.

The equations showed that it is the lateral position of drivers who traverse each characteristic point of the curve at the highest possible for the curve speed that would be mostly affected by speed. Speed affected mostly lateral position at the approach and apex points of the curves. These findings applied for both real road and simulator environment.

However, the equations also showed that lateral position in terms of absolute values between the environments at each characteristic point of the curved sections would be quite different. That is to say, the two sets of drivers who would traverse at the same speed any characteristic point of the curve would position their vehicle at a different distance from the edge of the road. It was shown that simulator drivers would always drive closer to the edge of the road by ≈40cm compared to their real road counterparts at any of the characteristic points of the curves. This effect was valid for all 15 data points on the curves except for the approach point of curve C1 where lateral positioning for the two environments was the same. This C1 finding is difficult to explain. It is worth mentioning that this point was the first point where measurements were taken.

When driving on real road straight sections, the equations showed that lateral position would increase as speed increases, and the effect would be more distinct at speeds higher than 100 km/h (the model applied for both straight sections and for each data point of the two straights). This finding did not apply for the simulator, where it was found that subjects' behaviour depends on each straight section and each data point of the straight section, i.e. there is no driving pattern. Thus, no conclusions could be derived for simulator lateral behaviour on straight sections. It could possibly be said that lateral position in the simulator on straight sections is not so dependent on speed, and it is obvious that the two sets of drivers position their vehicles at a different distance from the edge of the road in each environment using different cues. Further investigation of subjects' lateral behaviour when driving on straight sections is needed related to the identification of the respective cues that the two sets of drivers use in the two environments.

8.4. Recommendations for the design of validation experiments

Since the first behavioural validation studies in 1975, a limited number of validation studies has been conducted in old simulators (e.g. scale models) and even fewer in driving simulators using CGI (Computer Graphics Imagery) systems. It is well known and accepted in the simulator community that behavioural validation studies are not renowned for their methodological rigour (e.g. cross-sectional studies without examination of reliability, extrapolation from small studies, paucity of replication studies, inability to agree on criteria for validity). This is not to deny that the area is a complex and probabilistic one where data are noisy, and uncontrolled and uncontrollable factors are present. It seems that the rapid, constant and continuous development of simulator technology inhibits research and engineers tracking down the derived changes in simulator driving behaviour. The following subsections will discuss lessons learned during this behavioural validation and ways of overcoming the observed inadequacies in order to improve the design and implementation of any future respective validation study.

8.4.1. Validation approach

It is recommended that driver behaviour should be observed in the genuine real road environment. It is suggested that driver behaviour data under controlled experimental condition (i.e. collecting data by using an instrumented vehicle) should be compared with uncontrolled observational data (i.e. observing and measuring genuine road drivers' data). No such studies have been performed until today and there is disagreement between researchers as to how valid the results are obtained from an instrumented vehicle, i.e. how closely simulator data is correlated to uncontrolled observational data. If it is proven that the instrumented vehicle can produce data highly correlated to the observational data then it can be used for future field studies. The use of an instrumented vehicle facilitates the set-up of the field study as well as the data collection and analysis.

8.4.2. Validation criteria

All researchers after 1982 have used and still use the absolute and relative criteria for validating their driving simulators as defined by Blaauw (e.g. Blaauw, 1982; Harms, 1993; Alm, 1995; Kaptein et al, 1995; Reed and Green, 1995; Harms et al, 1996).

In order to achieve absolute validity (as it was earlier defined in section 3.3.3 in Chapter 3), all parameters of the field study and the simulator experiment must be very carefully controlled. These parameters depend on:

a) the specific simulator context (hardware and software);
b) the performance variables;
c) the accuracy with which the real road data were collected;
d) the number of genuine road users and subjects, which in a way confines the statistical significance of the statistical test used for the analysis of the data; and finally
e) the power of the statistical test used to analyse the data.

Relative validity could be a way out of some of the above problems. However, it is very difficult to settle reliable and clear thresholds to be used to define the relative validity of a simulator due to the fact that they cannot always be quantified. The simplest criterion used is that if the direction of differences between the two environments is the same, then the simulator is relatively valid and vice versa. It was found typical statistical measures applied for testing the differences in means and variations are not capable of determining the behavioural validity of a simulator. It has also been proven that the statistical tests applicable in psychology for testing the validity of a test cannot be used for the simulator because the latter involves human-machine interaction. The need to establish thresholds, which will determine the behavioural validity of a simulator has been demonstrated. Therefore, it becomes evident that the interpretation of the behavioural validation findings is an extremely complicated task.

A driving simulator is an integration of systems, which are under continuous development and technological evolution. Few researchers in the field would argue with the statement that it has proven extremely difficult to track down the effect of simulator improvements into subjects' driving behaviour the last twenty years even when the same experiment is conducted (see for example the first and second validation studies of the VTI driving simulator, Harms, 1993 and Alm, 1995). As Harms et al (1996) concluded "the presence of critical but unnoticed source of variance, influencing subjects' speed and lateral position both in the field trials and simulator trials, may result in an unreliable conclusion of behavioural validation studies".

Improving the situation would require the design of a standardised simulator test, dependent on the type and capabilities of the simulator, which would be easy to replicate every time any of the simulator technical specifications were modified. There should be a direct link between the independent and dependent variables, i.e. between those technical specifications that are modified and the performance measures that are affected by the modification(s). The dependent variables should be easily and reliably measured in both environments. Real road measurements suffer from various uncontrolled and uncontrollable factors whereas the simulator environment is totally controllable. Therefore, real road data collection and statistical analysis techniques should be performed in such a way as to ensure maximum reliability, unbiased data and correct interpretation of results. As mentioned before the sample size and the power of the statistical test is of critical importance. The field study should remain unaltered and compared each time to the "adjusted" simulator experiment.

8.4.3. Simulator sickness

This particular study showed that the level of simulator sickness was not so high, even though LADS is a fixed based simulator. This means that the motion system can be one of the factors for minimising simulator sickness (Romano and Watson, 1994; Alm, 1995; Soma et al, 1996) but not necessarily the primary one. The percentage of subjects suffering from simulator sickness in LADS was 10% (73% females and 27% males). Only 27% of them suffered from severe symptoms (e.g. vomited). According to the "sick" subjects, things that caused nausea were swerving and trying to find their way back on the road; absence of movement and the bumpy steering wheel. According to the "healthy" subjects who felt nauseous but not enough as to quit the experiment (15%) things that caused nausea were the curved road sections (40%); the smell coming from the plastic of the car (!) (20%); the oncoming traffic (13.3%); changing gears, the steering wheel, too much concentration and looking at the instruments (6.7% each one).

8.4.4. The face validity of LADS

A continuation of the existing behavioural validation study would be to improve the features of the simulator, which seem to cause the most problems to subjects both in terms of their performance and face validity (e.g. the steering and the braking systems). The second step would be to perform the simulator experiment exactly the same but this time with the problematic features improved. The comparison of the "before" and "after" studies would indicate if indeed the improvement of these simulator features also improved subject driving performance.

It has been indicated in this experiment that subjects who believe that the simulator is quite realistic and easy to control in terms of speed and lateral position perform better than those subjects who believe the opposite. These subjects could be used in future experiments because they would give more credible and valid results. No sex and age differences have been observed, so equally men and women could be used for simulator experiments irrespective of their age (however this applies only for ages between 21 and 35 years old).

There is no standardised method for recording subjects' personal characteristics and opinions relative to the realism of the simulator. There are a number of methods for measuring the mental workload (e.g. the NASA-TLX test of Hart and Staveland, 1988) but no method for evaluating subjects' responses relative to the face validity of the simulator and no method for linking their responses to the actual simulator system.

8.4.5. Graphical presentation

The problem of representing the real road network (and in particular the complicated motorway network) has already been recognised by a number of researchers (Bayarri, Fernadez, Pareja and Coma, 1997; Papelis, 1998; Bailey, Jamson, Parkes and Wright, 1999). The primary thought in designing graphics software for a driving simulator should be its simplicity of use and efficiency. The scene generation tools should be able to operate at high levels and allow the user to combine smaller existing scenes into larger scenes suitable for user's needs (e.g. tile based scene generation technique; Kearney, Allen, Bahauddin, Bartelme, Chow, Evans, and Mannlein, 1996; Papelis and Bahauddin, 1998).

Another problem is the representation of other traffic on the simulator road. Representing exactly the real road conditions is virtually impossible. The problem faced on LADS when representing oncoming traffic was the difficulty of specifying the path that "drone" vehicles (i.e. vehicles which cannot "react" and "behave" according to the driving behaviour of the simulator vehicle) followed at a velocity that was independent of simulator driver actions. At this moment, research is under way in LADS investigating the methods to incorporate intelligence into the "drone" vehicles in the simulator and modelling the decision processes of a generic driver (see LADS web page: http://mistral.leeds.ac.uk and Bailey et al, 1999).

8.4.6. Data storage, retrieval, screening and backing up

An issue that can really limit the usability of a driving simulator is the system, which deals with data storage, retrieval, screening and backing up. A simple human error could cost from a loss of a single subject file to the loss of the entire database. During the course of the experiment, it became very clear that human error in the procedure of loading data and/or saving it could very easily happen. The lack of user-management software, able to keep track of all the associations between drivers and their parameters within the context of the experiment, became apparent. This problem is not faced only on LADS but has been identified by other researchers (Papelis, 1998).

Another issue that is critical to the successful completion of any simulator experiment is the process by which raw data produced by the simulation in real time is transformed into data that is useful for further analysis by simulator users. LADS has already advanced software that can automatically calculate some complicated variables at each time step (see LADS web page: http://mistral.leeds.ac.uk).

8.5. Thesis summary and final conclusions

The aim of this thesis was to provide a comprehensive behavioural validation of a fixed-base driving simulator and to indicate possible areas in which to modify the existing configuration of LADS. It is believed that the study provides researchers with a scientifically-based guide for interpreting results obtained on a simulator. It provides guidance on how the Leeds simulator can be modified to overcome any deficiencies that were detected.

It became apparent that both absolute and relative validity are confined to a specific simulator and the specific driving tasks under investigation and cannot be generalised to other tasks or other driving simulators. It was found that the Leeds Advanced Driving Simulator could not be characterised as absolutely valid both in terms of speed and lateral position whether driving on curved or straight road sections, with or without the presence of oncoming traffic. It could be characterised as relatively valid in terms of speed and partially in terms of lateral position (there were data points where relative validity was not achieved). More reliable results were produced for the curved than the straight road sections both in terms of speed and lateral position.

Valuable results were derived from the comparison of the real road and the simulator data in terms of simulator driving. It was found that differences in speed behaviour are expected at points where visibility is very poor (implying that hazard perception may differ in the simulator) and where road geometry confines drivers to limit their desired speed. In addition to the fact that speed perception is poor on a fixed-base simulator, great discrepancies between real road and simulator speed on straight sections are to be expected.

Lateral position behaviour differed on the approach to a curve, implying that curve negotiation differs between the two environments, although both sets of drivers adjusted their speed according to the preceding and following road sections and their ability to see far ahead on the road

It was found that subjects drive closer to the edge of the road by about 40 cm, compared to their real road counterparts whether they drive on curved and/or straight road sections. This estimation is based on the parameters of this experiment, therefore it is not recommended for generalisation without taking into consideration the context of the simulator used as well as the road geometry and environment of the experiment.

Lateral position standard deviation was about 200% higher in the simulator compared to the real road and about 30% higher for speed, i.e. simulator drivers deviate considerably more than their real road counterparts. This finding suggests that care should be taken when the simulator is used for example for alcohol and drug-induced experiments, where lateral position deviation is the crucial factor for the successful interpretation of the respective results.

Finally it was found that for both environments the overall presence of oncoming traffic on the road network affects drivers' behaviour both in terms of speed and lateral position. On the other hand, oncoming traffic in the near vicinity did not affect their speed at all and their lateral position only slightly on curves.

It is hoped that the work contained in this thesis will serve to inspire other researchers to progress the techniques of driving simulation for measuring driver behaviour and driver performance and in particular to minimise and treat the problem of lateral position in the simulator.

REFERENCES

Advisory Group for Aerospace Research and Development (AGARD) (1981). *Characteristics Of Flight Simulator Visual Systems* (Advisory Report 164). Neuilly sur Seine, France: NATO Author. (NTIS AGARD-AR-164).

Alicandri, E., Roberts, K. and Walker, J. (1986). *A Validation Study Of The DOT/FHWA Highway Simulator (HYSIM).* U.S. Department of Transport, Federal Highway Administration. FHWA/RD-86/067.

Allen, R.W. and Jex, H.R. (1980). *Driving Simulation - Requirements, Mechanization And Application.* Paper 800488, SAE, Warrendale, Pa., Feb.

Allen, R.W., Klein, R.H. and Ziedman, K. (1979). Automobile Research Simulators: A Review And New Approaches. *Transportation Research Board* 706, pp.9-15.

Allen, R.W., Mitchell, D.G., Stein, A.C. and Hogue, J.R. (1991). Validation Of Real-Time Man-In-The-Loop Simulation. *VTI Report.* No 372A, Part 4, pp.18-31.

Allen, R.W. and O' Hanlon, J.F. (1979). Driver Steering Performance Effects Of Roadway Delineation And Visibility Conditions. *Paper presented at the 58th Annual Meeting of TRB*, Washington, D.C.

Allen, R.W., Rosenthal, T.J., Aponso, B, Harmsen, A., and Markham, S. (1999). Low Cost PC-Based Techniques For Driving Simulation Implementation. *Paper presented at the Driving Simulation Conference (DSC'99).* Paris, France, 7-8 July.

Allen, R.W., Hogue, J.R., Rosental, T.J., and Parseghian, Z. (1988). *A Data Acquisition And Analysis System Based On A Laptop Computer.* Paper 423. Systems Technology Inc. Hawthorne. Ca.

Allen, R.W., Rosental, T.J., et al (1998). A Low Cost PC-Based Driving Simulator For Prototyping And Hardware-In-The-Loop Applications. *SAE Paper* No 98-0222, Society of Automotive Engineers, Warrendale, Pa.

Allen, R.W., Schwartz, S.H., Hogue, J.R., Stein, A.C. (1978). *The Effects Of Alcohol On The Driver's Decision-Making Behaviour.* U.S Department of Transportation, Vols. 1 and 2, Reports. DOT-HS-803 608 and 803 609, Feb. 1978.

Alm, H. (1995). Driving Simulators As Research Tools - A Validation Study Based On The VTI Driving Simulator. Unpublished.

Alm, H. and Nilsson, L. (1991). The Effects Of A Mobile Telephone Conversation On Driver Behaviour In A Car Following Situation. *DRIVE Project* BERTIE, Report No 73.

American Psychological Association (APA), (1985). *Standards for Educational and Psychological Testing.* American Psychological Association (pubs), pp 9-23.

Anastasi, A. (1988). *Psychological Testing.* Macmillan Publishing Company, New York.

Armour, M.A. (1984). A Review Of The Literature On Police Traffic Law Enforcement. *Australian Road Research* 14(1), pp.468-470.

Ashkenas, I.L. (1986). *Collected Flight Simulation And Simulator Induced Sickness.* AGARD. Flight Simulation.

Ashworth, R. (1976). A Videotape-Recording System For Traffic Data Collection And Analysis. *Traffic Engineering + Control* 17(11), pp.468-470.

Bailey, A.C., Jamson, A.H., Parkes, A.M., and Wright, S. (1999). Recent And Future Development Of The Leeds Driving Simulator. *Paper presented at the Driving Simulation Conference DSC'99*, Paris, France, 7-8 July, pp.45-62.

Barbosa, E. (1995). *Impacts Of Traffic Calming Measures On Speeds On Urban Roads.* PhD Thesis. Institute for Transport Studies. University of Leeds. England.

Barrett, G.V., Nelson, D.D., and Kerber, H.E. (1965). Human Factors Evaluation Of A Driving Simulator. *Goodyear Aerospace Corporation* Final Report. Contract No PH 108-64-168.

Bartmann, A., Spijkers, W., and Hess, M. (1991). Street Environment, Driving Speed And Field Of Vision. In A.G. Gale (Ed.), *Vision in Vehicles III.* Amsterdam: Elsevier Science.

Bayarri, S., Fernadez, M., Pareja, I., Coma, I. (1997). An Integrated Interface To Design Driving Simulation Scenarii. *Paper presented at the Driving Simulator Conference DSC'97.* Lyon, France, September 8-9, pp.25-34.

Baxter, J. and Harrison, J.Y. (1979). A Non-Linear Model Describing Driver Behaviour On Straight Roads. *Human Factors* 21(1), pp 87-97.

Bertollini, G.P., Johnston, C.M., Kuiper, J.W., Kukula, J.C., Kulczycka, M.A. and Thomas, W.E. (1994). The General Motors Driving Simulator. *SAE Technical Paper Series.* No 940179.

Blaauw, G.J. (1982). Driving Experience And Task Demands In Simulator And Instrumented Car: A Validation Study. *Human Factors* 24(4), pp.473-486.

Blaauw, G.J. and Burry, S. (1980). ICARUS: An Instrumented Car For Road User Studies. *Journal A*, Vol. 21(3), pp.134-138.

Blaauw, G.J. and Riemersma, J.B.J. (1975). Interpretation Of Roadway Designs By An Analysis Of Drivers' Visual Scanning And Driving Behaviour On Straight And Curved Road Sections. *Report IZF* 1975 C-5. TNO Institute for Perception. Soesterberg. The Netherlands.

Blackham, G. (1999). Visual Display Systems For Car And Truck Simulators. *Paper presented at the Driving Simulation Conference (DSC'99).* Paris, France, 7-8 July, pp.137-151.

Blaiwes, A.S., Puig, J.A. and Regan, J.J. (1973). Transfer Of Training And The Measurement Of Training Effectiveness. *Human Factors* 15(6), pp. 523-533.

Blana, E. (1994). *Comparison of Greek and English drivers' attitudes and behaviour regarding speed.* MSc Thesis. Institute for Transport Studies. University of Leeds. UK.

Blana, E. (1996a). A Survey Of Driving Research Simulators Around The World. *ITS Working Paper* 481. Institute for Transport Studies. University of Leeds. Leeds. UK.

Blana, E. (1996b). Driving Simulator Validation Studies: A Literature Review. *ITS Working Paper* 482. Institute for Transport Studies. University of Leeds. Leeds. UK.

Blana, E. (1996c). The Leeds Advanced Driving Simulator: Three Years In Operation. *ITS Working Paper* 472. Institute for Transport Studies. University of Leeds. UK.

Blana, E. (1998). Driving Simulators As Research And Training Tools For Improving Road Safety. *Paper presented at the IMACS/IFAC International Symposium on Soft Computing in Engineering Applications (SOFTCOM'98).* Athens, Greece, 23 June.

Boff, K.R. and Lincoln, J.E. (1998). The Vestibular System In Engineering Data Compedium. *Human perception and performance*, AAMRL, Wright-Patterson AFB, OH, pp.766-787.

Boidin, P. (1994). Truck Training Simulation: A Fist Full Scope Simulator. *Paper presented at the Driving Simulation Conference RTS'94.* Palais de Congres, Porte Maillot, Paris, France, 11-14 January.

Boidin, P. (1997). Truck Driver Training Simulation: The Simulator Scope. *Paper presented at the Driving Simulation Conference DSC'97.* Lyon, France, 8-9 September.

Boughton, C.J. (1975). Accidents And Geometric Design. *Australian Road Research Board.* Research Report ARR 44.

Boulanger, O. and Chevennement, J. (1995). Analytical And Application Experiments: Two Necessary Approaches For The Driving Simulator Validity. *Paper presented at the Driving Simulation Conference DSC'95.* Toulouse, France, pp 26-39.

Box and Oppenlander, J.C. (1976). *Manual Of Traffic Engineering Studies.* Institute of Transportation Engineers, Fourth Edition.

Breda, W.M., Kirkpatrick, M., and Shaffer, C.L. (1972). A Study Of Route Guidance Techniques. *North American Rockwell.* Final Report. Contract No. DOT-FH-11-7708.

Brookhuis, K.A., De Vries, G., and de Waard, D. (1991). The Effects Of Mobile Telephoning On Driving Performance. *Accident Analysis and Prevention* 23, pp.309-316.

Brown, I.D. (1965). Effect Of Car Radio On Driving In Traffic. *Ergonomics* 8, pp.475-479.

Brown, J.L. (1975). *Visual Elements In Flight Simulator.* Report of Working Group 34. Washington DC: Committee on Vision, Assembly of Behavioural and Social Sciences. National Research Council. National Academy of Sciences.

Caro, P.W. (1973). Aircraft Simulators And Pilot Training. *Human Factors* 15(6), pp.502-509.

Carsten, O.M.J and Gallimore, S. (1993). The Leeds Driving Simulator: A New Tool For Research In Driver Behaviour. *Fifth International Conference on Vision in Vehicles*, Glasgow.

Casali, J.G. and Frank, L.H. (1986). Perceptual Distortion And Its Consequences In Vehicular Simulation: Basic Theory And Incidence Of Simulator Sickness. In TRB (Eds.) *Vehicular Simulation and User Behavioural Studies.* Washington, D.C.: Transportation Research Board, TRR 1059, pp.57-65.

Casali, J.G. and Wierwille, W. (1986). Potential Design Etiological Factors Of Simulator Sickness And A Research Simulator Specification. *Transportation Research Record* 1059, pp.66-74.

Cavallo, V., Bardy, B., and Laurent, M. (1991). *The Use Of Visual Information In Car-Following Situations*. Paper presented at the Fourth International Conference on Vision in Vehicles, Leiden, The Netherlands.

Cavallo, V., Brun-dei, M., and Laya, O. (1991). Perception And Anticipation In Negotiating Curves: The Role Of Driving Experience. In A.G. Gale et al. (Eds.), *Vision in Vehicles II*. Amsterdam: Elsevier Science, North Holland.

Charman, W.N. (1986). Vision And Driving. *Optician* (September 19^{th} & 26^{th}), pp.15-20 & 27-32.

Cirillo, J.A. (1968). Interstate System Accident Research Study II, Interim Report II. *Public Roads* 35, pp.71-75.

Cohen, J. (1994). The Earth Is Round ($p<.05$). *American Psychologist* 49, pp.997-1003.

Comte, S. (1996). Response To Automatic Speed Control In Urban Areas: A Simulator Study. *ITS Working Paper* 477. Institute for Transport Studies. University of Leeds. UK.

Coolican, H. (1994). *Research Methods And Statistics In Psychology*. Hodder & Stoughton. Second Edition.

Davis, B.T. and Green, P. (1995). Benefits Of Sound For Driving Simulation: An Experimental Evaluation. *Technical Report UMTRI*-95-16. University of Michigan. Ann Arbor.

De Waard, D. (1996). *The Measurement Of Driver's Mental Workload*. PhD Thesis, University of Groningen. The Netherlands.

Deutsch, M. and Krauss, R. (1976). *Theorien Der Sozialpsychologie*. Frankfurt/M: Fachbuchhandlung für Psychologie.

Dewar, R. and Ellis, J. (1994). The Design And Evolution Of Traffic Signs. *Proceedings 12^{th} Triennial Congress on the International Ergonomics Association*, 4: Ergonomics and Design, Toronto, Canada, pp.221-223.

Dickinson, K.W. and Waterfall, R.C. (1984). Image Processing Applied To Traffic. 1. A General Review. *Traffic Engineering + Control* 25(1), pp.6-13.

Dods, J.S. (1985). An Appreciation Of Some Overseas Video Techniques Used In Road Traffic Data Collection. Australian Road Research Board, *Internal Report AIR* 416-1.

Dixon, J.C. (1996). *Tires, Suspension And Handling*. Second Edition. Society of Automotive Engineers, Inc. Warrendale, Pa.

Dods, J.S. (1987). The ARRB Video Vehicle Detector. *Australian Road Research Board*. Technical Manual 21.

Donges, E. (1975). Experimental Investigation Of Human Steering Behaviour In A Simulated Road Driving Task. *ATZ Automobiltechnische Zeitschrift*, Vol.77, No. 5/6, pp.141-146.

Drosdol, J. and Panik, F. (1985). The Daimler-Benz Driving Simulator: A Tool For Vehicle Development. *SAE, The Engineering Resource for Advancing Mobility*. SAE 850334. International Congress and Exposition, Detroit, Michigan.

Duncan, B. (1995). *Calibration Trials Of TRL Driving Simulator.* Transport Research Laboratory. Unpublished Project report. PA/3079/95. S221A/RB.

East Yorkshire Borough Council (EYBC), Humberside County Council, East Yorkshire Chamber of Commerce And Industry (1994). *Howden To Bridlington Route, The Case For Improvement: A Road To Opportunity.* Final Report.

Ebel, R.L. (1961). Must All Tests Be Valid. *American Psychologist* 16. October.

ELPA and National Technical University of Athens (NTUA) (1999). *Feasibility Study For The Development And Operation Of A Driving Simulator For The Enhancement Of Road Safety.* Athens, April.

Emmerson, J. (1969). Speeds Of Cars On Sharp Horizontal Curves. *Traffic Engineering + Control* 11(3), pp.135-137.

Evans, L. (1991). *Traffic Safety And The Driver.* Van Nostrand Reinhold (Pub.), New York.

Federal Highway Administration (1982). *Synthesis Of Safety Research Related To Traffic Control And Roadway Elements.* Report TS-82-232. Washington D.C.: Federal Highway Administration Office of Research, Development and Technology.

Feyerabend, P.K. (1982). *Der Wissenschaftstheoretische Realismus Und Die Autorität Der Wisenschaften* (Ausgewählte Schriften Bd. 1). Braunschweig/ Wiesbaden: Vieweg & Sohn.

Flexman, R.E. and Stark, E.A. (1987). *Training Simulators.* In: G. Salvendy (Ed.). Handbook of Human Factors. New Work: Wiley & Sons (Pubs), pp.1012-1038.

Frank, L.H., Casali, J.G., and Wierwille, W.W. (1988). Effects Of Visual Display And Motion System Delays On Operator Performance And Uneasiness In A Driving Simulator. *Human Factors* 30(2), pp.201-217.

Fraser, P.J. (1984). The Australian Road Research Board Vehicle Detector Data Acquisition System (VDDAS). Inst. Elect. Eng. Conference. Proceedings. "Road Traffic Data Collection". (*IEE Conference Publication* No 242, pp.35-39).

Gallimore, S. (1993) Building Road Networks For Use In The Leeds Driving Simulator. *ITS Working Paper* 389. Institute for Transport Studies. University of Leeds. UK.

Gallimore, S. (1996). Adding Behaviour To Graphical Elements In The Leeds Driving Simulator: An Object Based Approach. *Paper presented at the Symposium on the Design and Validation of Driving Simulators.* Valencia, Spain, 21 May.

Gauss, F. (1976). Skid Resistance Properties Of Tires And Their Influence On Vehicle Control In Skidding Accidents. *Transportation Research Board* 621, TRB, National Research Council, Washington, D.C., pp.8-18.

Geltmacher, H.E. (1988). Recent Advances In Computer Image Generation Simulation. *Aviation Space and Environmental Medicine*, 59, pp.A39-A45.

Glennon, J.C., Neuman, T.R. and Leisch, J.E. (1985). *Safety And Operational Considerations For Design Of Rural Highway Curves.* Report FHWA-RD-86-035. FHWA, U.S. Department of Transportation.

Glennon, J.C. and Weaver, G.D. (1971). The Relationship Of Vehicle Paths To Highway Curve Design. *Tex. Transp. Inst. Res. Rep.* pp.134-135.

Godthelp, H., Milgram, P. and Blaauw, G.J. (1984). The Development Of A Time-Related Measure To Describe Driving Strategy. *Human Factors* 26, pp.257-268.

Good, M.C. (1978). Road Curve Geometry And Driver Behaviour. *Australian Road Research Board.* Special Report No 15.

Graham, C.H (Ed.). (1965). *Vision And Visual Perception.* New York: Wiley.

Grayson, G.B. (1997). Theory And Models In Traffic Psychology – A Contrary View. In *Traffic and Transport Psychology, Theory and Application.* Elsevier Science, Ltd. Pergamon (pubs), pp. 93-96.

Greenberg, J.A and Park, T.J. (1994). The Ford Driving Simulator. *SAE Technical Paper Series* 940176.

Groeger, J.A., Carsten, O.M.J., Blana, E., Jamson, H. (1997). Speed And Distance Estimation Under Simulated Conditions. *Paper presented at Vision in Vehicles Conference VII,* Marseilles, France, 14-17 September.

Groeger, J.A., Grande, G., and Brown, I.D. (1991). Accuracy And Safety: Effects Of Different Training Procedures On A Time-To-Coincidence Task. In A.G. Gale et al. (Eds.), *Vision in Vehicles III.* Amsterdam: Elsevier Science, North Holland.

Harris, P. (1986). *Designing And Reporting Experiments.* Open University Press.

Harms, L. (1993b). Driving Performance On A Real Road And In A Driving Simulator: Results Of A Validation Study. *Paper presented at Vision in Vehicles* IV, Glasgow.

Harms, L., ALM., H. and Törnos, J. (1996). The Influence Of Situation Cues On Simulated Driving Behaviour: A Summary Of Three Validation Studies. *Paper presented at the Symposium on the Design and Validation of Driving Simulators.* ICCTP'96. Valencia.

Hart, S.G. and Staveland, L.E. (1988). Development Of NASA-TLS (Task Load Index): Results Of Empirical And Theoretical Research. Ref. In *Human Mental Workload.* P.A. Handock and N. Meshaki (Eds.). Elsevier Science Publishers B.V. (North-Holland).

Haug, E.J. (1990). *Feasibility Study And Conceptual Design Of A National Advanced Driving Simulator.* Iowa City: University of Iowa, College of Engineering, Centre for Simulation and Design Optimization of Mechanical Systems.

Haug, E.J., Cremer, J., Papelis, Y., Solis, D.A., and Ranganathan R. (1998). Virtual Proving Ground Simulation For Vehicle Design. *ASME Design Automation Conference.* Submitted.

Heyes, S., Hardy, M., HUmphreys, R., and Rookes, P. (1993). *Starting Statistics In Psychology And Education.* Second Edition. Weidenfeld & Nicholson.

Highway Link Design, (1989). Department of Transport. *Advice Note* TA 43/84. HMSO, London.

Highway Link Design, (1989). Department of Transport. *Advice Note* TD 9/81. HMSO, London.

Hochberg, J. (1971). Perception: II. Space and movement. In J.W. Kling, and L.A. Riggs (Eds.), *Experimental Psychology* (3rd ed., pp.475-550). New York: Holt, Rinehart, and Winston.

Hoffmann, E.R., and Mortimer, R.G. (1996). Drivers' Estimates Of Time-To-Collision. *Accident Analysis and Prevention*, 26, pp. 511-520.

Hogema, J.H. (1992). Effects Of Compensation For Delay In The Visual Display Of A Driving Simulator. *TNO Report IZF* 1992 A-40. TNO Institute for Perception. Soesterberg. The Netherlands.

Hogema, J.H. and Hoekstra, W. (1998). Description Of The TNO Driving Simulator. *TNO Report TM*-98-D007. TNO Institute for Perception. Soesterberg. The Netherlands.

Holbrook, E. (1880). Railroad Alignment. *Railroad Gaz.* Dec., p.39. Cited in Koehler (1946).

Holmes, E.H. (1939). Procedure Employed In Analysing Passing Practices Of Motor Vehicles. *Public Roads* 19(11), pp. 209-221.

Holmquist, C. (1970). Changes In Speeds Of Vehicles On Horizontal Curves. *Nat. Rd. Res. Inst. Sweden.* Report No 104.

Hughes, P.K. and Cole, B.L. (1986a). A Field Trial Of Attention And Search Conspicuity. *Human Factors* 26, pp.299-313.

Hughes, P.K. and Cole, B.L. (1986b). What Attracts Attention When Driving? *Ergonomics* 29, pp.377-391.

Hughes, P.K. and Cole, B.L. (1988). The Effect Of Attentional Demand On Eye Movement Behaviour When Driving. In A.G. Gale, M.H. Freeman, C.M. Haslegrave, P. Smith & S.P. Taylor (Eds.), *Vision in Vehicles II.* Amsterdam: North Holland.

Huguenin, R.D. (1988). The Concept Of Risk And Behaviour Models In Traffic Psychology. *Ergonomics* 31, pp. 557-569.

Huguenin, R.D. (1997). Do We Need Traffic Psychology Models? In *Traffic and Transport psychology, Theory and Application.* Elsevier Science, Ltd. Pergamon (pubs), pp. 31-41.

Hulscher, F.R. (1974). Selection Of Vehicle Detectors For Traffic Management. *Traffic Engineering + Control* 15(12), pp.915-925.

Hupfer, C. (1996). Personal Communication.

Hupfer, C. (1999). Personal Communication.

Janssen, W.H. (1979). Routeplanning En Geleiding: Een Literatuurstudie. *TNO Report IZF 1979* C-13. TNO Institute for Perception. Soesterberg. The Netherlands.

Janssen, W.H., Van der Horst, A.R.A. and Hoekstra, W. (1991). A Simulator Study Into The Effects Of Variable Message Signing On Route Choice And Driving Behaviour (in Dutch). *TNO Report* 1991 C-5. TNO Institute for Perception. Soesterberg. The Netherlands. (cited in Kaptein et al, 1995).

Janssen, W.H., Van der Horst, A.R.A. and Hoekstra, W. (1992a). Descriptive Information Presentation On Variable Message Signs (in Dutch). *TNO Report IZF 1992* C-7. TNO Institute for Perception. Soesterberg. The Netherlands. (cited in Kaptein et al, 1995).

Janssen, W.H., Van der Horst, A.R.A. and Hoekstra, W. (1992b). Effects Of Variable Message Signing On Route Choice And Driving Behaviour: The Influence Of Time Loss And The Presence Of Other Traffic (in Dutch). TNO Technische Menskunde. Soesterberg. The Netherlands. (cited in Kaptein et al, 1995).

Jorgensen et al (1978). Cost And Safety Effectiveness Of Highway Design Elements. *Transportation Research Board.* NCHPR Report 197. Washington, DC.

Johnston, I.R. and Fraser, P.J. (1983). Do "Visible" Detectors Really Influence Driver Behaviour? *Australian Road Research* 13 (3), pp.219-23

Käding, W. (1995). The Advanced Daimler-Benz Driving Simulator. *IPC-8 Technical Paper* No 9530012. Society of Automotive Engineers of Japan, Inc.

Kappé, B. and Körteling, J.E. (1995). Straight Road Steering: Visual Information In Driving Simulators (in Dutch). In preparation. TNO Technische Menskunde. Soesterberg. The Netherlands. (cited in Kaptein et al, 1995).

Kaptein, N.A., Theeuwes, J. and Van der Horst R. (1995a). Driving Simulator Validity: Some Considerations. Unpublished. TNO Institute for Perception. Soesterberg. The Netherlands.

Kaptein, N.A., Van der Horst R. and Hoekstra, W. (1996). The Effect Of Field Of View And Scene Content On The Validity Of A Driving Simulator For Behavioural Research. *Paper presented at the Symposium on the Design and Validation of Driving Simulators.* ICCTP'96. Valencia.

Kearney, J., Allen, S., Bahauddin, S., Bartelme, M.J., Chow, T., Evans, D., and Mannlein, B. (1996). Tile-Based Scene Modelling For Driving Simulation. *Proceedings of the 1996 Image IV Conference.* Scottdale, Arizona.

Kelada, J.M., Kemeny, A., and Lailler, D. (1997). Scenario Control Tools For A Dynamic Truck Simulator. *Paper presented at the Driving Simulation Conference (DSC'97).* Lyon, France, Sep., pp.215-226.

Kemeny, A. and Reymond, G. (1994). Automotive Training Simulator For Driver Safety Enhancement. *Proceedings of the 1994 Image VII Conference.* Tuscon, Arizona, 12-17 June.

Kennedy, N., Kell, J.H. and Homburger, W.S. (1973). *Fundamentals of Traffic Engineering.* Institute of Transportation and Traffic Engineering. University of California, LA.

Kneebone, D.C. (1964). Advisory Speed Signs And Their Effect On Traffic. *Proceedings of the 2nd ARRB Conference 2(1)*, pp.524-538.

Koehler, M.C. (1946). Discussion of Eichler and Eves. *Trans. Am. Soc. Civ. Eng.* 111, pp.997-1002.

Körteling, J.E. (1991). Visuele Informatie In Rijsimulatoren: Literatuurstudie En Onderzoekvoorstel (Visual information in driving simulators: Literature study and research proposal). *TNO Report IZF 1991* B-5. TNO Institute for Perception. Soesterberg, the Netherlands.

Koutsopoulos, H.N., Polydoropoulou, A., and Ben-Akiva, M. (1993). *The Use Of Driving Simulators To Investigate The Response To Traffic Information*. The Volpe National Transportation Systems Centre. Draft. pp.1-78.

Lamm, R., Choueiri, E. and Mailaender, T. (1991). Side Friction Demand Versus Side Friction Assumed For Curve Design On Two-Lane Rural Highways. *Transportation Research Record* 1303, pp.11-21.

Laya, O. (1992). Eye Movements In Actual And Simulated Curve Negotiation Tasks. *IATSS Research* Vol. 16, No. 1, pp.15-26.

Lee, D.N., (1976). A Theory Of Visual Control Of Braking Based On Information About Time-To Collision. *Perception* 5, pp.437-459.

Leeming, E.L. (1927). The Superelevation Of Highway Curves. *Sel. Eng. Paper Inst. Civ. Eng.* No 50.

Leonard, J.J. Jr and Wierwille, W.W. (1975). Human Performance Validation of Simulator; Theory and Experimental Verification. *Paper presented at the 19th Annual Meeting of Human Factor Society,* pp. 446-455.

Leong, F.T.L. and Austin, T. (Eds.) (1996). *The Psychology Research Handbook: A Guide For Graduate Students And Research Assistants*. Sage Publications Inc.

Lincke, W., Richter, B., and Schmidt, R. (1973). Simulation And Measurement Of Driver Vehicle Handling Performance. *Presented at SAE Automobile Engineering Meeting*, Detroit, May 14-18.

Magnenat-Thalmann, N., and Thalmann, D. (1987). *Image Synthesis: Theory and Practice*. Berlin: Springer-Verlag.

Malaterre, G. (1995). Comparison Between Simulation And Actual Driving Situations: Some Experiments. *Paper presented at the Driving simulator Conference (DSC'95)*. TEKNEA, Toulouse, France. pp.60-76.

Mavromatis, S. and Psarianos, V. (1998). Influence Of Combined Horizontal And Vertical Alignment On Two-Axle Vehicle Performance. *Paper presented at the 1999 Annual TRB Meeting*. Washington DC. January.

McCormic, E.J. (1970). *Human Factors Engineering*. New York: McGraw-Hill.

McCoy, W.K. Jr. (1963). Problems Of Validity Of Measures Used In Investigating Man-Machine System. *Human Factors* 5, pp.373-377.

McLane, R.C. and Wierwille, W.W. (1975). The Influence Of Motion And Audio Cues On Driver Performance In An Automobile Simulator. *Human Factors* 17(5), pp.488-501.

McLean, J.R. (1974). Driver Behaviour On Curves- A Review. *Australian. Road Research* 5(5), pp.76-91.

McLean, J.R. (1983). Speeds On Curves: Side Friction Factor Considerations. Australian Road Research board. *Research Report ARR* 126.

McLean, J.R. and Hoffmann, E.R. (1975). The Effects Of Lane Width On Driver Steering Control And Performance. *Proceedings of the 6th Conference of Australian Road Research Board* 6, pp.418-440.

McRuer, D.T., Allen, R.W., Weir, D.H., and Klein, R.H. (1977). New Results In Driver Steering Control Models. *Human Factors* 19, pp.381-397.

McRuer, D.T., and Krendel, E.S. (1974). *Mathematical Models Of Human Pilot Behaviour.* Paris: NATO AGARD-AG-188.

McRuer, D.T., and Klein, R.H. (1976). Comparison Of Human Driver Dynamics In An Automobile On The Road With Those In Simulators Having Complex And Simple Visual Displays. *Paper presented at the 55th Annual Meeting of the Transportation Research Board*, Washington D.C.

Van der Mede, P.H.J. and Berkum, E.C. (1993). *The Impact Of Traffic Information: Dynamics In Route And Departure Time Choice.* Thesis. Delft University of Technology. Delft. The Netherlands.

Michon, J.A. (1985). A Critical Review Of Driver Behaviour Models: What Do We Know, What Should We Do? In: L. Evans and R.C. Schwing (eds.). *Human behaviour and traffic safety.* New York: Plenum Press.

Miller, M. (1984). *New Essential Psychology: Experimental Design And Statistics.* Second Edition. Routledge.

Mintsis, G. (1988). Speed Distributions On Road Curves. *Traffic Engineering + Control,* pp.21-27.

Moraal, J. (1981). Evaluating Simulator Validity. In J. Moraal and K.F. Kraiss, eds. *Manned System Design: Method, Equipment and Applications.* New York: Plenum Press. pp.411-426.

Morrison, J.E. (ed.), (1991). *Training For Performance: Principles Of Applied Human Learning.* Wiley Series in Human Performance and Cognition. pp. 181-240.

Mourant, R.R., Rockwell, T.H., and Rackhoff, N.J. (1970). Drivers' Eye Movements And Visual Workload. *Highway Research Record* 292, pp.1-10.

Mudd, S. (1968). Assessment Of The Fidelity Of Dynamic Driving Simulators. *Human Factors* 10(4), pp.351-358.

Näätänen, R. and Summala, H. (1976). *Road User Behaviour And Traffic Accidents.* Amsterdam: North Holland Publishing Co.

Neuhardt, J.B., Herrin, G.D. and Rockwell, T.H. (1971). *Demonstration Of A Test-Driver Technique To Assess The Effects Of Roadway Geometry And Development On Speed Selection.* Dept. of Industrial Eng. Ohio State Uni. Project EES 326 B.

Nilsson, L. (1989). The VTI Driving Simulator (Description Of A Research Tool). DRIVE Project V1017. *VTI Report* No. 24.

Nilsson L. (1993). Behavioural Research In An Advanced Driving Simulator- Experiences Of The VTI System. *VTI Report* 197.

Nilsson, L. and Alm, H. (1991). Effects Of Mobile Telephone Use On Elderly Drivers' Behaviour —Including Comparisons To Young Drivers' Behaviour. *VTI Report* 176.

Norusis, M.J. (1993). SPSS® for Windows™. *Base System User's Guide.* Release 6.0.

O'Hanlon, J.F., Haak, T.W., Blaauw, G.J., and Riemersma, J.B.J. (1982). Diazepam Impairs Lateral Position Control In Highway Driving. *Science* 217, pp.79-80.

Ohta, H. (1993). Individual Differences In Driving Distance Headway. In A.G. Gale et al. (Eds.), *Vision in Vehicles IV.* Amsterdam: Elsevier Science, North Holland.

O'Flaherty, C.A. (1986). *Highways* –3rd edition. Volume 1: Traffic Planning and Engineering. Edward Arnold.

Olson, P.L. (1993). *Vision And Perception In Automotive Ergonomics*, (Eds.) Peacock, B. and Karkowski, W. Taylor & Francis. London. pp.161-183.

Padmos, P. and Mildres, M.V. (1992). Quality Criteria For Simulator Images: A Literature Review. *Human Factors* 34(6), pp.727-748.

Palmer, I.A. and Bonsal, P.W. (1997). Estimating The Impact Of Time-Based Road User Charges On Risk Taking By Drivers. *ITS Working Paper* 493. Institute for Transport Studies. University of Leeds. UK.

Papelis, Y. (1998). Software Challenges For High Fidelity Driving Simulators. *Paper presented at the IMACS/IFAC International Symposium on Soft Computing in Engineering Applications (SOFTCOM'98).* Athens, Greece. 23 June.

Papelis, Y. (1998a). Update Of University Of Iowa Activities Regarding The National Advanced Driving Simulator. *Paper presented at the IMACS/IFAC International Symposium on Soft Computing in Engineering Applications (SOFTCOM'98).* Athens, Greece. 23 June.

Papelis, Y. and Bahauddin, S. (1998). Rapid Development Of Domain Specific Correlated Databases Using Parametrized Tiles. *Proceedings of the 1998 Image IV Conference.* Scottsdale, Arizona.

Ponds, R.W., Brouwer, W.H., Van Wolffelaar, P. (1988). Age Differences In Divided Attention In A Simulated Driving Task. *Journal of Gerontology* 43, pp.151-56.

Provenmire, H.K., Roscoe, S.N. (1973). Incremental Transfer Effectiveness Of A Ground-Based General Aviation Trainer. *Human Factors* 15(6), pp.534-542.

Pyne, H.C., Dougherty, M.C., Carsten, O.M.J. and Tight, M.R. (1995). A Simulator Based Evaluation Of Speed Reduction Measures For Rural Arterial Roads. *ITS Working Paper* 434. Institute for Transport Studies. University of Leeds. UK.

Ranney, T.A. (1994). Models Of Driving Behaviour: A Review Of Their Evolution. *Accident Analysis and Prevention* 26, pp.733-750.

Rasmussen, J. (1987). The Definition Of Human Error And A Taxonomy For Technical System Design. In J. Rasmussen, K. Duncan, & J. Lepalt (Eds.), *New Technology and Human Error.* Chichester: Wiley.

Reason, J. (1994). *Menschliches Versagen – Psychologische Risikofaktoren Und Moderne Technologien*. Heidelberg/Berlin/Oxford: Spektrum Akademischer Verlag.

Reed and Green, P., (1995). Validation Of A Low-Cost Driving Simulator Using A Telephone Dialling Task. *UMTRI*-95-19. University of Michigan. Ann Arbor.

Reinfurt, D.W., Zegeer, C.V., Shelton, B.J. and Neuman, T.R. (1991). Analysis Of Vehicle Operations On Horizontal Curves. *Transportation Research Record* 1318. pp.43-50.

Reymond, G., Kemeny, A., Droulez, J., and Berthoz, A. (1999). Contribution Of A Motion Platform To Kinaesthetic Restitution In A Driving Simulator. *Paper presented at the Driving Simulation Conference DCS'99*, Paris, France, 7-8 July, pp.123-136.

Riemersma, J.B.J. (1987). *Visual Cues In Straight Road Driving* (unpublished doctoral dissertation). Groningen. The Netherlands: Rijksuniversiteit.

Riemersma, J.B.J. (1989). The Effects Of Transition Curves And Superelevation On The Perception Of Road-Curve Characteristics. *TNO Report. IZF* C-18. TNO Institute for Perception. Soesterberg. The Netherlands.

Riemersma, J.B.J., Van der Horst, A.R.A. and Hoekstra, W. (1990). The Validity Of A Driving Simulator In Evaluating Speed-Reducing Measures. *Traffic Engineering + Control*, pp.416-420.

Ritchie, M.L., McCoy, W.K., and Welde, W.L. (1968). A Study Of The Relation Between Forward Velocity And Lateral Acceleration In Curves During Normal Driving. *Human Factors* 10, pp.255-258.

Roberts, K.M. (1980). The FHWA Highway Driving Simulator. *Public Roads* 44(3).

Rockwell, T.H. (1972). Eye-Movements Analysis Of Visual Information Acquisition In Driving: An Overview. *Australian Road Research Board.* Paper No 948.

Rockwell, T.H. (1988). Spare Visual Capacity In Driving – Revisited. In A.G. Gale, M.H. Freeman, C.M. Haslegrave, P. Smith & S.P. Taylor (Eds.), *Vision in Vehicles II.* Amsterdam: North Holland.

Rolfe, J.M., Hammerton-Frase, A.M., Poulter, R.F., and Smith, E.M.B. (1970). Pilot Response In Flight And Simulated Flight. *Ergonomics* 13, pp.761-68.

Rolfe, J.M. and Staples, K.J. (1986). *Flight Simulation.* Cambridge, England: Cambridge University Press.

Romano, R. and Watson, G. (1994). *Assessment Of The Capabilities Of The Iowa Driving Simulator.* Internal Report, January.

Rothengatter, J.A. and Heino, A. (1994). Safety Evaluation Of Collision Avoidance Systems. In ERTICO (ed.), Towards an intelligent transport system. *Proceedings Of The First World Congress On Applications Of Transport Telematics And Intelligent Vehicle-Highway System.* Artech House, Boston, pp.2047-2054.

Rouse, W.B., Edwards, S.L., and Hammer, J.M. (1993). Modelling The Dynamics Of Mental Workload And Human Performance In Complex Systems. *IEEE Transactions On Systems, Man And Cybernetics*, 23, pp. 1662-1671.

Royal-Dawson, F.G. (1936). *Road Curves For Safe Modern Traffic And How To Set Them Out.* (Spon: London).

Royal-Dawson, F.G. (1938). *Motorways, Flyovers And Mountain Roads.* (Spon: London).

Rumar, K. (1988). In-Vehicle Information Systems. *Intern. Journal of Vehicle Design* 9 (4/5), pp.548-557.

Schlutsmeyer, A.P. (1982). *Wide Area Detection System (WADS).* Report No. FHWA RD-82/144. Federal Highway Administration, Washington, DC.

Scenario (1996). *Workshop On Scenario And Traffic Generation In Driving Simulation.* December 6-7, Orlando, Florida.

Semple, C.A. (1981). Simulator Training Requirements and Effectiveness Study (Stress). *US Air Force Report* AFHRL-TR-80-63.

Shuttel, H.H., Schumacher, S.P., and Gatewood, R.D. (1971). Driver Training Simulators, Ranges And Modified Cars: A Review And Critique Of The Experimental Literature. *American Institute for Research Rept.* AIR-86400-7/71-IR, July.

Smirnov, N.V. (1948). Table For Estimating The Goodness Of Fit Of Empirical Distributions. *Anuuals of Mathematical Statistics* 19, pp.279-281.

Smith, S.A., Purdy, J.E., McBee, H.W., Harwood, D.W., St John, A.D., and Glennon, J.C. (1981). *Identification, Qualification And Structuring Of Two-Lane Rural Highway Safety Problems And Solutions.* Vol.III – Physical and Safety Characteristics of Two-Lane Rural Highways. Unpublished. Appendix. JHK and Associates, Inc. Alexandria, Va.

Solomon, D. (1964). *Accidents On Main Rural Highways Related To Speed, Driver And Vehicle.* Federal Highway Administration, US Department of Transportation, Washington, D.C., July.

Soma, H., Hiramatsu, K., Satoh, K. and Uno, H. (1996). System Architecture Of The JARI Driving Simulator And Its Validation. *Paper presented at the Symposium on the Design and Validation of Driving Simulators.* ICCTP'96. Valencia.

Sommer, B. and Sommer, R. (1991). *A Practical Guide To Behavioural Research: Tools And Techniques.* Third edition. Oxford University Press.

Stapleford, R.L. (1968). Multi-Modality Pilot Models For Visual And Motion Cues. *Proceedings of the fourth annual NASA-University Conference on Manual Control.* University of Michigan. Ann Harbor. pp.47-57.

Staplin, L. (1995). Simulator And Field Measures Of Driver Age Differences In Left Turn Gap Judgements. *Paper presented at the 74th TRB Annual Meeting.* Paper No 950276. January 22-28, 1995. Washington, D.C.

Stein, A.C., Allen, R.W., et al (1995). Application Of Low Cost Driving Simulation. *Paper presented at the Driving Simulation Conference (DSC'97).* Lyon, France, 8-9 Sep., pp.421-435.

Stoner, J.W. (1994). Ground Vehicle Simulator Fidelity And Selection Of Appropriate Applications. *Paper presented at the Driving Simulation Conference*, Palais de Congres, Porte Maillot, Paris, France, 11-14 January.

Stonefield Omicron (1984). *Clip-4 Image Processing Systems*. Issue 1. Omicron Electronics Ltd. Horsham, West Sussex RH12 1DL.

Stonex, K.A. and Noble, C.M. (1940). Curve Design And Test On The Pennsylvania Turnpike. Highway Research Board. *Proceedings of the 20th Annual Meeting*, pp.429-51.

Summalla, H. (1988). Risk Control In Not Risk Adjustment: The Zero-Risk Theory Of Driver Behaviour And Its Implications. *Ergonomics* 31, pp.491-506.

Summalla, H. (1994). *Automatization, Automation, And Control Of Attention Among Car Drivers*. First automation technology and human performance conference, April 7-9. Washington, DC: Catholic University of America.

Summalla, H. (1996). *Accident Risk And Driver Behaviour. Safety Science* 22, pp.103-117.

Taragin, A. (1954). Driver Performance Oh Horizontal Curves. Highway Res. Board. *Proceedings of the 33rd Annual Meeting 33*, pp.446-466.

Taylor, M.A.P. and Young, W. (1988). *Traffic Analysis. New Technology & New Solutions.* J. Anderson (eds.). Hargreen Publishing Company.

Tenkink, E. (1988). Lane Keeping And Speed Choice With Restricted Sight Distances. In T. Rothengatter & R. de Bruin (Eds.), *Road User Behaviour: Theory and Research.* Maastricht, the Netherlands: van Berkum, pp.167-177.

Tenkink, E. (1989). The Effect Of Road Width And Obstacles On Speed And Course Behaviour (in Dutch). *TNO Report IZF* 1989 C-4. TNO Institute for Perception. Soesterberg. The Netherlands.

Tenkink, E. (1990). Effects Of Road Width And A Secondary Task On Speed And Lateral Control In Car Driving (in Dutch). *TNO Report IZF* 1990 C-27. TNO Institute for Perception. Soesterberg. The Netherlands.

Tenkink, E. and Van der Horst, A.R.A. (1991). Effects Of Road Width And Curve Characteristics On Driving Speed (in Dutch). *TNO Report IZF* 1991 C-26. TNO Institute for Perception. Soesterberg. The Netherlands. (cited in Kaptein et al, 1995).

Tharp, K.J. and Harr, M.E. (1965). A Quantitative Evaluation Of The Geometric Aspects Of Highways. *High. Res. Rec.* 83, pp.29-44.

TNO (1978). A Large-Scale Simulation System For The Study Of Navigation And Driving Behaviour. *Documentation Sheet 39e*, May. TNO Institute for Perception. Soesterberg. The Netherlands.

Valverde, H.H. (1973). A Review Of Flight Simulator Transfer Of Training Studies. *Human Factors* 15(6), pp. 510-523.

Van der Horst, A.R.A. (1980). The Use Of Video-Techniques In Traffic Research. *Proceedings of a conference on Manned Systems Design: New methods and Equipment*, September 22-26, Freiburg, Germany, pp.179-190.

Van der Horst, A.R.A. (1990). *A Time-Based Analysis Of Road User Behaviour In Normal And Critical Encounters*. Thesis. TNO Institute for Perception. Soesterberg. The Netherlands.

Van der Horst, A.R.A. (1991). Time-To-Collision As A Cue For Decision-Making In Braking. In A.G. Gale et al. (Eds.), *Vision in Vehicles III.* Amsterdam: Elsevier Science, North Holland.

Van der Horst, A.R.A. and Sijmonsma, R.M.M. (1978). Behavioural Observations At The Demonstration Cycle Routes At The Hague And Tilburg 1: The Development Of A Measuring Instrument (in Dutch). *TNO Report IZF 1978* C-32. TNO Institute for Perception. Soesterberg. The Netherlands.

Van Winsum, W., and Heino, A. (1996). Choice Of Time-Headway In Car-Following And The Role Of Time-To-Collision Information In Braking. *Ergonomics*, 39, pp. 579-592.

Van Wolffelaar, PC., Rothengatter, J.A., and Brouwer, W. (1991). Elderly drivers; traffic merging decisions. In A.G. Gale et al. (Eds.), *Vision in Vehicles III.* Amsterdam: Elsevier Science, North Holland.

Warren, R., and Wertheim, A.H. (eds.). (1990). *Perception And Control Of Self-Motion.* Hillsdale, NJ: Erlbaum.

Waterfall, R.C. and Dickinson, K.W. (1984). Image Processing Applied To Traffic. 2. Practical Experience. *Traffic Engineering + Control* 25(2), pp.60-67.

Weiler, R., Henschen, Dr and Kuhlmann, Dr (1997). Truck Driving School Simulator. *Paper presented at the Driving Simulation Conference (DSC'97*). Lyon, France, 8-9 Sep., pp.251-258.

Weir, D.H. and Clark, A.J. (1995). A Survey Of Mid-Level Driving Simulators. *SAE* 950172.

Weir, D.H. and Wojcik, C.K. (1971). Simulator Studies Of The Driver's Dynamic Response In Steering Control Tasks. HRB, *Highway Research Record* 364, pp.1-15.

Weir, D.H. and McRuer, D.T. (1968). A Theory For Driving Steering Control Of Motor Vehicles. *Highway Research Record* 247, pp.7-28

Weir, D.H. and McRuer, D.T. (1973). Measurement And Interpretation Of Driver/Vehicle Dynamic Response. *Human Factors* 15, pp.367-378.

Wheaton, G.R., Kinslow, W.E., and Krumm, R.L. (1966). Validation Of A Part-Task Automobile Driving Simulator. *Radio Corporation of America* Contract No. PH 108-64-167.

Wickens, C.D., Todd, S., and Seidler, K. (1989). *Three-Dimensional Displays: Perception, Implementation And Application* (Report CSERIAC-SOAR-89-001). Dayton, OH: University of Dayton Research Institute.

Wierwille, W.W. (1973). A Part-Task Driving Simulator For Teaching And Research. Trans., Computers In Education Division, *American Soc. For Engineering Education*, Vol.5, Dec., pp.193-203.

Wierwille, W.W., Hulse, M.C. Aritin, J.F., and Dingus, T.A. (1988). Visual Attentional Demand Of An In-Car Navigation Display System. In A.G. Gale, M.H. Freeman, C.M. Haslegrave, P. Smith & S.P. Taylor (Eds.), *Vision in Vehicles II.* Amsterdam: Elsevier Science, North Holland, pp.307-316.

Wierwille, W.W., Hulse, M.C., Fischer, T.J., and Dingus, T.A. (1988). Safety Aspects Of CRT Touch Panel Controls On Automobiles. In A.G. Gale, M.H. Freeman, C.M. Haslegrave, P. Smith & S.P. Taylor (Eds.), *Vision in Vehicles II.* Amsterdam: Elsevier Science, North Holland, pp.335-344.

Williges, B.H., Roscoe, S.N. and Williges, R.C. (1973). Synthetic Flight Training Revisited. *Human Factors* 15(6), pp.543-560.

Wojcik, C.K. and Weir, D.H. (1970). Studies Of The Driver As A Control Element -Phase 2. Report No 70-J73. *Institute of Transp. and Traffic Eng.* Uni. of California. L.A.

Wong, Y.D. and Nicholson, A. (1992). Driver Behaviour At Horizontal Curves: Risk Compensation And The Margin Of Safety. *Accident Analysis & Prevention* 24(4), pp.425-36.

Zeeger, C., Stewart, D., Reinfurt, D., Council, F., Neuman, T., Hamilton, E., Miller, T. and Hunter, W. (1990). *Cost-Effective Geometric Improvements For Safety Upgrading Of Horizontal Curves.* Report FHWA-RD-90-021. FHWA, U.S. Department of Transportation.

Appendices

Appendix 4-1 Literature review - speed on curves

Riemersma (1989) in his literature review about driver's behaviour on road curves concluded that "*the design of curves is not related to curve driving behavioural studies*" but "*is based mainly on considerations of the mechanics of pavement-car interactions*".

A historical review of the horizontal alignment design policies shows that the first policies were based on the assumption that vehicle/driver behaviour is consistent along the curve (and unfortunately the same assumption has been carried forward to current design standards). Only a few direct observations of road user behaviour (Stonex and Noble, 1940) were taken into account in the early design policies and by that time (1920-1950) the basic design standard was the side friction (comfort criterion). The early empirical studies on vehicle/driver behaviour had concentrated on speed measurements at the mid-point of the curve only.

Taragin (1954) was the first one who used observed vehicular speeds on circular curves and attempted to relate the measurements to geometric features carried out. He was the first to question the validity of the constant speed design assumption by comparing vehicle speeds measured at several sites around a road curve. His conclusion was that "*Drivers of free-moving passenger cars do not change their speeds appreciably after entering a horizontal curve even when the curvature is as sharp as 15 degrees. Most of the adjustment in speed that is made, whether because of curvature, limited sight distance, or other reason, is made on the approach to the curve*".

A number of studies carried out after his pioneer research and their results were contrary or almost contrary to his final conclusion about drivers' speed selection before entering the curve. Some of these studies are presented here in brief.

Kneebone (1964) measured speed distributions before and after advisory speed signs were erected at a curve in New South Wales. The distributions revealed a relatively small speed change within the centre of the curve.

Tharp and Harr (1965) measured approach speeds on three circular curves and compared them with a theoretical speed based on a "continuum" model of traffic flow. Their conclusion was that for very small radii curves "*the vehicles continue their deceleration at a more progressive rate as the feature is approached and when the minimum speed is reached (at approximately the centre of the turn) the vehicle immediately undertake an acceleration*". Similar results were reported by an earlier study of Leeming and Black (1950).

Emmerson (1969) measured speed on curves with radius smaller and greater than 100m. He found that for the first category, drivers decrease their speed while negotiating the curve where for the second category there was no reduction in speed.

Holmquist (1970) reported that "... *the speed adaptation did not cease at the end of the straight road section, but continued after the entrance of the vehicle into the curve... These studies showed that the deceleration before and the acceleration after the curve were mirror reflections of each other. Furthermore, the measurements indicated that the speed was approximately constant along a road section over the central part of the curve. The length of this road section was on average equal to one of the arc length of the curve*".

Neuhardt, Herrin and Rockwell (1971) measured speed distributions over a one-mile section of highway containing curves of 380 ft, 440 ft and 640 ft radii under a relaxed and an emergency driving scenario. In the first case (relaxed scenario) the minimum speed was reached some distance beyond the centre of the curve whereas in the second one, the minimum speed was reached at the centre of the curves.

McLean (1974) research showed that "... *vehicles generally decelerate through the approach half of the curve, reaching their minimum speed on the departure side of the curve centre. Passenger cars tended* *to accelerate through the remainder of the curve, while commercial vehicles maintain minimum speed*". This behaviour corresponds with that reported by Neuhardt et al (1971).

Glennon et al (1985) measured free-flowing vehicle speeds in 60 curve approaches. They found that the sharpness of the impending curve was the factor most associated with speed changes by the drivers. Drivers tended to begin adjusting their speeds only as the curve became imminent, and speed reduction increased linearly with increasing degree of curve. Only a slight difference in speed changes was found for narrow versus wide roadways.

Mintsis (1988) studied vehicle speed distributions on single and dual carriageway curves with radii of less than 500 m. Speeds were measured on entry, apex and exit of the curves for both directions (although no speed difference was found between them). He found that the pattern of variation in vehicle speeds around the curves is highly dependent on the level of curvature. Especially "*on high curvatures with R<220 m car speeds appeared to vary considerably throughout single and dual carriageway curves reaching a minimum value near the centre curve. A more constant car speed variation was observed for large radius curves where speed adjustments mainly occurred before the curve entry*". No particular trends were noted for either left or right hand curves.

Reinfurt, Zeeger, Shelton and Neuman (1991) measured speed 250 ft before the midpoint and at the midpoint of 78 curves. They found that "*average speed reduction and edgeline encroachments on curves to the right appear to be positively associated with degree of curve for curves about 5 degrees. As curves become sharper, there is a proportionally greater increase in speed reduction and edgeline encroachments for curves to the right. Centreline encroachments on curves to the left also increase more drastically than those on curves to the right*". Their results are in accordance with Zeeger at al (1990) results of accident analyses and Glennon et al (1985) findings of driver cutting-off the centreline on sharp curves.

The literature review of speed on curved road sections showed that researchers do not exactly agree on how drivers perceive curves and consequently adapt their driving behaviour when traversing it. Real road measurements have not concluded to a driving behaviour model due to all these controversies. The innovation of this field study is that driving behaviour is recorded along the whole length of the curve at four distinctive points and not only in the apex of the curve (as it is the common practice). This enables us to monitor not only driving behaviour in a continuous basis but also the same driver's behaviour.

Literature review - Speed on straights

Two fundamental mathematical models have been developed to describe driver's behaviour on straight roads: a linear "cross-over" model (Weir and McRuer, 1968, 1973; McRuer and Weir, 1969; McRuer et al, 1977) and a non-linear model (Baxter and Harrison, 1979). These models are primarily related to steering behaviour than speed behaviour.

When driving on a straight road with no external disturbances, driver's input can be considered as essentially visual and his output a steering wheel displacement and any disturbance as driver-induced (Baxter and Harrison, 1979).

Literature review - Lateral position of vehicles

Emmerson (1969) in his study for speeds of cars on sharp horizontal curves observed that "*many cars on curves of radius less than 500 ft sought to increase the curvature of their path by cutting the curve corner, and although those vehicles crossing the road centreline were not recorded many other cars had shift of 2 and 3 ft in lateral placement between the beginning of the curve and its centre...*". It is not known whether the study curves had spiral transitions or not. He also found significant reduction of speed on the sharp curves at virtually all speed levels.

Neuhardt et al (1971) found that path curvatures were typically lower than the roadway curvature, decreased with increased lane width and increased with increased curve length. They also observed that drivers crossed the road centreline more often from the outside lane than the inside lane.

Glennon and Weaver (1971) investigated vehicle path curvatures by using photographic techniques. They found that for virtually all vehicles, the vehicle path curvature at the point of maximum friction demand (for most cases in the first or last quarter of the curve) exceeded the centreline curvature of the road. They attributed this to difficulties in making the transition from tangent to curve on the unspiraled study curves.

McLean (1974) in his overview of the existing curve negotiation studies concluded that speed on curves is influenced by the curve radius and sight distance and corner-cutting strategies are common on small radius curves.

Johnston (1983) also reported a corner-cutting strategy based on an assessment of the vehicle position at the curve mid-point and he noted a significant effect of curve geometry on driving performance, especially on speed and lateral acceleration.

Glennon et al (1985) measured lateral placement of vehicles in five horizontal curves. They found that some drivers overshoot the curve radius producing minimum vehicle path radii sharper than the highway curve. This tendency was found to be independent of vehicle speed.

Reinfurt et al (1991) found that "*As curves become sharper, there is a proportionally greater increase in edgeline encroachments for curves to the right. Centreline encroachments on curves to the left also increase more drastically than those on curves to the right*". Their results are in accordance with Glennon et al (1985) findings of driver cutting-off the centreline on sharp curves.

Wong and Nichoson (1992) studied drivers' behaviour on curves before-and-after their realignment. They found that path radius can be significantly different from the curve radius and estimates of the required side friction ought to be based upon the path radius. On the other hand Taragin (1954) and McLean (1983) when studied drivers' behaviour on horizontal curves, they assumed that path radius and curve radius are much the same, thus they estimated the required side friction using the curve radius. It has to be mentioned here that McLean didn't find any empirical evidence that drivers respond to actual or subjectively predicted side friction in selecting their speed around a curve.

Appendix 4-2 Literature review of data collection methods

Traditional traffic engineering methods

The traditional traffic engineering methods for monitoring vehicle movement include mainly the collection and measurement of spot speed data as well as some other vehicle characteristics but not the measurement of lateral position. These methods are distinguished into two main categories: the direct and the indirect (Taylor and Young, 1988). The direct ones enable measuring speed directly on the basis of the Doppler principle (such as radar meters) and the indirect involve the estimation of speed from a travel time observation such as the enoscope (Kennedy, Kell and Homburger, 1973), the electronic timing and vehicle detectors.

Vehicle detectors were first introduced in Baltimore in 1928 and worked with sound. Since then the development of vehicle detectors has been rapid and nowadays they fall into two main categories: a) the presence detectors (Fraser, 1984) including the inductive loops and the traffic counter/classifier by "Nu-Metrics" and b) the passage detectors including the pneumatic tubes, the treadle switches, the "Jarvis brick", the triboelectric or "noisy" cable and the piezoelectric cable (Dods, 1987).

The most common vehicle detectors are inductive loops and pneumatic tubes. Much of the research into the effect of visible detectors on driver behaviour has proved to be inconclusive, i.e. it is not exactly known if they affect adversely driver behaviour when they are visible (Holmes, 1939; Hulscher, 1974; Johnston and Fraser, 1983; Armour, 1984; Dods, 1987; Barbosa, 1995).

However, none of the above mentioned methods was specifically developed for the simultaneous measurement of speed and lateral position of the detected vehicle. Nowadays, this can become reality with the use of video imaging vehicle detection systems. As an alternative way, an instrumented vehicle can play the role of the detected vehicle itself using again part of the video imaging technology. The main difference between the use of video cameras and the use of instrumented vehicles is the type of observation requested by the researcher: in the first cases the researcher will obtain uncontrolled observational data and in the second case partially controlled experimental data.

Instrumented vehicles

The use of instrumented vehicles as a "general purpose" driving laboratory for road user studies has increased gradually since 1960. At that time, conventional electronics and tape recording were used to meet basic data monitoring and storage requirements (Michon and Koustaal, 1969). In recent years, the development of microprocessor and microcomputer technology stimulated the use of flexible data acquisition systems in instrumented cars (Blaauw and Burry, 1980; Allen, Hogue, Rosenthal and Parseghian, 1988).

An instrumented vehicle provides quick and standardised procedures to set up and execute experiments. It can be equipped with the appropriate devices so that any vehicle motion characteristics such as forward velocity, distance travelled, rotational velocities, lateral position on straight and curved roads can be measured easily. Road geometry can be measured. It is able to record drivers' head and eye movements, drivers' performance when they have to react to specific auditory or visual stimuli and drivers' reactions (e.g. acceleration, deceleration, braking, changing lane etc.) to different traffic situations. Also several physiological variables can be measured (e.g. heart rate, respiration rate, galvanic skin response) (Blaauw and Riemersma, 1975).

On the other hand their utilisation has disadvantages in the area of driver behaviour, such as the unfamiliarity of subjects with the vehicle, the presence of the experimenter and the technician inside the vehicle (although not always, in modern instrumented vehicles the subject drives the vehicle alone and data is recorded automatically) and the knowledge that an experiment is taking place. Overall, an instrumented vehicle driven on a test track is more close to an artificial environment (as the simulator environment is) than to the real world (road environment). To the author's knowledge there are no studies comparing data taken from instrumented vehicles and genuine real road data in order to investigate: a) the influence of the experimenters inside the vehicle and/or b) the influence of driving an unfamiliar vehicle on a test track without the presence of other road users to driver's behaviour.

Instrumented vehicles have been widely used lately for real road data collection, since they seem to increase the accuracy of the data and make the comparison with the simulator data easier. However it is not exactly known the difference in accuracy between the road data collected by traditional traffic engineering methods and the one collected by instrumented vehicles, neither it is known the effect of drivers' awareness that they participate in an experiment on their behaviour on the road. Lately, video recording systems are used to monitor driving behaviour along the road network.

Video data collection and analysis systems

Video analysis of road traffic scenes is appropriate for studying interactions between road users themselves, between road users and the environment or for observing behaviour in terms of vehicle movements.

Main advantages of video recording include: a) the provision of a complete, permanent record of the traffic flow, which can always be re-analysed and re-examined at a later stage and b) additional information (e.g. vehicle classification, headway, overtaking etc.) can be obtained. The disadvantage is that a considerable period of time is needed after the survey, to extract the data from the video record (it has been estimated that data from one videotape results in ten hours of analysis from an experienced researcher, using video analysis software). Manual methods tend to be tedious and expensive, so the technique is still not particularly useful for routine surveys.

Video analysis is a method recommended by a number of researchers for the investigation of driver behaviour and performance, in terms of practical aspects and potential for future technical developments (van der Horst and Sijmonsma, 1978; Ashworth, 1976; Dickinson and Waterfall, 1984; Waterfall and Dickinson, 1984; Dods, 1987; Taylor and Young, 1988). However, it is mainly used nowadays for parking surveys, origin-destination surveys, turning movements, automatic incident detection, motorway detection/surveillance/management, motorway ramp control, vehicle counting/classification, collection of traffic signals, wrong-way detection and queue length analysis.

Dods (1987) refers to a number of video analysis systems, has separated them accodingly into semi-automated and fully automated systems. In the first category fall VISTA, developed by Wotton and Potter (1981) and VIDARTS developed by the TNO Institute for Perception (van der Horst, 1980). In the second category fall a) a system developed by the Department of Electrical Engineering at UMIST called WADS (Wide Area Detection System) (Schlutmeyer, 1982), b) a system developed by University College London called CLIP (Cellular Logic Image Processor) fully described by Stonefield Omicron (1984) and briefly described by Dods (1985), c) a system developed by Takaba and Ooyama (1984) and d) the ARRB VVD (the Australian Roads Research Board Video Vehicle Detection system) (Dods, 1987).

Recent video imaging vehicle detection systems include ViVAtraffic (Hupfer, 1996), Autoscope™ wide area video vehicle detection system by Image Sensing Systems, Golden River traffic information and management systems and Peek Traffic Video Track®-900 Image Processing System by Peek-Traffic Ltd.

However of the above mentioned systems, only the ViVAtraffic system specialises in the areas of driving behaviour and traffic safety (whereas the other systems are mainly used for motorway surveillance). By the time of the study, ViVAtraffic was the most publicised video analysis software on the market for observing driver behaviour and measuring driver performance. Thus it appeared to be the most applicable to the study and it was decided to be considered for the analysis of the video data.

Appendix 4-3 ViVAtraffic software

The development of ViVAtraffic began in 1986. ViVAtraffic consists of an IBM-compatible PC, a special video card (a frame grabber), and the software. The basis of the system is a projective model. By means of this model a point on the street can be related to a respective point on the screen. Thus, all points on the street plan which can be seen in the video picture are known. A prerequisite for the usage and best accuracy of this model is the calibration of the cameras, i.e. four points *on the street* must be known and be recognisable on the screen. Of these four points, two points must lie on one line. The best accuracy is given when measuring a 4 x 90 degrees rectangle with sides of 3 x 4 meters because it is the easiest one to be measured on the street with no need of any surveying tools (e.g. theodolite), just by using a measuring tape.

The measurement of speed, acceleration and lateral position using ViVAtraffic is very easy. For speed, two different pictures are required, for acceleration three and for lateral position one. For the measurement of lateral position a line is drawn parallel to the line from which we want the measurement (e.g. a line parallel to the edge white line of a rural road or the edge of the sidewalk) and the orthogonal distance between that line and the vehicle (or pedestrian) is measured automatically. The automatic classifying and counting of vehicles is derived from the differences between two pictures. By subtracting the pictures, unchanged spots have a sum of 0, spots with changes (movements) have a value larger than 0.

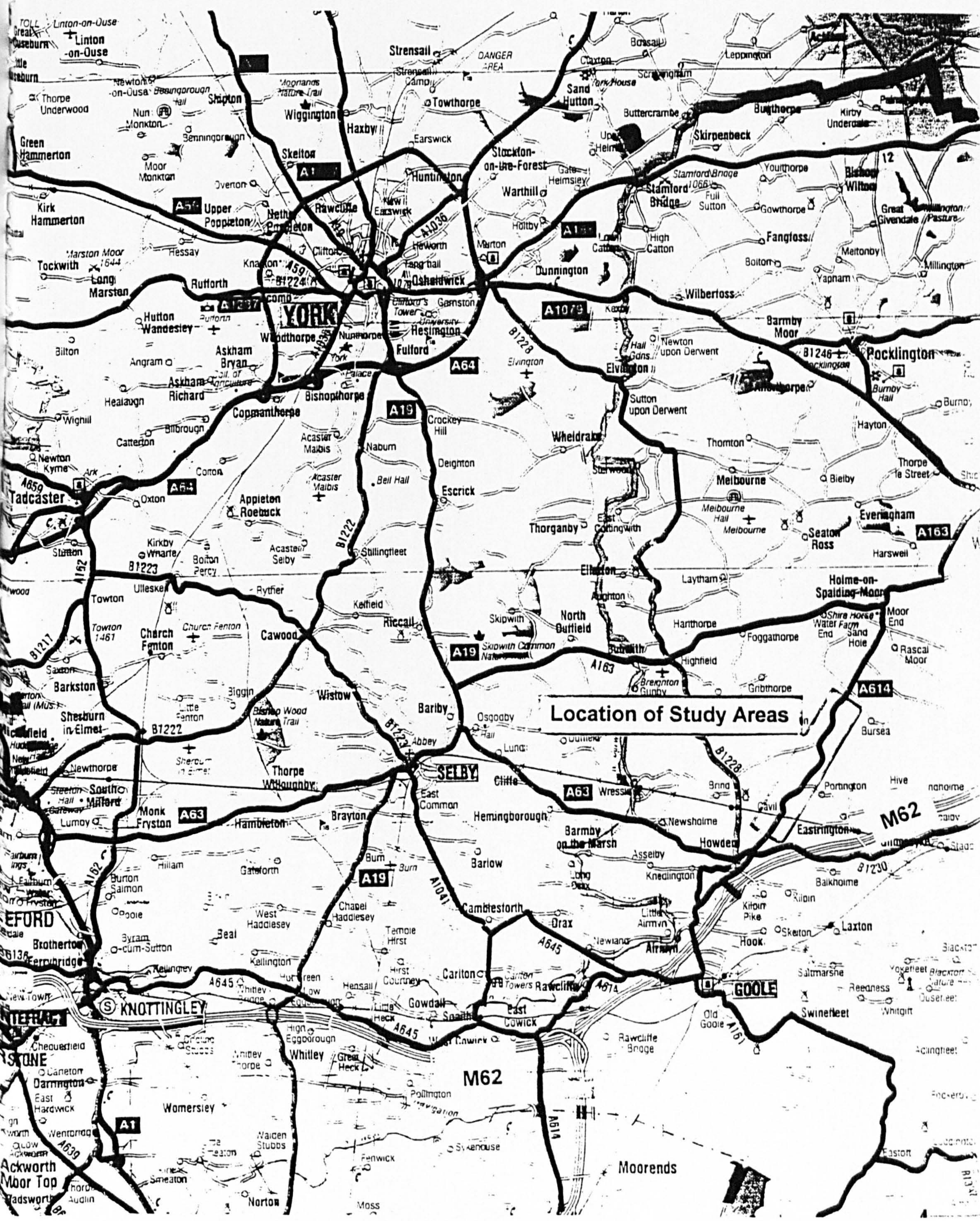
ViVAtraffic can be used for:

a) measuring distances (variable and orthogonal), speeds and accelerations;
b) automatic classifying and counting vehicles; and
c) analysing traffic conflicts in video pictures (it can plot road users' paths, e.g. vehicles, pedestrians etc.).

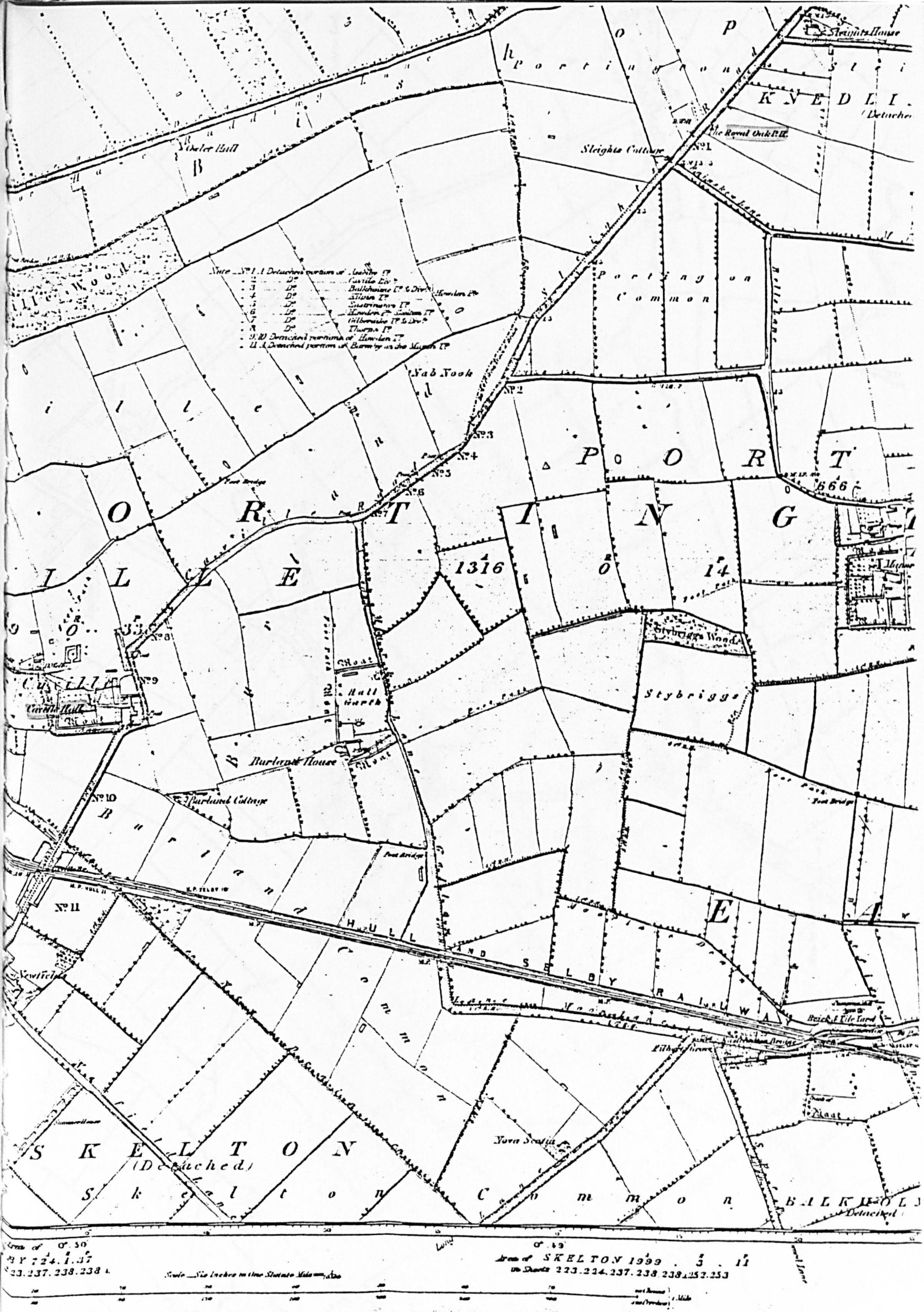
The picture evaluation in ViVAtraffic is restricted to a number of lines. The operator must secure two points as basis of a line, on which the system carries out the automatic analysis of the pictures. This line must lie on the road in such a position, so as to be "over-run" by most of the vehicles. This way the system recognises the vehicles, measures their lengths (i.e. the length of the vehicle in the picture which later is used for classifying the vehicles in the evaluation) and speeds as well as the time gaps between vehicles (which are directly related to and provide information on traffic flow and traffic quality) and then saves the data and the measured times. A problem arising from this automatic analysis is that the length of the vehicle in the picture is not very accurate. Passenger cars can be classified easier since it is known to have a length of 3 or 4 meters, whereas vehicles falling in the category of 5 and 6 m cannot be classified into a specific category (e.g. are they vans, trucks?). Transport means of 1 and 2 m may be bicycles or motorcycles or just a fault in measurement. In other words no accurate vehicle classification can be made.

The main disadvantage of this software is that although data is recorded automatically, measurements must be handled manually from the operator, when the user needs to record data at specific data points. The system does not have the ability to measure e.g. speed at specific points of the road and the only way is to go image by image and even so there is a possibility that there will be no accurate measurement in that specific point because there was no image captured at that moment.

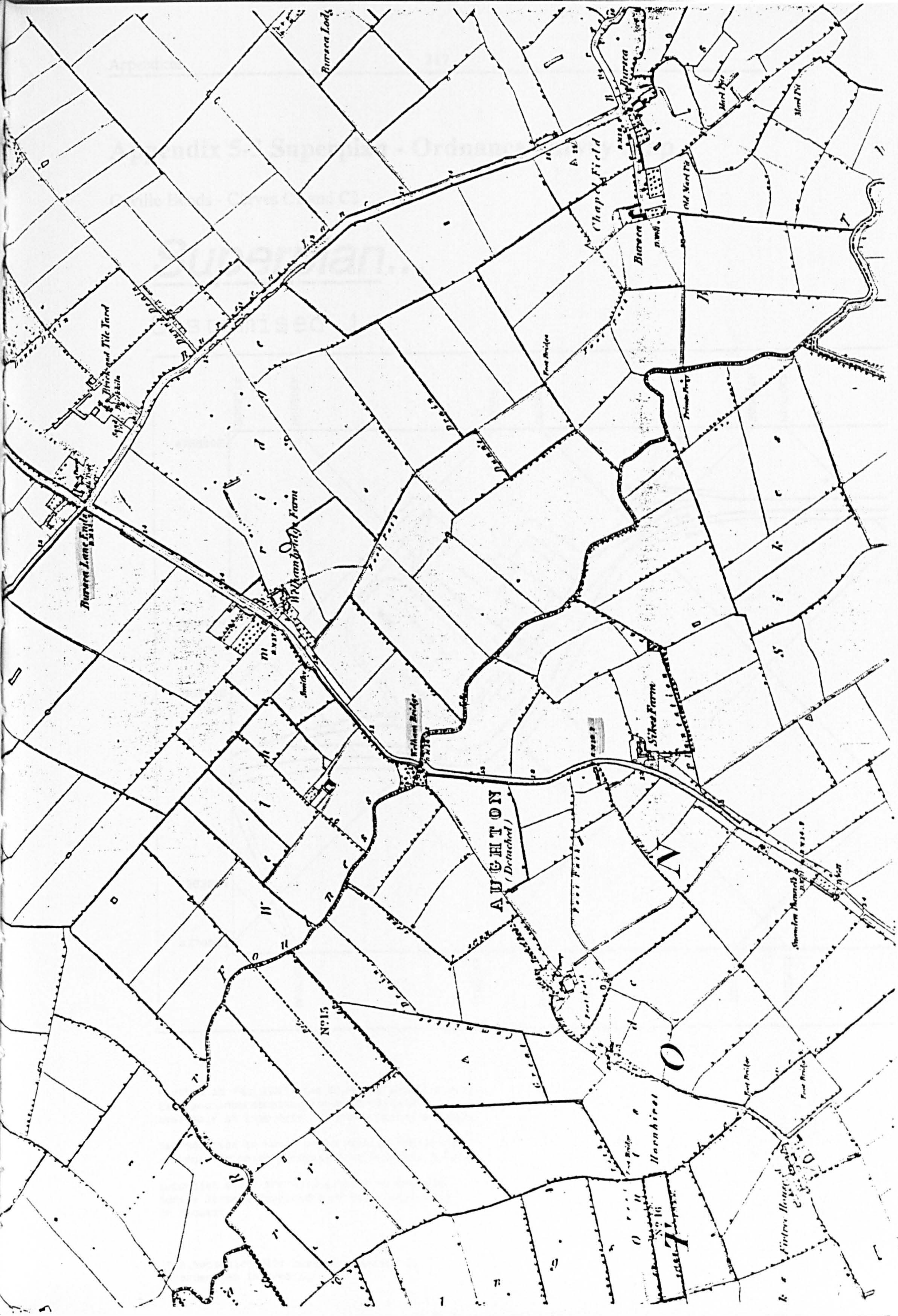
Appendix 5-1 Map of the area



Appendix 5-2 The 1855 Ordnance Survey Map



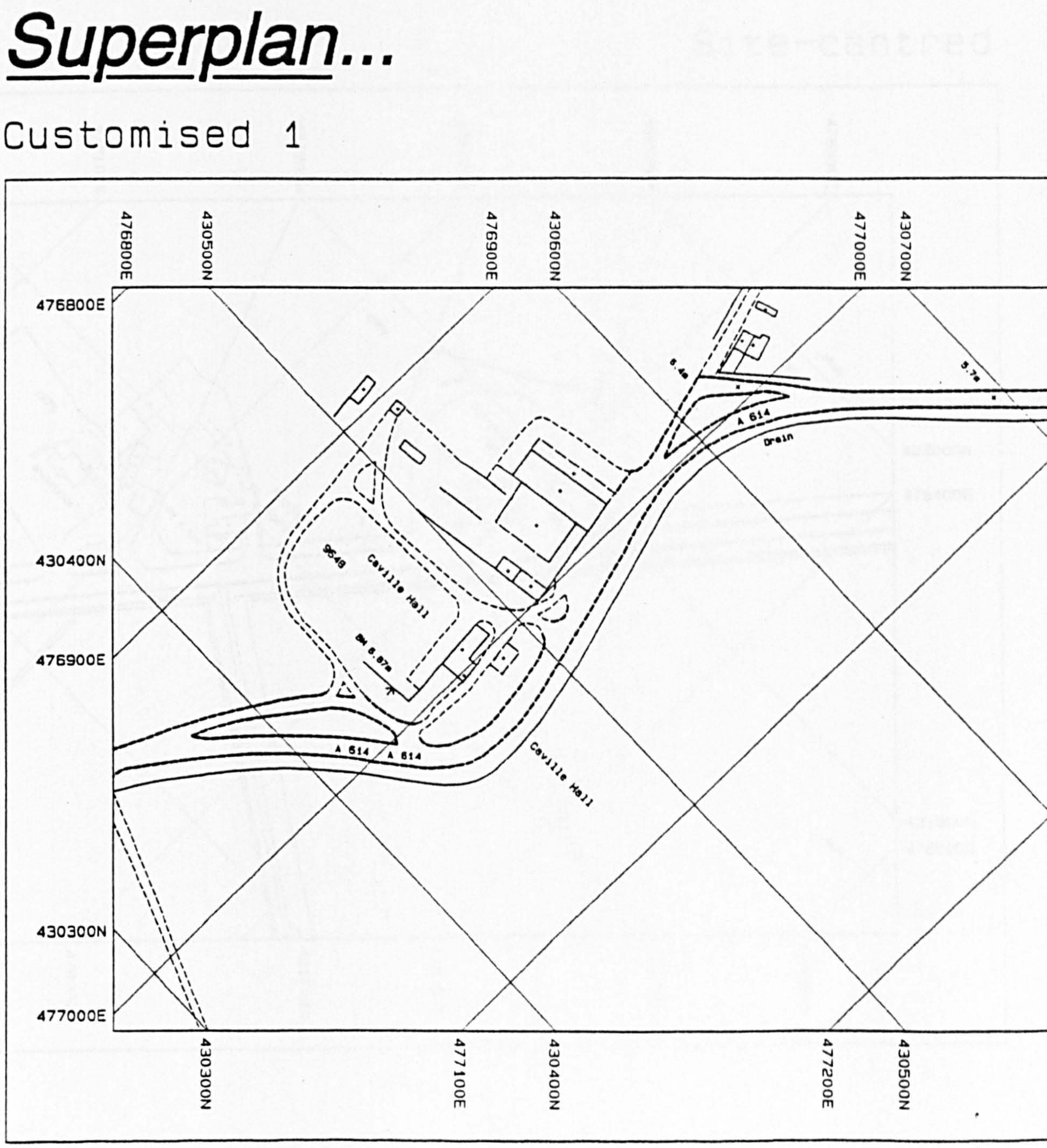
Sleights House
Portington
KNEDLI
(Detached
The Royal Oak P.H.
Sleights Cottage
No.1
Portington Common
Nab Nook
No.2
No.3
No.4
No.5
No.6
No.7
PORTINGTON
1316
666
Foot Bridge
Stybriggs Wood
Stybriggs
Moat
Hall Garth
Burland House
Burland Cottage
No.8
No.9
No.10
No.11
Castle Hall
HULL AND SELBY RAILWAY
Brick & Tile Yard
Nova Scotia
Moat
SKELTON
(Detached)
Skelton Common
Detached
Area of SKELTON 1999 . 3 . 11
Scale — Six Inches to One Statute Mile



AUGHTON
(Detached)
Brick and Tile Yard
Chapel Field
Marl Pit
Old Marl Pit
Foot Bridge
Foot Path
No 15
No 16

Appendix 5-3 Superplan - Ordnance Survey Map

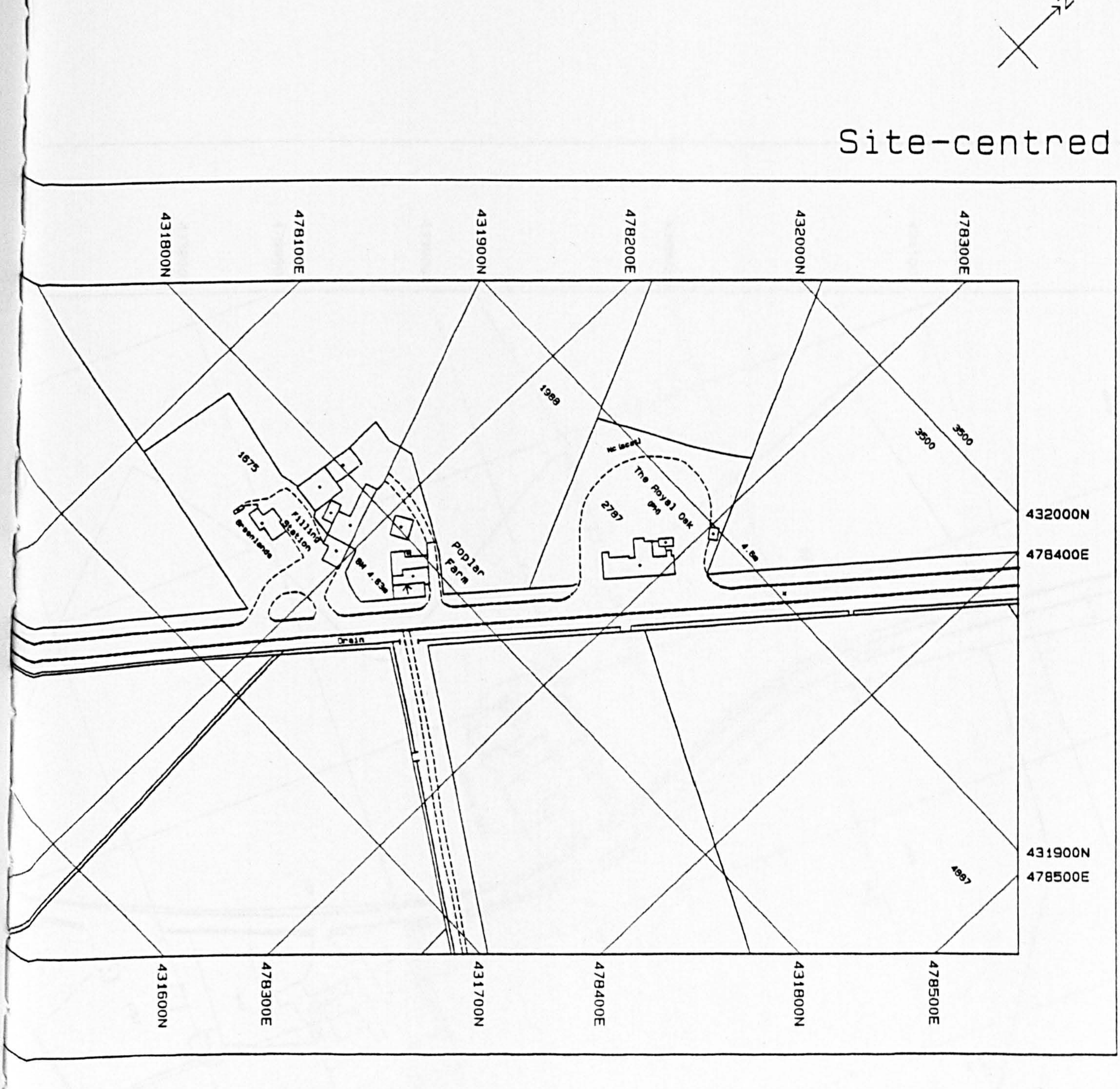
Caville Bends - Curves C1 and C2



Plotted 15 Feb 1996 from Ordnance Survey digital data and incorporating surveyed revision available at this date. © Crown Copyright 1996.

This Superplan Plot does not contain all recorded map information.

The Royal Oak Pub - Straight 1



National Grid sheet reference at centre of this Superplan: SE7731

The representation of a road, track or path is no evidence of a right of way.

Heights given in metres above the Newlyn Datum.

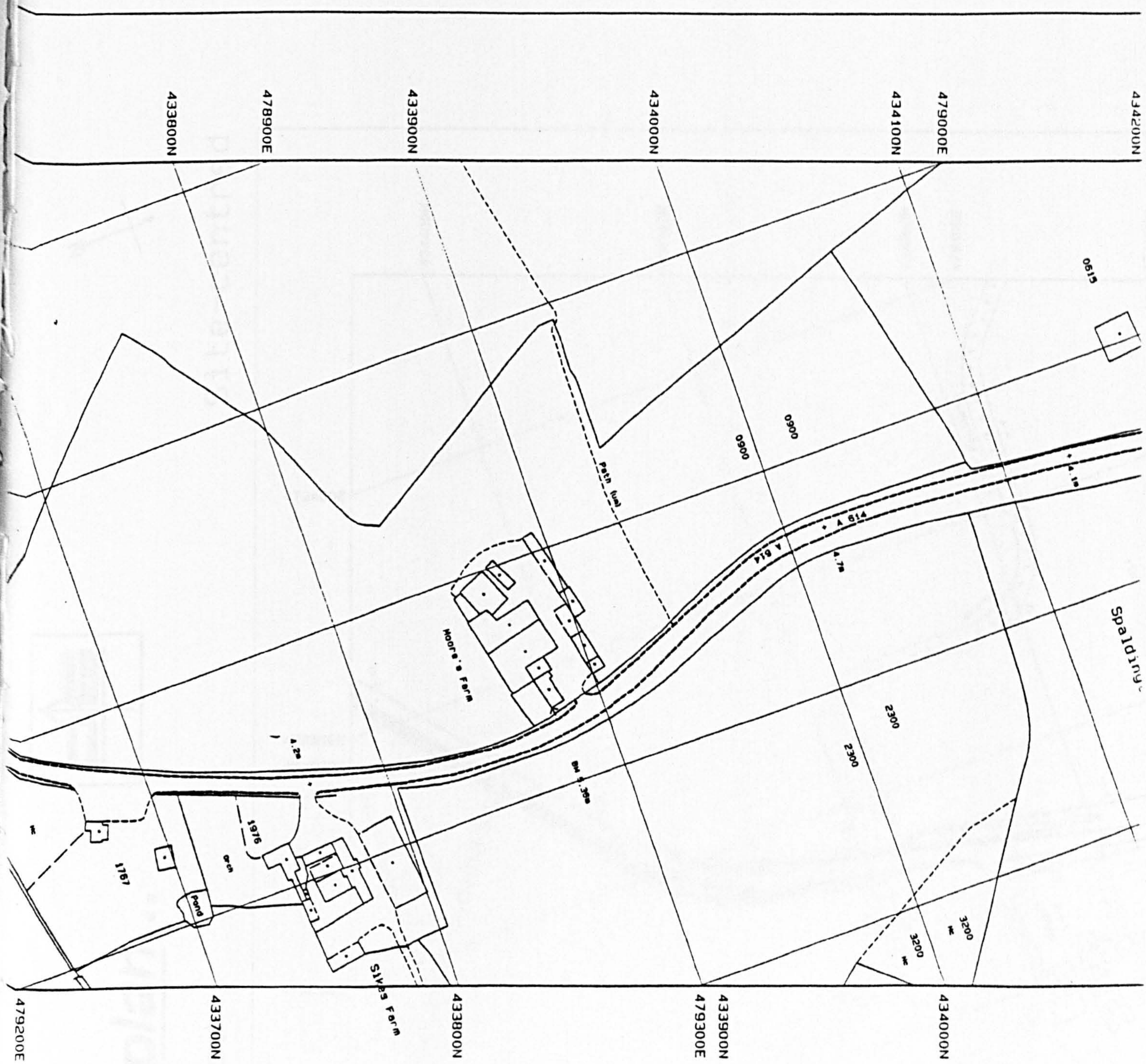
The alignment of tunnels is approximate.

Plot Centre Coordinates: 477660 431171

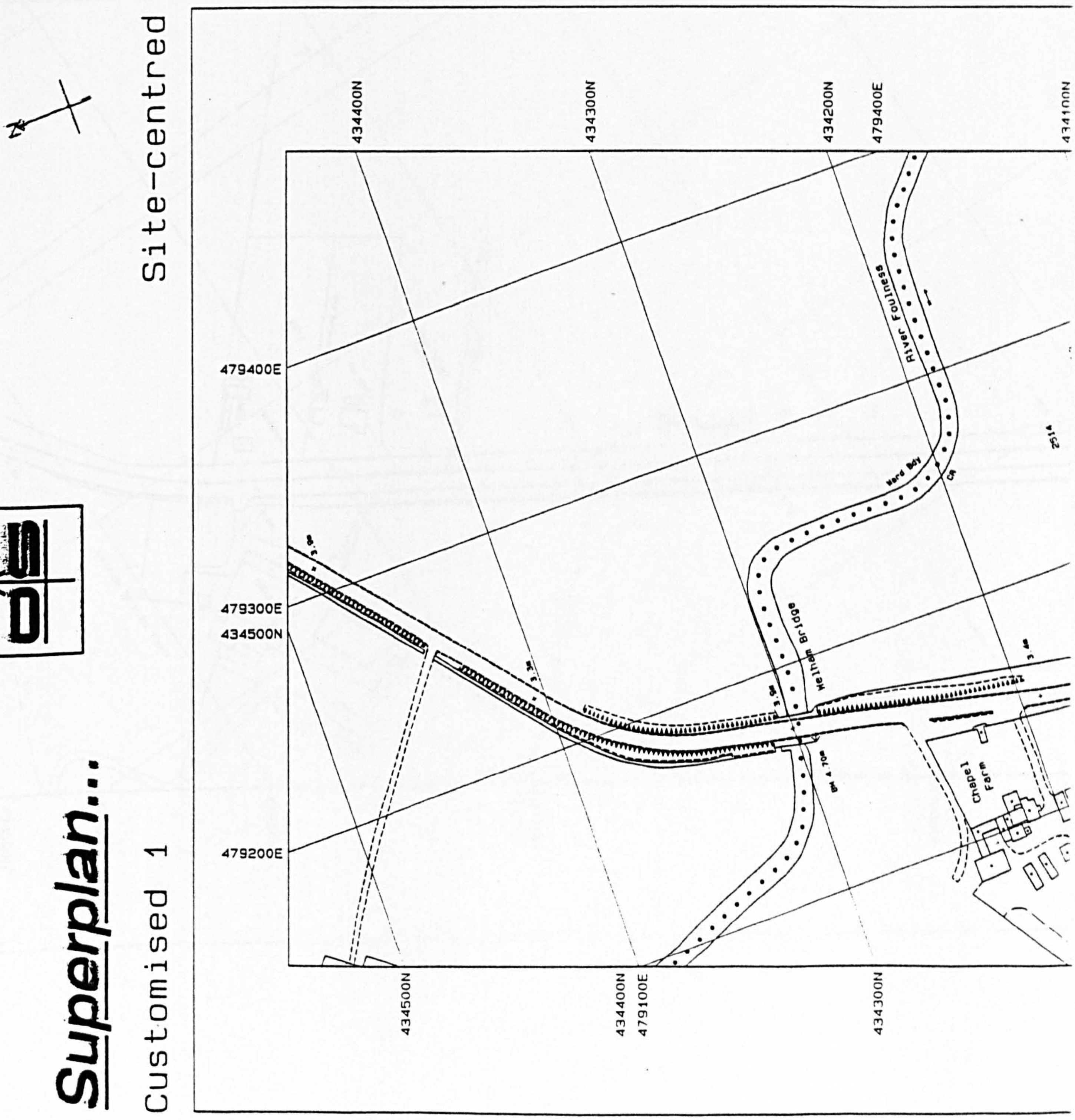
Supplied by: Waterstone's Manchester

Plot Serial Number: 12597

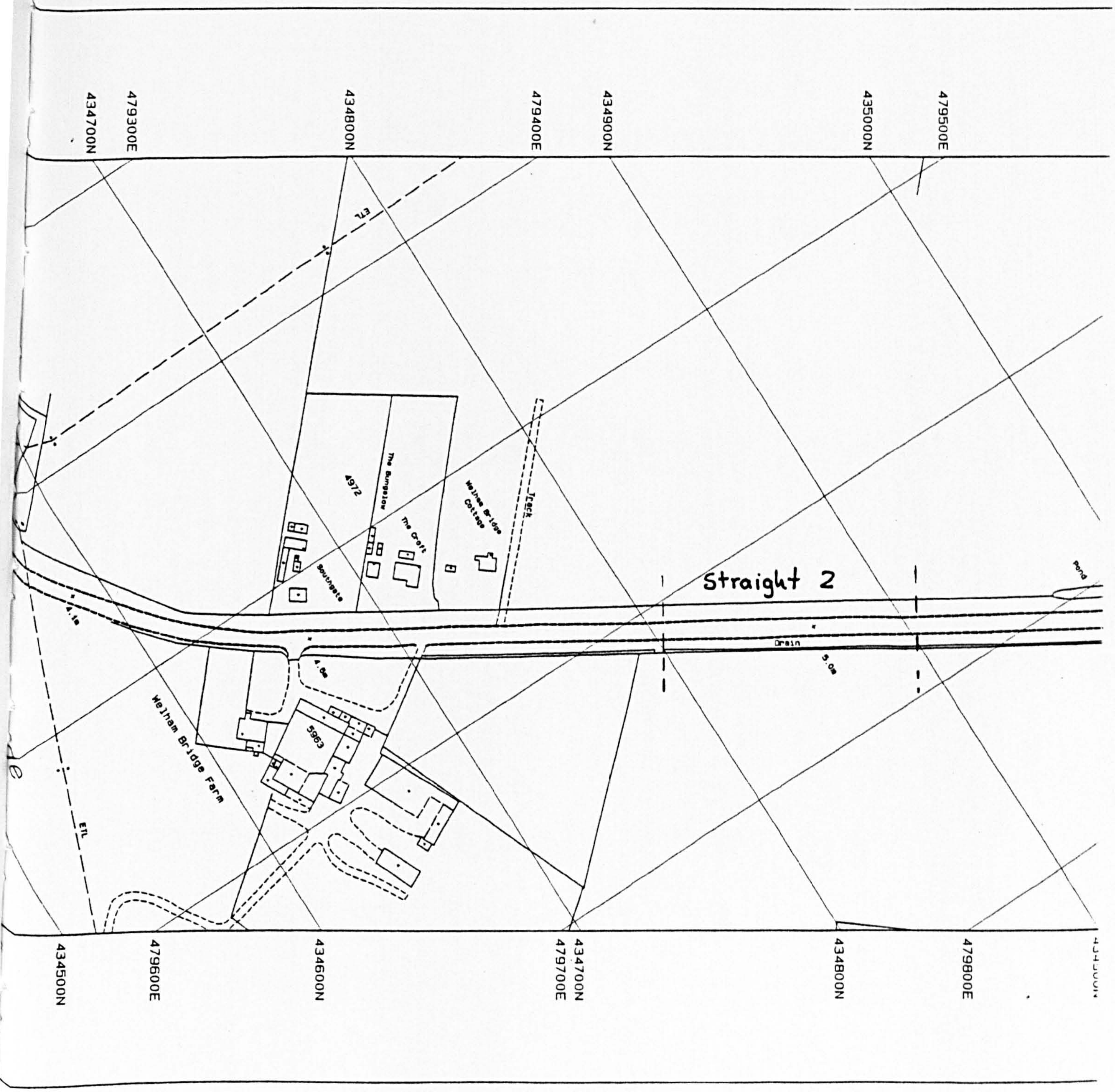
Moore's Farm - Curve C3



Welham Bridge - Curve C4



Straight 2


434700N
479300E
434800N
479400E
434900N
435000N
479500E
ETL
The Bungalow
4972
The Croft
Welham Bridge Cottage
Track
Southgate
Straight 2
Pond
Drain
Welham Bridge Farm
5963
434500N
479600E
434600N
434700N
479700E
434800N
479800E

Appendix 5-4 Speed and lateral position real road data

Site 1 - Moores Farm/Welham Bridge, A614 Howden - Monday 13 May 1996

1916y ab1 bf57 ID	Speed at Point 6 km/hr	Lateral Distance at Point 6 mm	Opposing Traffic at Point 6	Speed at Point 15 km/hr	Lateral Distance at Point 15 mm	Opposing Traffic at Point 15	Speed at Point 7 km/hr	Lateral Distance at Point 7 mm	Opposing Traffic at Point 7	Speed at Point 8 km/hr	Lateral Distance at Point 8 mm	Opposing Traffic at Point 8	Speed at Point 9 km/hr	Lateral Distance at Point 9 mm	Opposing Traffic at Point 9	Speed at Point 10 km/hr	Lateral Distance at Point 10 mm	Opposing Traffic at Point 10
1	69.80 *	684	yes	65.60	1339		77.40	932		87.30	955		89.20	1038	yes	99.30	1003	
2	66.50 *	713		63.70	943		72.20	770		89.90	1091		90.30	1050		92.90	926	yes
3	74.40 *	900		65.70	1082		77.40	649		98.10	1023		96.10	1050		90.00	1123	
4	84.70 *	656		86.60	1896		93.20	1249		99.30	1336		110.70	1350		112.30	1200	
5	65.40 *	1022		61.90	1350		74.70	1014		81.70	1036		84.70	1142	yes	87.80	951	
6	70.80 *	1022		56.70	600	yes	65.60	762		80.30	859		87.20	865		96.20	686	
7	63.50 *	666		61.90	1029		74.70	689		80.20	1173		77.80	1292		89.10	1089	
8	67.50 *	703		63.70	1307		74.70	1046		80.90	1050		78.30	842		88.20	857	
9	62.60 *	975		60.20	1146		74.30	981		81.20	1186		82.30	1177	yes	87.30	823	yes
10	80.00 *	994		65.40	1104		64.70	1014		90.30	1105	yes	92.90	969	yes	106.60	857	
11	60.20 *	713		57.30	1125		63.70	924		74.10	900	yes	73.80	1096		92.30	1037	
12	72.50 *	863		61.90	1404		74.10	576		91.20	1200		92.90	1223		96.30	1140	
13	72.10 *	713		72.20	1521		76.90	559		80.30	845	yes	80.00	819		87.20	609	
14	57.60 *	816		59.40	1125		65.60	949		69.90	995	yes	70.30	935		75.50	969	
15	72.40 *	497	yes	67.70	921	yes	78.10	576		89.70	723		92.40	877		101.30	806	yes
16	67.50 *	741		60.20	1189		72.20	908		85.10	886		84.70	831		80.00	891	
17	63.50 *	666		60.80	1221		69.10	932		81.30	941		80.10	969		90.30	900	
18	80.40 *	891		74.70	1243		76.60	778	yes	91.40	995		90.30	946		102.30	823	
19	60.30 *	666		61.90	1350		66.10	1200		91.20	1173	yes	91.20	1246		96.40	994	
20	60.40 *	675		60.70	1350		62.30	900		74.10	1036		73.80	1073		77.80	814	yes
21	72.10 *	909		63.70	964		70.00	673		74.60	1036		75.90	912	yes	86.10	874	yes
22	72.90 *	816		65.70	1307		72.20	900		70.30	886		73.40	946		80.00	883	
23	77.10 *	900		74.30	1061		83.10	957		92.10	1159		93.10	1235		110.20	1114	
24	78.50 *	497	yes	72.20	1350		80.10	778		100.40	982	yes	102.80	900		115.20	737	yes
25	58.40 *	825		61.90	1211		57.30	762	yes	72.10	777		72.00	669	yes	75.70	763	yes
26	63.40 *	984		69.90	1093		69.10	932		88.80	695		90.30	796		97.40	754	
27	60.80 *	891		59.40	943		63.40	673		75.00	1036		74.50	1131		82.30	1011	
28	66.80 *	713		60.30	1221		69.10	989		69.20	1173		71.20	1338		80.30	1157	
29	63.50 *	572		63.70	1243		72.00	859		85.60	1036		84.70	958		90.30	737	
30	55.40 *	750		57.40	868		63.70	1022		70.60	1214		71.90	865	yes	82.20	969	
31	56.80 *	769		57.30	1254		63.10	689		75.10	900		78.70	838		80.10	806	
32	63.60 *	713		63.40	1382		64.20	754		67.70	1077		70.30	1038		75.60	814	
33	60.00 *	750		54.00	1329		58.70	908		73.80	941		75.80	808		82.30	840	yes
34	68.50 *	666		64.70	782		73.90	868		84.00	968		84.70	865		87.80	763	
35	59.90 *	497		60.00	1232		69.90	835	yes	78.50	1009		78.40	935		83.20	857	yes
36	61.70 *	534		57.70	1157		61.70	754		70.90	805		73.40	923		77.80	643	
37	60.80 *	656		57.10	1168		67.40	989		77.60	955		75.60	1038		82.20	874	
38	60.30 *	788		52.80	643		64.20	827		70.20	941		71.90	738		83.20	660	
39	75.30 *	806		72.20	889		79.40	1078		90.70	1159		91.50	1062		92.30	1037	
40	66.80 *	984		60.80	1468		64.70	1014		84.40	1173		82.30	1073		90.10	986	yes
41	73.20 *	1041		72.10	1639		79.40	835		90.30	805	yes	96.40	1027		99.30	1097	
42	60.80 *	544		57.80	1371		62.10	568		80.10	1132		79.90	1223		87.10	1157	
43	74.40 *	722		74.00	1446		77.40	965		83.20	627		85.70	819	yes	96.20	737	yes
44	74.60 *	778		71.30	1554		79.40	608	yes	82.70	1023		85.40	1004		92.10	789	
45	68.60 *	994	yes	61.90	1018		67.10	1014		95.30	1186		96.80	1015		96.00	909	yes
46	66.40 *	891		62.40	1200		64.70	876		88.70	982	yes	89.70	1108		92.30	806	
47	62.60 *	947		50.10	1286		59.70	1330		88.10	1105		91.40	1223		99.10	951	
48	65.40 *	656		63.70	1157		64.70	730	yes	80.90	955		84.70	992		92.10	951	
49	73.20 *	488		72.40	1243		80.30	462		87.20	955		97.70	935		102.30	1046	
50	65.40 *	666		57.70	1061		64.70	892		86.70	1091		93.10	946		104.40	814	yes
Averages	**67.19**	**766**		**63.60**	**1196**		**70.41**	**859**		**82.65**	**1006**		**84.24**	**1004**		**90.89**	**901**	

Site 1 - Moores Farm/Welham Bridge, A614 Howden - Monday 13 May 1996

1916y ab58 b 117 ID	Speed at Point 6 km/hr	Lateral Distance at Point 6 mm	Opposing Traffic at Point 6	Speed at Point 15 km/hr	Lateral Distance at Point 15 mm	Opposing Traffic at Point 15	Speed at Point 7 km/hr	Lateral Distance at Point 7 mm	Opposing Traffic at Point 7	Speed at Point 8 km/hr	Lateral Distance at Point 8 mm	Opposing Traffic at Point 8	Speed at Point 9 km/hr	Lateral Distance at Point 9 mm	Opposing Traffic at Point 9	Speed at Point 10 km/hr	Lateral Distance at Point 10 mm	Opposing Traffic at Point 10
51	75.80 *	891		67.40	1136		70.30	1078		102.20	1050		105.60	1004	yes	120.00	1097	
52	61.70 *	647		55.60	1886		65.10	1046		77.10	995		76.70	1027	yes	77.80	986	yes
53	74.50 *	638		65.50	1125		70.30	754		90.20	1118		99.30	1096	yes	102.80	1037	yes
54	61.70 *	919		61.90	1136		67.70	851		72.70	955		73.80	969		77.80	900	
55	80.00 *	759	yes	77.40	1018		80.30	908		95.90	750		96.10	1085		84.70	994	
56	62.60 *	881		55.60	1146		57.80	924		52.20	641		53.30	877		55.70	737	
57	64.40 *	863		62.30	879		67.40	1216		93.20	900		95.60	912		90.10	1089	
58	56.80 *	788		54.10	1704	yes	63.70	576	yes	66.20	873		65.50	842		67.10	1020	
59	54.10 *	806		54.00	739		60.20	941		73.10	1159		75.90	1212		78.50	1029	
60	60.90 *	825		63.10	1286		69.90	835		76.70	873		78.40	1050		72.00	737	yes
61	66.50 *	806		67.70	1382		75.30	859		82.10	859	yes	82.10	773		79.40	883	
62	61.90 *	750	yes	61.90	975		69.10	941		74.90	1105		76.40	1050		75.40	960	
63	77.10 *	516		74.70	1414		76.90	632		90.10	655	yes	93.20	727		96.40	943	yes
64	81.50 *	656		80.20	1243		86.00	551		88.70	914		90.10	888		92.90	1217	
65	78.60 *	872		80.20	1168		84.20	1022		93.80	736	yes	96.40	819		99.10	900	
66	73.20 *	403		72.20	1661		76.60	705	yes	91.60	859		92.10	715		90.20	797	yes
67	77.10 *	722		70.70	1286	yes	77.10	1168		93.50	1241		92.90	1235		90.80	1174	
68	72.00 *	975		67.70	1254		76.10	819		86.80	900		90.00	1038		95.40	960	
69	60.30 *	966		60.20	1296		65.20	746		70.10	886	yes	73.80	808	yes	78.20	951	
70	64.40 *	759		65.60	1746		70.30	1062		77.10	641	yes	77.80	819		80.10	969	
71	60.80 *	478	yes	57.10	1125	yes	64.70	730		66.70	586		68.60	346		75.80	703	
72	73.20 *	1022		67.80	739		76.30	770		81.20	1173		84.60	1246	yes	90.30	1166	yes
73	66.10 *	703		63.70	1179		69.40	924		94.70	1036		93.10	1004		102.80	994	
74	68.00 *	572		65.60	1018		74.10	819		73.10	1023		72.40	1177		82.90	994	
75	62.60 *	881		57.30	1136		62.30	1046		75.00	1214		75.10	1015		80.30	1123	
76	60.40 *	956		58.50	1521		67.30	1054		81.70	1036		80.30	842		96.70	891	
77	70.80 *	947		68.10	1371		76.10	778		97.20	1132		99.30	1281		106.60	1166	
78	62.60 *	656		65.60	1532		74.20	470		83.10	695		84.70	854		90.20	754	yes
79	80.70 *	394		74.40	1768		76.90	908		87.00	900		87.30	1062		84.70	969	
80	68.50 *	731		61.90	1082		69.40	1005		78.20	1091		80.10	1200		83.10	1046	
81	58.40 *	816		57.10	1157	yes	65.00	941		73.70	1227		74.30	958	yes	73.80	866	
82	68.30 *	825		67.70	975		74.10	924	yes	83.90	995		84.70	1073		92.80	1080	
83	66.50 *	806		63.40	1200		74.00	868	yes	80.10	982		83.30	1200		96.20	1157	
84	77.10 *	853		74.90	879		83.00	1184		90.00	1268		89.10	1154		90.30	994	
85	56.10 *	694		52.80	1682		59.80	835	yes	62.30	1009		65.60	1004	yes	70.20	797	
86	72.40 *	788		69.90	932		70.80	819		79.90	1186		82.30	796		82.30	866	
87	62.60 *	750		58.70	1554	yes	61.90	924		72.70	859	yes	73.50	1004	yes	77.80	1011	
88	80.10 *	891	yes	77.40	1211		80.30	786	yes	98.00	886		96.10	1142		102.60	1131	yes
89	60.20 *	759	yes	60.20	1318		67.10	924		75.60	1077		77.80	1200		80.40	1114	
90	62.40 *	534		63.70	1275		72.00	932		74.30	436		73.80	750		73.80	840	
91	73.20 *	900		60.90	686		70.10	665		74.90	1159		74.30	1096		75.80	986	yes
92	80.40 *	769		74.70	1157		80.20	924		74.90	1064		75.60	923	yes	79.40	831	
93	57.60 *	656		54.80	1093	yes	65.00	819		73.80	1200		74.30	1315		74.90	1183	
94	73.20 *	1059		57.30	654		62.30	1111		72.90	982		73.40	1108		72.00	1003	
95	64.50 *	1088		65.60	707	yes	64.70	1022		75.10	982		72.60	1062		81.20	977	yes
96	56.80 *	609	yes	55.50	696		60.30	941		76.50	764		77.80	1035		73.80	849	
97	51.30 *	647		54.10	943		63.10	835		61.20	859		60.10	935		64.10	866	
98	50.30 *	553		55.60	975		63.10	478		80.00	477		80.40	946		84.10	874	
99	54.40 *	759		43.30	1082		50.40	859	yes	70.10	886		70.60	865		72.00	823	
100	47.70 *	844		47.30	761		52.10	1030		73.10	1064		72.30	1142	yes	78.90	1011	
Averages	**66.29**	**768**		**63.46**	**1178**		**69.59**	**879**		**79.78**	**947**		**80.85**	**995**		**83.88**	**969**	
	75.30			**72.20**			**77.40**			**91.20**			**93.10**			**99.10**		

Site 2 - Caville Hall, A614 Howden - Tuesday 25 June 1996

1916z

ab1.ba57

ID	Speed at Point 6 km/hr	Lateral Distance at Point 6 mm	Opposing Traffic at Point 6	Speed at Point 7 km/hr	Lateral Distance at Point 7 mm	Opposing Traffic at Point 7	Speed at Point 8 km/hr	Lateral Distance at Point 8 mm	Opposing Traffic at Point 8	Speed at Point 9 km/hr	Lateral Distance at Point 9 mm	Opposing Traffic at Point 9	Speed at Point 10 km/hr	Lateral Distance at Point 10 mm	Opposing Traffic at Point 10
1	64.20	1146		70.40	855		81.80	408		85.40	954		90.70	875	yes
2	68.70	1104	yes	81.60	1027		94.70	423	yes	92.30	600	yes	93.90	675	
3	44.40	1189		47.50	1082		75.00	638		68.40	686		67.40	763	yes
4	46.90	1018		47.80	818	yes	90.00	854		83.70	804		74.60	550	
5	59.30	1050	yes	61.80	673	yes	94.70	1008		87.80	1125		83.80	875	
6	58.20	1264		64.00	1091		94.60	962		100.00	986		99.30	988	
7	59.00	1104	yes	60.10	973	yes	85.60	969		81.80	1179		82.50	1150	
8	48.30	868	yes	53.70	1055	yes	78.30	992		76.60	1071		79.60	838	yes
9	59.10	1104		65.80	882		95.10	1023		102.30	1136		98.80	1175	
10	56.20	1286		61.80	1191		100.10	1000		85.70	1114		88.40	688	yes
11	50.00	1029	yes	53.70	936	yes	69.30	946		71.30	996		77.10	788	
12	59.10	1136	yes	63.80	1055		90.20	508		75.60	621		77.60	700	
13	47.90	932		48.60	1045		72.30	585		72.10	911		71.70	850	
14	55.60	996		50.20	1045		95.60	715		95.60	943	yes	93.90	1113	
15	57.30	1393		61.90	1236		69.70	900	yes	72.30	664		79.50	888	
16	50.30	1264		52.40	1227		72.50	515		80.00	1018	yes	90.50	913	
17	57.80	1018		63.80	1000		78.30	777		85.60	525		86.40	763	
18	55.30	1125	yes	58.20	1091		78.90	769	yes	72.10	857		77.20	625	
19	60.00	868		63.70	618	yes	81.80	992		88.50	1125		80.00	925	
20	54.70	1200		60.00	873	yes	78.30	1138		86.50	1168		86.40	1113	
21	47.70	750		51.00	627	yes	94.70	846		95.80	1029		102.80	1013	
22	63.20	1254		68.20	1164		101.60	1123		101.30	1157		103.70	1175	
23	52.10	1093	yes	52.30	845		70.30	1008		72.10	1104		69.90	1000	
24	45.40	1211	yes	48.60	1091		71.60	931	yes	74.50	1157	yes	74.50	1138	
25	54.70	1071		57.10	727		94.10	992		90.20	879	yes	98.10	800	yes
26	54.70	1007		60.30	1073		78.10	900		91.20	868	yes	86.40	950	
27	55.80	1146		61.10	1027		75.60	846	yes	78.30	932		78.10	875	
28	57.30	1179		61.90	1100		85.70	1215		84.60	1307		83.80	813	
29	50.20	1082	yes	53.80	973		78.30	923	yes	76.60	964		80.00	513	
30	49.10	1018		52.40	818	yes	75.40	854		70.60	964		76.80	1113	yes
31	59.10	1082		61.40	682		90.70	600		95.80	1029		98.80	1088	
32	54.80	1157		58.30	818		78.10	469	yes	74.60	396	yes	79.70	750	
33	55.00	1125		55.10	700	yes	78.20	731	yes	71.60	814	yes	83.80	1075	
34	53.20	1071		56.60	1018		72.00	954		71.40	1093	yes	69.70	1113	
35	50.90	1082		52.10	873	yes	85.90	1038		85.90	1082		83.80	888	
36	50.60	814		56.50	1064		82.10	885		88.10	964		93.90	663	yes
37	47.20	1071	yes	49.80	909		60.20	831		61.40	782		60.00	750	
38	53.70	1168		53.70	1055		64.80	623		71.50	846		74.50	450	
39	53.80	1168		58.30	1036		75.80	554		74.60	1104		77.20	750	
40	55.10	568		57.10	782		65.80	738		74.70	911		83.20	600	yes
41	49.60	1243		53.60	1009		85.70	1162		81.30	1264		83.10	958	
42	56.80	1254		62.30	927		88.60	800	yes	80.00	964		84.30	912	
43	50.10	1189		56.10	1009		81.80	931		78.30	975		80.60	727	
44	69.20	1307		72.80	1182		103.50	1123		92.30	1179		98.80	969	
45	66.10	1232		65.80	1073		81.10	731		83.70	1007		86.40	877	
46	57.70	1243		61.80	1027		69.20	785	yes	73.40	868		74.40	762	yes
47	55.30	1136		58.30	882	yes	83.10	946		85.60	1082		93.90	1038	
48	51.20	932		52.40	1236		71.00	1031		74.10	1125		77.00	819	yes
49	50.10	1243	yes	49.80	1009	yes	106.10	1008	yes	92.00	1082	yes	89.40	1085	
50	56.70	1018		61.90	518	yes	86.20	777		87.80	1114		90.00	923	
Averages	54.77	1100		58.22	961		82.24	850		81.94	971		83.92	877	

Site 2 Caville Hall, A614 Howden - Tuesday 25 June 1996

1916z

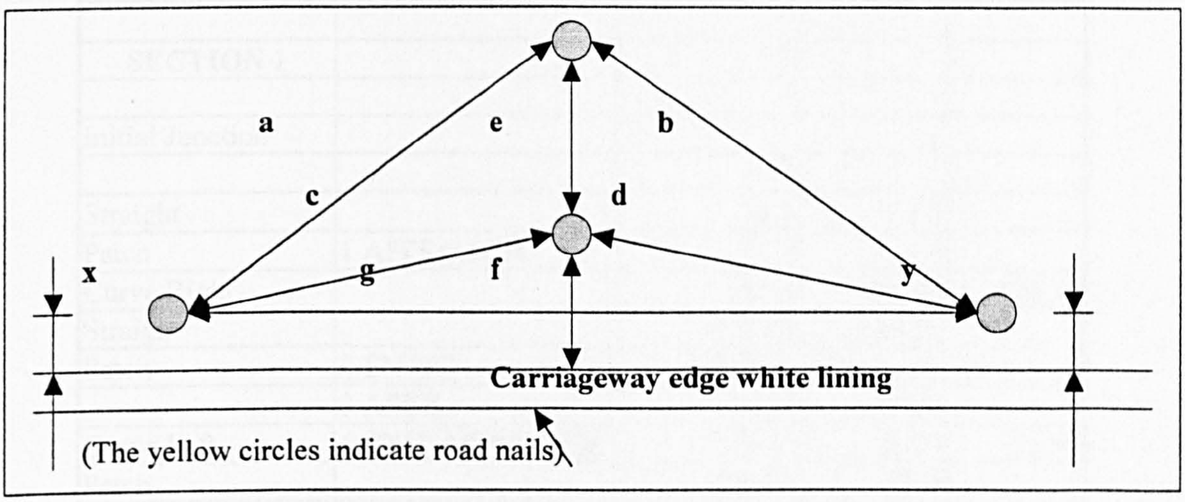
ab58 ba117

ID	Speed at Point 6 km/hr	Lateral Distance at Point 6 mm	Opposing Traffic at Point 6	Speed at Point 7 km/hr	Lateral Distance at Point 7 mm	Opposing Traffic at Point 7	Speed at Point 8 km/hr	Lateral Distance at Point 8 mm	Opposing Traffic at Point 8	Speed at Point 9 km/hr	Lateral Distance at Point 9 mm	Opposing Traffic at Point 9	Speed at Point 10 km/hr	Lateral Distance at Point 10 mm	Opposing Traffic at Point 10
51	69.40	1221		73.00	818		73.10	954		78.30	954		83.10	950	
52	59.40	1189		63.20	964		66.80	1023		69.80	943	yes	72.40	888	
53	53.20	857	yes	55.40	600	yes	64.30	854		73.40	1007	yes	77.10	900	
54	50.40	1404		58.70	818	yes	64.70	877		75.00	1104	yes	74.50	963	
55	45.50	1307		51.60	891		81.70	715		85.70	771	yes	80.20	975	
56	53.10	664	yes	53.70	591		85.40	846		87.30	857		86.40	900	
57	58.60	964	yes	60.30	1009		95.10	962		85.90	1018	yes	83.80	913	
58	51.10	1029		58.30	973		102.40	900	yes	90.20	1039	yes	98.20	825	
59	50.90	1082		57.60	982		81.60	1115		84.20	1157		86.60	1150	
60	51.30	1093	yes	59.40	1055	yes	75.90	1169		71.60	1286		70.00	1063	
61	50.60	1189		59.30	1145	yes	58.60	962		60.30	921		61.30	1025	
62	52.20	1168		59.30	1136		78.40	585	yes	69.30	814		70.30	900	
63	57.60	1200		61.70	927		96.20	892	yes	70.30	1007		70.90	1025	
64	60.00	1339		63.80	1145		79.40	1062		82.50	1125		90.70	1113	
65	58.10	1200	yes	64.30	655		86.10	746		87.80	718		97.10	1025	
66	58.30	1114		60.20	991		69.30	715		72.40	793		79.40	563	
67	65.50	1307		79.60	1000		76.40	969		80.10	986		80.70	1138	
68	75.10	1200		85.20	836	yes	97.80	1123		102.80	1286	yes	113.70	1125	
69	69.30	1350		73.10	1291		88.30	977		92.30	1018		95.00	713	
70	54.20	1296		58.20	1055		81.20	1169		78.40	1232		86.50	1100	
71	54.20	964		58.90	918		79.30	738		72.60	793		70.10	313	
72	59.30	1071		64.10	1055		74.10	946		85.70	1071		83.30	1100	
73	54.20	1050		57.90	1091	yes	82.10	931		82.90	986		85.40	563	
74	81.60	1318		92.50	845		106.80	962		104.30	1029		103.80	625	yes
75	58.10	1275		60.10	1273		96.30	654		94.80	771		102.20	1013	
76	60.00	1296		61.90	1073		94.50	854		94.10	1018		104.70	875	
77	61.30	996	yes	64.00	773	yes	86.40	1085		85.80	975		93.90	1088	
78	61.40	932		65.70	936		72.10	931		73.90	954		74.50	850	
79	51.30	1039	yes	57.60	1045		81.20	846		85.40	1179		93.40	1250	yes
80	52.40	1061		57.60	900	yes	91.30	792	yes	85.60	932	yes	82.10	663	
81	70.30	1189		75.60	973		78.30	1115		87.10	857		86.40	1075	yes
82	68.10	1168		70.30	882		86.10	1054		86.30	1136		89.70	1188	
83	58.60	1168		61.90	1091		71.10	1008		79.10	1114	yes	76.20	938	
84	57.40	1232	yes	61.50	1027		75.30	846		79.80	696		83.20	263	
85	55.30	1168		60.70	864		62.30	754		65.40	600		70.30	775	
86	55.80	1232		59.20	1118		69.50	969		69.10	1039	yes	70.90	1000	
87	60.30	1114		65.80	882		92.30	1046		94.10	1018		98.10	692	
88	70.70	1200		75.80	1109		91.40	1262		91.30	1125		88.70	831	
89	49.30	1071		51.10	709		67.90	769		69.70	857	yes	74.40	669	
90	59.40	1254		64.20	1073		82.50	1231		64.10	1211		67.50	923	
91	60.30	1200		66.30	973		72.60	854		75.30	975		77.10	842	
92	69.70	1264		72.90	873		64.50	738		63.60	868		70.10	762	
93	64.10	1361		68.20	1373		78.30	885		78.40	879		80.40	646	
94	64.60	1211		68.90	791		70.30	238		75.00	589	yes	80.00	646	
95	65.00	1221		65.10	1027		90.00	969	yes	81.80	1082		88.30	1062	
96	75.10	1232		81.30	955		62.10	862		67.20	889		74.90	842	
97	49.00	1200		49.80	973		64.50	1000		65.60	1029		70.00	935	
98	51.60	1136		53.70	891		50.60	654		58.10	750		66.10	485	yes
99	60.20	1082		66.10	709		78.30	1077		77.00	1157	yes	77.10	969	
100	62.50	1339		69.10	1191		81.20	1015		85.60	1136		98.10	946	
Averages	**59.30**	**1164**		**64.07**	**965**		**79.12**	**914**		**79.53**	**975**		**82.78**	**882**	
85th %'ile Speed	64.20			68.20			94.60			91.30			95.00		

Appendix 5-5: Camera positioning

Camera ID	Horizontal Distance (mm) from back of c/way white lining (edge)	Average Distance from edge (mm)	Vertical Distance above ground level	Vertical Angle of Camera (o)
Site 1				
1	2400	986.5	1080	34
2	3100	1005	1000	20
3	2690	521	1060	25
4	2200	795	1020	26
5	1850	732.5	1030	33
6	2030	1132	1110	20
7	1340	963	1020	24
8	670	882	980	22
9	1950	973	1030	21
10	1250	879.5	1020	34
Site 2				
1	1130	632.5	940	30
2	950	737	960	32
3	900	679.5	1030	35
4	1450	608	1030	31
5	1120	801.5	1010	30
6	1260	767	1020	29
7	2580	1187	1250	37
8	920	869	1200	35
9	1440	976.5	1070	31
10	1240	999.5	1040	26
11	1070	935	970	31

Appendix 5-6: Road nails position



Camera ID	a	b	c	d	e	f	g	x	y
Site 1									
1	925	630	780	470	300	220	1200	50	55
2	1070	605	960	370	300	325	1200	60	70
3	1025	720	920	600	300	210	1500	60	65
4	600	950	470	850	300	150	1300	55	30
5	840	690	690	490	300	260	1100	45	25
6	670	600	530	425	300	270	810	135	120
7	770	880	640	740	300	280	1300	70	70
8	450	650	260	525	300	235	800	170	140
9	1210	870	104	670	300	355	1500	-60	-40
10	675	670	570	535	300	145	1100	45	40
Site 2									
1	805	800	615	600	300	300	1080	0	0
2	690	760	460	590	300	260	920	0	30
3	705	890	460	720	300	280	1160	0	0
4	670	1180	450	1050	300	290	1360	0	0
5	670	945	460	830	300	280	1200	60	40
6	870	810	685	625	300	290	1180	0	0
7	750	680	550	450	300	300	815	0	15
8	840	795	650	615	300	300	1125	0	5
9	855	715	675	510	300	300	1010	0	0
10	770	740	560	540	300	295	930	-5	0
11	1005	605	835	330	300	295	950	0	0

Appendix 5-7: Geometric characteristics of the real A614

ROAD SECTION	MEASUREMENTS	CHAINAGE	LENGTH	RADIUS
SECTION 1				
Initial Junction			1	
		0		
Straight		11.5	11.5	
Patch	1 APPROACH	17.5	5	
Curve Right		92.34	74.84	476.48
Straight		105.59	13.25	
Patch	2 ENTRY	118.59	13	
	3 APEX	151.58	32.99	
Curve Left	4 EXIT/APPROACH	184.57	32.99	55.59
Patch		206.97	22.4	
Straight		216.97	10	
Patch		231.97	15	
Straight		242.57	10.6	
Patch	5 ENTRY	252.57	10	
	6 APEX	309.25	56.68	
Curve Right	7 EXIT	365.93	56.68	108.25
Patch		375.93	10	
Straight		425.93	50	
Patch		433.43	7.5	
Straight		513.43	80	
Curve Right		613.06	99.63	475.71
Straight		702.45	89.39	
Curve Right		842.95	140.5	230.67
Straight		865.2	22.25	
Patch		883.95	18.75	
Curve Left		1030.98	147.03	223.82
SECTION 2				
Patch		1046.98	16	
Straight		1072.97	25.99	
Patch		1082.97	10	
Straight		1100.97	18	
Patch		1132.97	32	
Straight		1160.98	28.01	
Curve Left		1382.79	221.81	563.83
Patch		1395.29	12.5	
Straight		1450.76	55.47	
Patch		1499.79	49.03	
Curve Right		1715.65	215.86	1081.68
Patch		1755.65	40	

SECTION 3				
Straight		1780.65	25	
	8 STRAIGHT	1830.65	50	
	9 STRAIGHT	1930.65	100	
		1970.65	40	
Straight		1988.15	17.5	
Straight		2004.4	16.25	
Straight		2016.9	12.5	
Straight		2051.9	35	
Straight		2067.9	16	
Straight		2111.65	43.75	
Straight		2191.65	80	
	10 STRAIGHT	2274.65	83	
Straight		2307.9	33.25	
SECTION 4				
Straight		2436.65	128.75	
Straight		2439.65	3	
Straight		2509.65	70	
Straight		2524.65	15	
Straight		2630.15	105.5	
Curve Left		3036.62	406.47	509.46
Straight		3226.62	190	
Patch		3239.12	12.5	
SECTION 5				
Curve Right		3548.01	308.89	519.51
Straight		3578.01	30	
Curve Right		3726.77	148.76	1036.79
Curve Left		3862.54	135.77	545.84
Patch		3875.04	12.5	
Straight		3907.54	32.5	
Patch		3912.54	5	
Straight		3980.04	67.5	
Patch		3985.04	5	
Curve Right		4054.87	69.83	415.03
Patch		4059.87	5	
Straight		4089.37	29.5	
Patch		4104.37	15	
SECTION 6				
Curve Left		4228.45	124.08	418.19
Patch		4238.45	10	

Straight	11 APPROACH	4249.45	11	
Straight		4296.95	47.5	
Patch	12 ENTRY	4311.95	15	
Curve Left	13 APEX	4386.72	74.77	200.59
	14 EXIT	4461.49	74.77	
Patch		4486.49	25	
Straight		4498.49	12	
Straight		4503.49	5	
Curve Right		4595.81	92.32	187.43
Patch		4613.81	18	
Straight		4639.56	25.75	
Curve Right		4700.19	60.63	507.71
Straight	15 APPROACH	4765.69	65.5	
Straight		4800.19	34.5	
Patch		4810.19	10	
Straight	16 ENTRY	4865.69	55.5	
Patch		4877.69	12	
Curve Right	17 APEX	4922.88	45.19	141.51
		4968.07	45.19	
Straight	18 EXIT	4984.32	16.25	
Patch		5024.32	40	
SECTION 7				
Curve Right		5277.09	252.77	2405.14
Curve Left		5357.16	80.07	192.92
Straight	19 STRAIGHT	5457.41	100.25	
Straight	20 STRAIGHT	5537.41	80	
Straight	21 STRAIGHT	5617.41	80	
Straight (End)		5879.66	262.25	

Appendix 5-8 Example of generation of oncoming traffic in the simulator

A614 - LIGHT TRAFFIC

```
#include <standard.cars>

path on_10 {<10 0>}
path on_20 {<20 0> <10 0>}
path on_30 {<30 0> <20 0> <10 0>}
path on_40 {<40 0> <30 0>}
path on_50 {<50 0> <40 0>}
path on_60 {<60 0> <50 0>}
path on_2 {<2 0> <60 0>}

car 10   ROVER216   RED      on_10   800.0   1.6    70.0   trigger 6010
{
  giveway never
}

car 20   ROVER216   WHITE    on_10   750.0   1.6    65.0   trigger 6020
{
  giveway never
}

car 30   ROVER216   WHITE    on_10   600.0   1.6    65.0   trigger 6030
{
  giveway never
}

car 40   HGV        DARKRED  on_10   500.0   1.58   45.0   trigger 6040
{
  giveway never
}

car 50   ROVER216   YELLOW   on_10   400.0   1.6    70.0   trigger 6050
{
  giveway never
}

car 60   ROVER216   WHITE    on_10   300.0   1.6    70.0   trigger 6060
{
  giveway never
}

car 70   ROVER216   PURPLE   on_10   200.0   1.6    75.0   trigger 6070
{
  giveway never
}

car 80   HGV   DARKBLUE   on_10   100.0   1.58   60.0   trigger 6080
{
  giveway never
}

car 90   ROVER216   GREEN    on_10   50.0    1.6    90.0   trigger 6090
{
  giveway never
}
```

Appendix 5-9: Test protocol

Due to the 3 different conditions relative to the oncoming traffic, there were six combinations (3!=6), therefore the order was as follows:

Sub	1st run	2nd run	3rd run	Sub	1st run	2nd run	3rd run	Sub	1st run	2nd run	3rd run	Sub	1st run	2nd run	3rd run
1	C	M	H	26	C	M	H	51	M	H	C	76	C	H	M
2	C	H	M	27	H	M	C	52	M	C	H	77	M	C	H
3	M	H	C	28	C	H	M	53	H	C	M	78	H	C	M
4	M	C	H	29	M	C	H	54	H	M	C	79	M	H	C
5	H	C	M	30	H	C	M	55	M	H	C	80	C	H	M
6	H	M	C	31	M	H	C	56	C	H	M	81	M	C	H
7	M	H	C	32	C	H	M	57	M	C	H	82	C	M	H
8	C	H	M	33	M	C	H	58	H	M	C	83	H	M	C
9	M	C	H	34	C	M	H	59	H	C	M	84	H	C	M
10	H	M	C	35	H	M	C	60	C	M	H	85	C	H	M
11	H	C	M	36	H	C	M	61	M	C	H	86	H	M	C
12	C	M	H	37	C	H	M	62	C	H	M	87	M	H	C
13	M	C	H	38	H	M	C	63	H	M	C	88	H	C	M
14	C	H	M	39	M	H	C	64	H	C	M	89	M	C	H
15	H	M	C	40	H	C	M	65	M	H	C	90	C	M	H
16	H	C	M	41	M	C	H	66	C	M	H	91	H	C	M
17	M	H	C	42	C	M	H	67	C	H	M	92	C	H	M
18	C	M	H	43	H	C	M	68	H	C	M	93	C	M	H
19	C	H	M	44	C	H	M	69	C	M	H	94	H	M	C
20	H	C	M	45	C	M	H	70	M	H	C	95	M	H	C
21	C	M	H	46	H	M	C	71	H	M	C	96	M	C	H
22	M	H	C	47	M	H	C	72	M	C	H	97	C	M	H
23	H	M	C	48	M	C	H	73	M	H	C	98	M	C	H
24	M	C	H	49	C	M	H	74	C	M	H	99	H	C	M
25	M	H	C	50	C	H	M	75	H	M	C	100	C	H	M

Due to simulator sickness and other problems relative to the driving simulator the final order was as follows:

Sub	1st run	2nd run	3rd run	Sub	1st run	2nd run	3rd run	Sub	1st run	2nd run	3rd run	Sub	1st run	2nd run	3rd run
1	C	M	H	26	H	C	M	51	H	C	M	76	C	H	M
2	C	H	M	27	M	H	C	52	C	M	H	77	H	C	M
3	M	H	C	28	C	H	M	53	M	C	H	78	C	M	H
4	M	C	H	29	M	C	H	54	C	H	M	79	H	C	M
5	H	C	M	30	C	M	H	55	H	M	C	80	H	M	C
6	H	M	C	31	H	C	M	56	H	C	M	81	M	H	C
7	M	H	C	32	C	H	M	57	C	M	H	82	M	C	H
8	C	H	M	33	M	H	C	58	C	H	M	83	H	C	M
9	M	C	H	34	H	C	M	59	H	C	M	84	M	C	H
10	H	M	C	35	M	C	H	60	C	M	H	85	C	M	H
11	H	C	M	36	C	M	H	61	M	H	C	86	C	M	H
12	M	C	H	37	H	C	M	62	H	M	C	87	M	C	H
13	C	H	M	38	C	M	H	63	M	C	H	88	C	H	M
14	H	M	C	39	H	M	C	64	M	H	C	89	M	H	C
15	H	C	M	40	M	H	C	65	C	M	H	90	C	M	H
16	M	H	C	41	M	C	H	66	H	M	C	91	H	C	M
17	C	M	H	42	C	H	M	67	C	H	M	92	H	C	M
18	C	H	M	43	M	H	C	68	M	C	H	93	C	M	H
19	H	C	M	44	M	C	H	69	M	H	C	94	M	C	H
20	M	H	C	45	H	C	M	70	C	H	M	95	C	M	H
21	H	M	C	46	H	M	C	71	M	C	H	96	H	M	C
22	M	C	H	47	M	H	C	72	C	M	H	97	C	H	M
23	M	H	C	48	C	H	M	73	H	M	C	98	M	H	C
24	H	M	C	49	M	C	H	74	H	C	M	99	M	C	H
25	C	H	M	50	H	M	C	75	H	M	C	100	H	C	M

Appendix 5-10: Simulator experiment - Pre-experiment questionnaire

Institute for Transport Studies, University of Leeds

VALIDATION EXPERIMENT

DATA SHEET 1: PRE-SELECTION QUESTIONNAIRE

Sub No: ....

(Please circle the number where necessary)

1. Are you?
    1. Male
    2. Female

2. What is your age?

....

3. What is your occupation?

....

4. How long have you held a full driving licence?
    1. 1-5 years
    2. 6-10 years
    3. over 10 years

5. Have you taken any advanced driving courses? Please specify.

....

6. How many miles do you drive per year?
    1. under 5000
    2. 5000 - 10000
    3. 10000 - 15000
    4. over 15000

7. Have you driven the Leeds Advanced Driving Simulator before?
    1. yes
    2. no

8. Do you wear glasses or contact lenses when you drive?
    1. glasses
    2. contact lenses
    3. N/A

9. Are you familiar with arcade games?
    1. Yes
    2. No (if no, please proceed to No 11)

10. How often do you play them?
    1. once per week or more
    2. once per month
    3. once per year

11. Where did you see the advertisement/poster?...

Appendix 5-11: Simulator experiment - Code of good practice for subject handling

1. Welcome the subjects, make them feel like home. Smile and be talkative.
2. Ask them if they feel OK, if they need something (water, tea, coffee).
3. Take them to the small room (with the two tables), tell them to sit down and sit down next to them (they should always have in front of them the questionnaires and a pencil)

   Let them read the instructions first and then quickly summarise what they are going to do and ask them if everything is clear.
   - if yes, then they should fill in the 3 first pages (preselection questionnaire, wellbeing scale (pre tasks) and consent form)
   - if no, you will have to repeat the nature of the experiment and ask them what they didn't understand. When everything is fine, tell them to fill in the first 3 pages (as above)
4. While they fill in the questionnaires, go inside the simulator room and load the simulator (dsim, load etc.). Do not let them in, while the software is loading (due to the funny shape of the screen). Always load the practice run in the beginning.
5. Go out and take them inside the simulator room and ask them if they have already used the simulator
   - if yes, you don't have to say more, they are already familiar with the situation
   - if no, explain to them how it works, i.e. all the controls work like in real life, the pedals are the same, the simulator has a 5 gear box, they must release the hand brake before they start etc.
6. Ask them to get in the car and adjust their seat to feel comfortable. Remind them that they should drive as they would drive on real life using a real car (e.g. start up the engine, release the handbrake etc.) and make sure that they don't press the "emergency" button by mistake. Remind them that they should start with a practice run and then the test runs will follow.
7. During the practice run you will seat close to them but outside the car. When they finish, turn on the lights, take them to the small room to fill in the questionnaire (wellbeing scale) and go the simulator room to load the first condition (there will be a paper telling you which condition goes first) (be sure to keep this order). Always ask the subjects if they feel OK.

8. When the scenery is loaded go out and tell them to come in.
9. Wait until they get in the car and put their seat belt and then switch off the lights. You don't have to stay in the room, there is a monitor in the other room where you can watch what they are doing.
10. When they are approaching the end of the road, go into the run, wait until they come to a complete halt and turn on the lights. Take them to the small room as before and you should go back to reload the software.
11. Between each break make sure they complete the wellbeing scale and they feel OK.
12. There will be subjects who get sick even from the practice run and they will have to quit and subjects who misbehave. This misbehaviour can be either excessive speeding, they treat the simulator as an arcade game or driving too slowly because they cannot readjust to the simulated conditions. This type of subjects can skew the data , therefore is "not wanted". You should interrupt the procedure and let them know that they cannot continue because there is something wrong with the simulator and that you would let them know when you will need them again. If you are unsure of what to do then just let them finish and write a note for me. You will still have to pay all subjects.
13. After they finish, they should complete the last wellbeing scale, the last questionnaire relative to the realism of the simulator and sign the payment form after they received the money.
14. Ask them if they would like something to drink, or anything else, otherwise they are free to go. Make sure that they feel OK and satisfied for their contribution to this project.

Appendix 5-12 Speed and lateral position simulator data

Run 2+3. medium and heavy oncoming traffic

Subj	Run	Condition	sp1	lp1	sp2	lp2	sp3	lp3	sp4	lp4	sp5	lp5	sp6	lp6	sp 7	lp7	sp 8	lp8	sp 9	lp9	sp 10	lp10	sp 11	lp11	sp 12	lp12	sp 13	lp13	sp 14	lp14
4	2	2	54.78	218	49.54	-83	44.13	-97	49.9	-90	45.13	382	50.42	559	51.1	751	89.66	-193	82.23	-149	87.28	-91	66.16	-40	57.44	-350	52.86	-348	58.32	-180
9	2	2	47.3	1161	45.85	892	42.89	2	47.76	276	45.87	761	56.11	771	60.3	1450	117.81	948	119.1	679	120.76	683	89.95	305	54.98	546	68.66	258	64.49	292
13	2	2	53.68	672	48.2	421	42.28	385	38.47	120	38.58	681	40.39	846	45	1065	85.16	198	75.45	594	84.04	467	73.74	327	45.95	519	53.79	42	49.91	159
18	2	2	63.73	1221	53.54	420	43.1	176	48.8	447	30.63	1074	45.91	457	66.5	644	97.55	110	98.47	87	103.7	782	77.92	646	68.92	336	71.95	43	74.45	345
21	2	2	55.66	1111	53.3	925	49.84	537	48.24	-66	37.17	450	42.44	625	47.1	638	86.28	463	96.8	671	91.35	1022	72.35	286	68.01	-16	67.8	214	65.86	-43
26	2	2	47.37	893	41.92	703	41.54	264	46.37	314	44.42	405	46.82	631	57.6	579	96.89	699	101.64	681	99.4	782	86.66	662	67.64	510	67.23	303	63.81	409
30	2	2	49.04	650	43.96	290	39.4	125	39.61	134	43.07	587	46.29	654	52.2	856	88.47	462	84.45	245	100.13	334	71.86	118	48.14	121	54.92	-221	48.59	12
37	2	2	63.91	-214	62.48	-80	51.51	657	40.91	795	35.77	206	36.43	289	46.3	24	88.42	48	93.57	205	111.48	578	47.77	202	50.39	159	54.01	137	56.44	692
45	2	2	66.38	158	56.23	-178	46.23	-470	47.07	123	48.97	468	59.61	261	67.8	55	104.51	64	109.72	-646	114.74	-27	96.31	-600	81.67	-58	67.88	7	71.09	-260
48	2	2	51.8	947	35.61	577	36.48	356	39.75	674	39.27	933	38.71	944	51.4	977	90.16	582	98.06	648	95.17	691	59.7	246	49.92	673	59.08	238	58.6	196
49	2	2	53.8	1214	51.75	440	47.83	-106	47.72	197	42.74	476	57.9	603	55.8	524	76.28	493	65.59	489	68.89	368	71.17	92	50.13	372	60.99	-23	69.34	-188
57	2	2	54.31	1330	52.25	71	45.21	-637	40.27	-466	46.28	515	53.4	934	50	981	98.36	367	98.08	378	94.9	381	72.85	236	58.16	622	66.2	-426	62.66	-384
63	2	2	42.57	1348	40.68	-115	42.63	-236	45.05	-716	41.42	386	45.95	897	56.9	396	87.37	511	88.52	222	82.92	392	52.35	459	40.05	528	61.34	-44	56.94	-439
66	2	2	66.42	1043	59.17	816	51.78	1049	49.05	1154	52.33	1166	45.62	754	51.1	891	86.05	732	89.3	924	99.09	745	81.42	126	72.75	39	63.88	-363	63.73	77
69	2	2	36.2	1323	35.65	725	37.93	186	32.38	580	32.91	757	39.86	868	46.3	1014	87.7	578	95.92	879	75.03	878	67.57	487	55.47	381	57.46	-296	51.89	-9
72	2	2	57.39	914	51.48	597	45.15	-688	43.71	639	44.43	386	52.9	836	61.7	591	105.18	299	107.99	773	115.63	765	98.41	456	85.72	501	80.97	129	82.81	110
74	2	2	35.68	1642	32.96	1046	26.31	746	38.64	8	37.91	1614	42.27	1277	54.1	663	91.63	933	93.42	1557	98.08	1400	71.71	638	55.43	387	65.63	-524	65.6	-498
77	2	2	48.05	550	46.4	229	43.62	-157	44.53	655	46.32	486	49.27	839	56	875	112.92	284	96.53	-52	101.13	256	80.64	-92	65.29	-141	60.29	-388	71.68	-435
78	2	2	51.3	498	44.51	-5	42.55	-296	46.19	-383	42.26	171	49.94	66	60.8	250	108.01	8	106.29	57	110.7	146	88.99	-276	58.47	22	70.77	-271	62.76	-341
84	2	2	49.61	964	45.86	449	41.12	330	37.85	-69	41.23	353	41.71	676	42.4	667	75.89	574	80.24	781	76.02	772	54.86	429	44.78	489	39.98	129	47.44	311
85	2	2	45.6	713	43.92	329	39.73	-303	37.17	-472	40.87	593	42.73	1042	44.3	688	78.62	164	79.48	368	81.27	339	70.61	227	69.86	176	58.12	-318	56.58	25
87	2	2	64.62	850	53.13	575	46.95	283	49.73	2	48.65	663	49.23	936	57.6	950	107.99	395	109.17	516	115.57	919	101.56	283	79.99	678	77.54	192	81.83	29
90	2	2	52.96	1303	50.82	538	47.49	171	44.75	322	41.66	422	43.44	788	45.4	877	64.97	-16	63.88	387	61.69	305	71.53	226	49.45	535	53.76	290	57.88	47
92	2	2	55.35	1055	50.15	772	44.85	45	43.74	186	45.03	505	50.79	924	57.8	1092	92.3	519	86.73	587	95.11	754	86.61	319	76.72	615	63.14	133	71.4	580
98	2	2	38.68	1128	31.42	320	33.67	-137	35.88	330	36.01	728	40.3	795	39.9	862	87.25	438	82.11	667	89.42	798	60.36	690	37.17	373	44.92	46	46.21	210
100	2	2	45.05	850	39.39	577	43.65	-41	46.59	40	48.24	624	51.51	842	55	730	93.21	127	91.53	424	94.21	392	62.29	400	56.9	565	55.65	163	53.8	-43
104	2	2	45.05	814	41.59	343	37.72	457	36.36	-140	37.1	648	42.6	658	50.1	685	78.88	321	80.91	506	87.12	484	58.14	332	45.76	356	46.2	1	44.06	2
107	2	2	57.91	1015	38.27	282	41.82	113	43.45	545	46.43	821	53.81	903	52.6	1189	113.33	553	110.16	751	129.49	509	91.31	270	86.76	313	80.11	131	70.52	-104
109	2	2	48.92	1327	44.34	496	39.76	-631	45.8	292	37.14	1180	52.12	746	50.6	785	77.2	352	81.35	491	97.59	765	61.24	288	47.91	318	54.4	2	56.25	-139
110	2	2	44.42	1233	41.14	686	39.19	-104	42.02	606	38.66	1089	46.24	917	50.8	828	88.45	192	80.91	338	93.49	341	48.88	376	47.65	619	52.79	39	49.2	-4
115	2	2	54.17	781	48.76	375	47.01	-351	48.65	-104	46.48	553	57.43	1057	65.1	1378	86.81	16	89.74	420	87.5	281	72.34	103	63.05	325	64.01	-228	60.21	-111
5	3	2	59.19	1035	49.01	647	45.94	494	44.98	478	47.28	604	56.47	144	61.9	707	116.42	845	122.89	601	112.59	1100	84.94	891	58.51	538	68.11	323	61.7	82
8	3	2	67.77	1018	45.06	706	41.72	287	48.9	640	49.07	897	59.24	981	70.7	541	140.57	1244	123.69	645	133.93	1236	104.89	428	77.29	689	70.02	140	69.38	-51
11	3	2	64.99	1245	61.78	616	55.76	423	55.94	-56	56.62	340	62.72	987	71.3	438	102.42	411	102.35	432	113.34	222	87.25	-242	76.99	183	66.72	63	74.03	-53
14	3	2	65.56	897	59.1	666	48.68	290	37.93	-298	38.16	503	54.08	598	53.7	841	92.98	182	83.98	428	91.87	489	78.45	160	59.75	-5	60.28	-641	64.52	-676
17	3	2	66.65	748	59.02	408	49.83	629	43.48	213	41.54	107	53.11	228	57.1	1156	66.7	375	71.95	495	79.87	29	65.86	47	60.04	-138	53.13	-74	52.66	108
19	3	2	54.76	1333	52.01	591	48.29	195	46.81	546	46.27	1044	45.49	819	50	868	85.62	438	87.2	855	91.05	561	75.67	-11	67.15	495	58.46	-17	65.16	299
22	3	2	62.76	672	56.2	20	47.46	1226	43.9	96	41.14	367	48.82	590	40.7	591	92.22	132	93.8	811	102.54	629	77.95	91	74	-268	64.43	526	63.55	821
31	3	2	54.3	595	49.47	380	43.7	525	45.81	809	47.42	519	52.62	146	59.6	219	101	854	101.14	680	102.1	872	91.12	275	72.43	180	75.99	160	70.29	-213
33	3	2	52.93	1000	48.18	686	42.99	156	48.05	330	52.18	576	54.25	712	59.6	843	85.33	791	85.41	902	85.06	1022	63.71	601	51.79	479	58.76	142	60.62	-33
35	3	2	53.76	685	43.15	97	37.48	-668	47.5	-20	42.37	588	57.2	731	70.9	735	97.67	139	89.34	689	112.32	198	71.94	-205	55.44	128	67.09	247	69.66	-24
39	3	2	69.94	556	63.86	26	52.19	93	47.75	-69	47.09	273	48.48	388	55.1	361	89.54	632	88.77	817	100.49	754	81.88	718	71.22	-136	60.54	333	55.25	464
40	3	2	69.16	1068	57.42	795	48.23	151	52.11	30	59.78	717	63.24	731	74.1	602	110.22	740	109.03	451	111.77	921	95.09	515	77.05	753	73.08	279	69.04	-66
43	3	2	49.8	1182	47.72	808	41.61	583	38.91	339	42.54	619	40.47	749	48.6	581	89.58	532	85.27	298	85.91	473	69.43	333	50.59	521	54.14	-38	53.7	-125
46	3	2	60.22	370	42.6	35	42.19	-614	45.28	-356	43.4	263	60.95	642	60.7	664	96.68	-387	90.68	-138	88.77	301	78.87	-705	68.54	-168	73.46	-366	75.46	-770
53	3	2	62.05	755	56.31	78	47.76	-44	48.31	56	40.2	250	54.73	668	62.9	1021	112.09	363	112.93	55	113.79	116	92.84	201	80.16	420	69.3	191	78.2	129
56	3	2	49.3	1100	52.2	841	47.12	436	46.91	25	49.42	1035	57.06	568	60.3	1011	103.81	330	105.89	300	105.34	949	82.58	507	73.84	138	64.24	-27	55.3	-186
65	3	2	76.9	1316	60.99	866	50.74	296	53.8	281	53.6	723	59.69	886	71.4	344	112.85	644	113.56	603	119.35	851	94.91	711	72.22	654	74.33	268	79.05	212
67	3	2	40.4	636	39.35	801	40.21	842	41.31	412	39.3	472	44.14	1127	47.8	722	85.49	458	86.34	211	88.36	716	64.35	696	56.12	434	63.73	225	61.45	57
70	3	2	63.21	63	48.24	-138	45.31	-385	52.08	-15	45.11	507	53.35	583	60.7	936	97.06	-583	101.94	-174	110.36	186	88.26	-495	78.42	-31	80.81	-279	77.74	-413
71	3	2	52.48	1270	47.74	1018	42.11	-97	41.82	496	43.35	407	43.87	1219	46.7	815	97.09	201	101.26	452	103.25	373	78.88	1044	74.37	594	57.73	491	54.87	21
79	3	2	59.55	470	52.69	386	46.46	-60	51.86	145	47.84	133	49.91	483	65	114	93.2	703	98.01	98	97.11	504	85.18	132	62.7	257	69.41	177	74.44	95
82	3	2	64.93	1008	61.76	841	55.83	1544	52.1	392	56.64	668	53.25	1197	59.8	746	93.83	479	94.13	846	94.02	980	72.18	768	55.58	556	63.81	426	68.51	425
86	3	2	35.57	677	33.2	393	33.91	354	38.99	402	42.34	786	43.05	870	47.1	1003	87.17	589	84.69	746	77.79	500	55.24	480	41.41	267	48.61	233	44.39	186
88	3	2	66.62	1267	58.95	910	50.55	527	46.62	1068	43	323	54.21	690	62.5	772	94.92	562	103.17	-9	92.5	284	66.65	519	56.02	348	58.54	22	63.46	64
89	3	2	48.2	873	46.73	603	43.39	199	47.4	695	39.57	630	58.8	873	63.7	1001	109.92	464	109.54	340	89.72	805	81.15	452	66.08	320	70.01	334	69.59	320
91	3	2	50.94	1111	43.58	1019	42.72	20	47.38	356	51.09	503	58.41	1009	58.3	1150	81.99	670	84.3	510	88.78	263	76.32	260	56.22	393	58.09	158	65.51	47
96	3	2	41.82	981	37.66	297	35.34	890	33.35	759	29.89	311	38.76	796	44.9	528	62.46	573	63.91	731	71.69	447	56.53	453	50.36	287	46.71	380	43.11	409
102	3	2	46.69	1182	45.23	743	42.26	508	41.56	574	48.83	638	46.63	748	49.5	781	88.66	543	82.94	758	87.8	702	64.25	668	52.01	563	53.14	370	52.06	-45
105	3	2	52.6	1240	48.17	425	42.72	-37	39	42	41.79	803	49.85	1048	46.7	1013	73.83	211	79.69	546	79.72	755	54.38	451	47.95	923	56.93	273	55.31	-262
106	3	2	53.31	1145	39.76	549	37.14	80	43.22	470	42.6	497	51.95	603	56.4	753	89.98	791	89.79	913	87.49	815	69.75	484	45.36	486	54.04	661	51.36	547
111	3	2	61.59	14	54.8	-103	54.26	720	46.71	-617	43.29	293	55.73	214	69.5	152	80.89	-85	83.92	250	91.56	301	75.61	389	66.04	-403	60.29	-91	65.04	-67
114	3	2	50.2	1007	49.59	597	50.78	491	46.1	576	45.66	655	59.22	559	66.8	1051	129.15	569	131.88	1212	139.77	1148	82.05	451	54.45	344	66.73	608	65.27	68
5	2	3	71.51	763	49.5	201	44.99	379	45.12	357	53.7	878	54.06	516	56.3	776	100.07	369	104.91	760	94.01	588	71.09	304	54.09	446	60.44	-209	60.93	-143
6	2	3	52.07	939	40.69	532	39.65	-475	38.52	-363	47.81	-218	46.36	663	46.2	1037	108.61	533	84.9	556	84.53	546	75.4	550	46.4	605	60.71	317	46.26	-128
10	2	3	41.12	756	38.58	356	35.53	-22	35.64	53	38.41	314	47.36	384	53	29	81.58	677	81.43	507	87.24	742	85.63	-7	69.24	206	55.02	119	57.96	-305
11	2	3	67.37	1703	60.96	-90	47.43	-612	50.17	-274	55.33	1020	61.32	1642	64.7	977	99.48	88	90.88	513	100.52	285	72.64	-266	59.05	-192	61.41	-248	67.35	-228
17	2	3	55.39	1020	50.26	520	43.91	105	39.96	625	44.5	518	45.5	965	46.4	1054	76.29	301	76.78	625	77.45	-314	60.98	138	55.22	136	49.38	-152	50.75	-282
20	2	3	53.29	994	48.89	465	45.47	60	45.08	2	54.41	1095	50.16	1004	56.5	552	93.81	433	95.66	756	91.91	817	77.98	235	69.95	390	60.11	344	59.93	75
22	2	3	49.76	878	37.83	-62	38.5	-274	45.38	252	52.58	810	45.07	1256	40.1	685	86.43	-64	86.12	84	101.47	458	66.85	-77	66.92	-457	58.39	-377	51.87	-189
25	2	3	51.07	1079	48.11	536	45.93	419	46.71	558	51.29	342	58.99	670	71.2	629	98.28	255	94.06	82	88.5	389	68.51	377	63.14	459	60.12	86	61.91	-30
28	2	3	33.86	790	32.66	369	33.58	174	37.91	288	42.76	590	38.35	1020	47.6	1297	71.65	695	63.42	633	78.6	948	61.86	230	61.59	227	57.3	-164	55.69	-58
31	2	3	46.86	445	42.02	104	40.25	454	45.86	316	53.8	631	53.22	583	56.8	748	80.04	175	86.71	-9	89.39	433	74.53	188	52.78	-185	61.13	243	64.54	449
34	2	3	58.78	1627	52.99	1168	46.64	-428	50.32	142	53.28	853	56.28	1190	63	1256	117.34	537	119.04	615	110.14	378	77.61	40	59.52	248	58.39	159	55.11	124
35	2	3	48.9	901	42.01	40	31.24	-1196	47.37	-654	38.28	972	45.34	280	41	876	87.97	246	86.08	293	88.14	484	63.67	-290	50.54	-34	61.93	-191	57.98	-227
40	2	3	68.88	1422	52.73	451	47.15	-166	54.55	92	59.8	634	60.29	1042	68.3	489	118.72	323	120.45	875	98.38	1035	98.67	497	73.88	364	75.23	146	84.03	581
42	2	3	62.16	1434	55.32	509	54.87	286	52.19	664	57.58	940	64.5	1837	65.4	1175	110.23	535	114.35	746	121.17	623	100.38	-47	90.28	667	83.91	556	85.88	153
50	2	3	70.22	1181	34.57	386	40.12	335	52.61	561	51.78	905	60.89	754	62.7	945	122.06	128	126.38	372	133.23	681	87.28	235	61.25	262	66.88	99	66.07	-38
53	2	3	56.78	825	50.98	133	47.01	-169	47.36	338	48.48	689	44.15	764	52.8	822	97.99	471	101.08	247	102.82	366	80.16	-251	70.99	-138	68.93	-93	62.96	-4
54	2	3	71.07	1755	67.2	876	59.56	1092	49.49	-612	41.5	791	45.54	865	55	972	94.91	399	95.7	383	94.04	769	77.89	299	63.85	53	62.77	-212	58.95	-312
58	2	3	61.89	1164	51.5	658	41.84	-320	49.98	551	48.77	625	62.41	615	70.7	836	117.92	18	108.85	853	102.72	682	84.29	261	72.23	410	72.39	257	62.63	-111
65	2	3	79.76	1589	67.96	833	53.32	260	58.63	296	57.09	617	58.39	739	65.3	670	115.26	594	115.6	231	111.31	808	87.7	276	69.79	427	69.35	-19	74.6	130
70	2	3	70.92	-49	42.44	-563	40.94	-885	44.78	-372	49.96	174	45.96	577	54.4	749	113.14	-453	112.2	-398	98.57	-630	82.33	-614	74.14	-345	77.91	-471	77.54	-850
73	2	3	44.35	875	31.55	319	33.24	22	44.48	602	36.41	576	40.21	889	50.5	917	98.34	169	102.26	400	100.75	605	70.1	103	55.91	148	55.27	155	50.62	-218
76	2	3	61.63	1309	59.23	1056	52.52	453	48.68	-393	44.98	674	47.12	1023	58.7	900	115.23	1066	119.05	824	111.12	635	78.91	-609	57.66	-42	64.01	-186	48.91	-16
79	2	3	56.16	793	44.06	306	41.06	-193	43.6	-298	41.83	513	48.29	311	61.5	204	87.68	503	85.32	345	94.53	312	89.09	-25	77.04	84	67.67	27	70.32	-226
81	2	3	37.33	946	25.81	491	36.74	303	38.95	49	34.57	777	40.55	1205	47.5	963	88.12	536	80.18	577	95.75	-19	65.93	277	35.84	326	48.16	50	58.91	-82

82	2	3	65.37	1398	54.99	520	47.07	144	47.03	-104	54.55	915	56.8	998	62.2	1061	91.86	467	92.45	718	93.65	631	70.88	533	64.33	483	61.14	-76	62.43	160
88	2	3	55.8	500	41.98	259	31.09	387	40.01	279	42.9	280	44.82	461	50.4	868	91.36	272	90.49	-15	100.61	561	81.79	-317	48.98	-222	37.31	66	44	239
94	2	3	56.32	460	42.85	314	40.61	-120	39.38	-217	39.54	226	42.91	623	48.1	452	75.58	-92	74.3	-119	78.22	355	64.34	295	57.66	266	51.81	-348	51.6	63
102	2	3	49.6	1228	48.17	904	45.23	-67	43.55	276	48.29	579	53.4	1067	51.7	1130	87.61	632	87.92	525	86.46	656	66.08	451	56.56	551	56.2	335	56.18	273
103	2	3	25.37	1117	32.15	941	30.49	2	33.33	39	34.73	515	33.59	945	40.7	120	64.86	355	61.29	275	80.57	99	58.04	495	43.78	338	45.69	119	42.21	-117
111	2	3	42.24	623	51.07	-4	37.86	-1774	51.66	-163	35.82	333	51.85	662	49.3	475	115.39	141	114.75	-82	120.04	105	70.31	420	67.12	22	57.63	52	58.4	-127
112	2	3	33.1	724	31.65	72	31.2	194	37.04	28	40.77	653	38.17	668	41.8	398	74.31	-169	75.12	88	76.22	149	55.7	198	44.18	16	40.24	-1	37.43	-47
4	3	3	55.38	489	50.2	-263	44.52	-622	53.72	-245	56.39	170	64.35	506	69.1	230	104.12	-122	89.55	-212	80.64	-199	78.82	-309	65.65	-545	63.8	-206	55.25	-254
7	3	3	64.95	713	44.81	429	39.12	-185	43.86	-150	52.45	620	54.53	931	56.3	894	109.53	114	111.19	529	108.56	593	87.67	229	68.83	54	70.75	55	62.96	-109
12	3	3	55.89	674	37.04	557	40.25	-290	41.74	314	45.49	592	46.49	961	50.3	1151	82.87	318	86.73	593	82.09	351	66.48	268	60.73	369	59.43	-268	52	-79
16	3	3	72.35	1488	60.94	1027	51.91	452	49.87	589	58.62	555	57.12	873	73	817	118.95	931	108.51	973	111.4	459	74.21	375	60.35	749	70.28	423	62.52	79
21	3	3	57.54	1484	51.71	388	45.04	230	46.12	454	49.76	529	54.56	448	67.2	888	102.66	-53	96.05	582	104.41	699	86.68	89	76.14	245	67.11	287	57.64	-62
27	3	3	57.29	1157	41.7	516	50.59	313	60.08	768	52.38	409	60.12	1065	74.9	993	110.99	473	110.78	486	107.65	234	79.68	-105	56.42	380	61.02	-197	56.22	-271
36	3	3	81.8	591	59.96	658	46.91	70	43.79	131	48.03	630	52.72	1000	68	447	99.94	550	107.55	703	103.35	677	62.53	10	60.39	365	70.41	720	65.29	214
37	3	3	48.78	893	42.66	2	38.5	-392	35.96	698	35.63	773	40.1	530	45.2	401	99.61	512	88.31	931	83.56	837	47.19	436	42.64	35	37.4	426	47.22	854
44	3	3	50.92	799	43.68	442	41.13	771	49.04	1153	47.5	911	53.96	521	63.5	572	99.37	395	99.76	476	106.93	537	70.74	116	54.47	161	57.75	-31	51.95	-835
45	3	3	52.36	431	47.34	-179	42.2	-504	44.01	-244	50.31	370	56.76	547	63.5	479	99.3	-415	97.61	316	104.37	176	85.89	-352	74.39	80	66.32	-120	70.97	74
48	3	3	51.46	1192	33.4	753	44.82	294	45.72	667	38.25	824	54.04	1023	64.9	1229	92.84	828	88.85	696	96.44	626	63.83	634	46.91	729	56.28	525	49.97	118
51	3	3	53.07	808	39.74	365	41.62	-507	51.81	396	53.6	560	51.52	777	65.4	863	99.29	92	92.59	208	112.45	796	87.16	-54	66.64	431	75.77	33	63.62	-345
55	3	3	46.16	1439	41.94	894	37.76	450	41.38	379	44.74	851	51.37	1274	59.5	1177	91.48	768	91.75	933	93.24	659	71.73	616	60.46	491	60.18	357	63.32	72
60	3	3	83.75	935	73.98	518	51.59	452	41.19	-259	52,59	96	59,61	469	64.8	554	111.46	-121	104.09	126	113.96	347	90,02	-671	68.61	192	63.03	160	69.16	-440
63	3	3	51.06	1305	40.21	443	36.79	-565	46.29	-355	47.29	604	57.08	758	65.2	1214	88.92	302	94.96	261	109.15	478	57.93	530	47.01	609	57.74	34	51.37	-163
64	3	3	47.58	785	47.4	576	47.51	-925	56.35	-840	62.91	519	67.59	1206	76.8	1512	136.37	194	126.6	833	135.58	365	99.89	331	69.76	368	66.45	-171	72.99	-467
69	3	3	41.59	1017	36.85	252	38.38	-64	40.82	123	36.45	833	48.43	1015	58.9	589	100.63	426	103.06	397	113.89	668	64.89	339	59.13	524	51.27	269	52.48	-259
72	3	3	54.33	990	51.72	702	48.42	291	49.28	598	50.2	749	52.98	985	59.1	848	106.23	309	109.15	505	114.75	701	76.23	600	71.24	82	71.64	154	71.41	-182
75	3	3	59.5	1110	54.98	375	45.86	774	42.16	-244	46.95	406	58.96	778	61.6	878	109.97	53	102.16	487	115.76	186	83.44	-178	68.25	175	73.73	411	62.73	-453
77	3	3	52.21	408	51.55	-213	47.03	-185	54.74	531	57.05	264	54.74	853	70.9	863	99.05	-68	102.11	46	106.27	207	82.03	-424	69.14	-285	72.47	-211	65.95	-714
80	3	3	43.17	981	40.11	265	38.39	37	39.81	375	41.66	555	50.95	995	56.9	907	96.28	478	92.11	412	97.3	145	71.75	124	60.89	575	57.31	-183	58.12	-17
83	3	3	60.71	1060	54.25	365	46.02	-526	58.84	601	52.35	715	52.1	1202	64.2	632	108.58	638	105.24	641	90.47	849	64.7	314	61.43	120	61.41	-113	54.98	154
84	3	3	43.07	913	34.64	612	28.89	421	29.85	-47	38.7	353	37.87	843	41.6	522	78.87	413	78.22	760	86.27	627	61.13	283	54.25	303	43.31	-264	47.43	217
90	3	3	27.78	604	31.93	110	29.89	436	31.2	228	32.1	236	37.17	765	37.1	282	81.07	398	88.11	363	71.35	380	48.15	567	44.57	560	38.56	136	40.89	207
95	3	3	49.95	917	33.04	801	38.72	397	42.34	441	43.85	293	50.73	516	53.3	992	77.84	356	77.43	694	84.02	310	72.33	264	47.52	726	51.38	368	51.23	-193
97	3	3	33.75	707	30.11	-32	36.6	75	35.96	-125	44.22	1050	44.42	707	49.5	148	73.2	230	82.85	8	69.3	50	47.13	194	40.64	-72	36.44	-28	43.07	66
98	3	3	50.3	871	18.91	266	29.69	285	34.75	235	33.17	546	39.7	1347	44.6	981	90.17	427	76.63	407	99.38	504	73.75	5	47.56	546	56.77	76	50.98	-181
100	3	3	42.36	1109	41.77	637	41.86	-360	43.02	442	49.52	358	51.56	862	58.8	901	95.56	539	91.79	533	95.37	561	64.49	399	48.46	642	57.92	321	57.44	-83
101	3	3	43.52	1259	35.94	560	34.64	2	37.77	187	35.93	776	43.77	922	53.1	966	66.44	633	69.34	652	73.85	763	62.26	259	45.88	473	48.97	231	45.66	-142
104	3	3	42.13	675	33.12	360	33.47	120	34.6	78	38.27	700	43.7	241	45.9	533	71.01	330	72.51	255	72.69	460	63.92	420	44.1	436	41.49	175	42.54	-35
107	3	3	61.32	1091	39.13	236	40.1	-229	42.96	76	49.55	811	54.11	893	55.8	1021	107.03	454	112.7	814	124.61	688	75.26	-46	61.7	57	62.51	-158	59.03	-122
108	3	3	57.39	862	49.63	147	46	40	51.28	595	57.33	1052	62.96	1301	68.1	357	107.32	150	96.66	241	109.01	228	84.68	52	68.34	-14	73.4	345	65.88	-246
109	3	3	47.59	825	43.85	489	42.62	-456	48.21	-49	48.4	836	52.57	1184	60.6	1022	93.66	925	93.86	770	94.02	640	71.99	132	55.7	503	54.7	-63	59.56	-363
113	3	3	41.55	611	38.83	373	41.07	-708	49.76	-355	32.41	220	36.26	236	50.1	143	72.34	143	74.55	149	85.83	446	64.78	101	52.43	460	48.65	13	48.25	-507

spd 15	lp15	sp 16	lp16	sp 17	lp17	sp 18	lp18	sp 19	lp19	sp 20	lp20	sp 21	lp21
65.34	-164	61.52	241	55.88	-275	73.8	-179	89.46	375	98.66	74	98.92	-6
84.1	347	67.53	300	59.86	987	57.03	192	93.37	665	103.33	878	108.94	706
73.75	259	49.89	226	50.67	269	62.53	238	79.53	690	76.4	587	79.82	535
80.7	784	65.59	348	68.07	1437	72.15	-180	92.49	1400	97.49	1046	94.3	688
70.82	306	72.18	196	69.77	410	70.44	367	93.19	623	99.3	809	103.33	582
83.24	210	53.01	560	60.36	371	72.78	395	98.92	917	103.2	777	106.4	474
83.62	291	54.83	403	56.46	108	68.6	103	81.65	468	87.86	476	92.55	449
61.39	154	46.78	793	54.68	511	62.55	501	75.16	364	74.16	683	83.63	548
84.63	-100	68.23	48	59.06	280	72.16	-116	100.27	507	109.38	382	107.87	275
86.87	429	57.22	608	60.66	366	73.7	365	95.86	814	99.04	702	104.56	767
72.52	134	44.09	363	57.73	152	71.05	130	80.74	736	81.09	743	81.41	472
67.54	203	58.15	598	58.99	703	0	0	86.37	974	93.49	743	99.49	383
88.91	153	74.45	-21	74.93	809	0	0	99.71	1196	102.08	908	108	797
70.88	572	64.91	833	57.25	314	59.78	203	85.63	1003	89.36	1051	83.69	696
79.75	822	36.94	728	62.62	781	0	0	95.15	272	98.64	682	100.49	499
96.76	696	78.84	766	76.08	719	0	0	103.95	907	105.16	821	102.74	1042
74.49	1062	74.87	889	57.38	1033	75.09	654	91.49	977	103.73	602	113.55	566
83.94	-137	69.92	223	53.2	504	63.48	-60	95.28	472	103.39	495	106.56	440
83.42	94	65.59	112	75.36	116	72.7	121	104.46	571	110.73	169	115.16	180
63.75	364	46.57	344	48.91	438	50.18	557	68.98	901	66.26	479	68.18	455
77.7	262	68.68	417	50.83	563	62.23	444	82.37	428	91.29	172	98.33	81
104.77	536	73.55	707	76.23	615	85.76	548	109.9	476	116.31	835	111.09	837
58	161	39.64	252	51.92	471	60.56	311	72.66	674	69.98	442	76.93	464
82.55	159	78.96	529	66.88	1207	73.63	124	92.97	864	98.46	657	100.22	653
54.64	345	50.67	333	46.23	975	55.5	631	71.99	669	75.39	507	77.71	588
79.68	292	47.38	164	54.76	406	64.63	182	85.12	724	93.01	367	100	311
57.73	209	41.01	-26	44.43	578	51.62	538	67.71	649	69	580	68.68	581
65.34	321	67.33	431	66.17	718	65.95	326	89.07	687	93.86	660	99.91	569
69.19	52	62.09	132	65.3	497	70.93	786	94	598	100.75	875	97	505
66.46	79	57.9	374	58.54	935	0	0	91.62	795	95.36	551	98.44	564
75.97	168	67.66	380	59.89	386	60.31	549	85.73	536	90.19	451	88.41	292
77.48	192	69.11	477	63.86	303	65.24	354	101.42	695	109.8	684	116.15	803
95.31	552	94.02	583	83.13	148	77.57	759	103.06	481	111.41	1034	118.82	484
94.87	688	67.86	718	70.11	639	78.88	287	93.57	587	101.09	453	107.88	509
76.29	544	65	344	56.2	-36	58.5	-108	91.29	572	95.19	232	96.13	655
71.47	328	60.96	381	54.82	723	56.27	612	69.89	665	72.01	214	74.13	136
74.18	165	64.32	520	57.54	479	61.98	336	88.33	501	87.62	192	84.61	301
82.69	248	74.31	346	65.5	233	60.77	-202	94.44	1280	103.16	846	110.66	586
85.25	98	74.04	332	70.37	0	68.85	0	101.02	374	109.37	307	98.86	361
65.86	429	55.18	377	55.5	337	66.65	463	78.61	779	79.88	923	86.61	617
77.8	383	64.75	410	51.81	337	68.48	386	98.17	309	94.8	706	91.32	716
67.21	242	64.62	1243	56.33	165	57.71	14	76.86	730	85.03	475	92.32	261
97.85	881	75.29	669	75.9	480	81.98	890	106.7	883	111.66	1005	108.18	894
74.68	400	60.1	660	54.45	424	61.6	658	75.5	570	78.67	635	80.51	482
81.97	-253	61.83	-32	65	-485	76.03	225	97.1	-239	96.91	-135	95.91	134
84.85	716	67.8	184	66.36	605	74.98	16	99.27	828	107.18	935	114.47	677
66.81	135	59.96	-30	61.96	401	66.81	717	86.76	520	91.97	185	96.52	491
106.75	411	72.23	755	67.35	711	80.48	-39	110.34	686	116.82	746	115.12	659
66.28	477	58.82	401	55.08	489	63.99	695	84.15	761	86.83	988	88.93	504
85.3	27	79.39	-126	75.48	-338	82.32	118	97.04	299	105.98	57	114.24	603
83.15	305	66.47	93	59.02	726	64.23	511	95.36	975	102.07	832	107.28	786
74.32	454	59.73	505	53.41	135	65.49	-57	95.87	1027	100.62	972	104.61	956
78.78	230	65.23	261	60.26	841	65.02	-92	90.45	871	98.12	916	104	707
58.49	383	53.43	595	46.89	645	56.9	572	77.34	687	85.09	469	91.42	447
82.7	641	59.72	655	61.65	-561	66.43	499	99.13	1232	107.42	770	105.44	-41
91.15	512	70.45	686	67.78	669	74.21	207	100.23	900	104.44	762	93.44	634
83.27	456	63.55	311	59.92	303	67.57	466	87.03	596	93.05	505	98.52	451
52.08	304	46.44	679	43.12	480	45.25	532	49.97	510	56.77	390	62.19	281
65.05	380	50.1	451	59.13	612	64.4	516	85.44	792	91.49	708	92.38	576
70.17	293	63.43	264	57.41	335	64.94	419	83.38	668	92.82	746	94.53	443
74.82	369	50.65	428	53.8	453	66.15	207	81.63	789	85.04	854	88.58	563
93.46	554	84.75	102	74	298	72.37	0	92.97	115	101.43	-31	108.42	10
93.83	819	65.59	587	65.98	490	0	0	93.41	987	96.29	670	103.61	808
87.11	359	64.31	488	63.04	448	58.45	414	98.88	1366	105.97	995	114.01	973
82.2	-113	50.41	117	49.35	143	57.01	-132	87.42	194	91.48	481	90.68	595
87.57	76	63.59	186	56.33	459	66.64	-130	90.52	969	98.03	710	104.5	190
88.67	725	84.93	842	72.58	932	82.46	776	91.81	640	95.99	638	102.65	629
62.16	491	61.41	333	55.46	361	53.55	51	70.2	259	73.03	510	75.66	603
76.34	544	70.96	1056	61.98	1005	63.31	498	89.25	955	95.74	876	95.73	961
73.74	372	68.02	441	60.37	791	59.54	477	85.85	1393	73.92	701	82.2	650
84.44	453	56.75	662	62.06	485	73	413	82.21	786	88.76	836	90.64	751
59.82	511	56.75	658	51.59	867	48.19	640	68	843	69.8	1104	71.45	765
69.05	46	65.84	429	66.39	-40	68.85	108	93.05	558	99.84	340	102.36	-91
84.9	803	71.14	1128	56.67	1580	71.18	638	94.5	962	106.1	1119	107.98	1171
62.72	202	51.15	287	59.07	695	64.62	413	91.72	842	93.05	552	79.64	445
108.94	604	97.02	800	80.02	772	88.72	1080	109.67	740	117.35	812	118.71	1023
100.32	631	67.99	620	70.14	1320	86.02	886	104.97	1097	114.39	1069	123.16	867
95.37	140	67.97	291	64.09	704	73.28	771	98.63	740	107.83	719	115.92	629
88.45	174	74.63	364	65.33	779	68.42	847	95.31	768	99.46	785	105.59	318
84.1	564	76.16	947	65.75	1255	69.44	910	94.64	452	96.01	704	91.52	506
85.46	388	59.03	398	62.54	679	72.95	468	102.19	821	110.18	552	115.63	481
101.69	661	75.81	696	69.03	1053	82.14	202	109.52	845	113.32	825	116.37	770
94.93	-782	76.77	149	72.47	451	80.31	876	97.14	654	106.01	335	114	131
78.56	397	61.22	249	63.98	752	62.79	769	77.71	488	81.92	479	84.81	484
80.45	764	50.04	694	50.92	33	57.15	-217	88.34	142	100.7	94	106.35	50
96.66	109	92.04	833	81.18	912	75.95	679	90.39	692	87.54	673	87.76	755
88.16	171	53.64	522	52.63	926	69.3	694	95.45	646	86.21	765	86.68	723

76.93	436	65.46	233	59.24	771	67.03	185	86.27	838	94.42	946	97.27	1066
67.44	719	66.24	242	61.45	759	66.61	696	98.49	385	102.51	499	104.25	187
72	281	65.77	755	59.15	724	63.41	289	76.75	706	78.18	330	80.53	187
76.66	517	54.1	448	57.2	750	60.38	480	87.09	641	90.13	779	91.57	788
60.09	326	44.33	59	54.27	703	62.32	227	80.01	722	70.37	729	73.75	680
76.14	142	82.56	-164	69.96	454	72.37	42	94.38	89	100.4	-4	108.14	75
58.04	361	37.76	259	40.76	391	46.1	-57	71.3	634	75.29	511	72.14	356
91.75	308	72.34	338	68.53	8	76.3	-52	100.28	7	99.01	-192	86.3	-119
86.29	320	65.27	411	65.36	347	68.61	183	100.04	532	104.85	169	111.98	348
74.33	156	61.54	750	55.39	752	56.96	289	67.84	881	76.6	675	85.89	985
105.2	358	56.72	406	65.35	416	80.68	0	110.52	332	117.25	816	121.06	724
84.32	229	76.29	299	68.25	108	74.49	740	84.44	1193	92.35	1018	98.69	425
85.71	517	62.12	766	66.65	600	74.25	696	99.16	909	96.99	707	98.92	1014
92.18	183	73.41	1150	67.88	1348	65.15	403	79.68	683	90.2	531	98.99	700
73.15	37	66.27	575	62.74	288	59.5	-25	72.14	847	84.08	1119	93.43	20
92.17	560	62.28	439	61.05	541	69.16	471	102.5	959	104.29	692	110.86	687
86.42	-24	70.65	458	66.94	415	79.34	134	99.26	760	109.76	552	108.73	645
77.94	504	68.52	809	57.17	930	70.96	806	95.33	851	93.37	728	96.81	692
82.24	152	75.56	-104	74.83	630	74.7	0	98.14	849	106.03	992	111.82	505
82.26	685	68.53	600	66.24	1347	68.61	1063	93.59	1163	93.27	981	93.59	1015
92.53	229	82.01	154	71.99	413	80.22	1047	97.56	880	110.05	832	115.43	461
81.02	560	70.9	847	69.19	977	82.9	678	90.89	954	96.57	479	87.44	368
95.68	848	82.87	525	68.68	1136	80.47	443	107.45	1143	117.92	546	125.21	811
64.41	886	54.2	1055	52.62	967	60.54	430	90.43	1130	99.2	758	105	909
85.88	818	76.16	938	71.44	738	77.36	533	97.09	780	104.04	668	110.09	824
92.8	428	73.56	440	64.56	626	76.91	86	99.31	377	110.87	318	119.94	43
93.99	309	70.5	52	64.74	913	74.99	623	101.65	335	109.73	331	109.35	223
68.88	170	61.78	25	61.9	764	65.53	445	88.27	786	94.36	758	94.63	584
87.74	528	59.47	524	63.82	1037	71.16	20	96.36	725	102.26	608	105.79	784
63.39	418	40.61	209	46.81	251	52.85	389	69.9	597	79.73	773	82.61	608
51.82	348	45.86	465	42.73	1061	52.48	-131	74.53	484	72.31	493	72.17	501
68.68	772	52.67	306	55.29	727	61.7	286	90.64	929	85.6	525	87.27	509
81.86	-278	68.76	119	66.12	463	69.88	239	72.21	480	81.92	146	87.38	146
67	449	55.41	585	47.5	1192	50.27	407	73.2	626	66.67	662	78.12	578
80.99	318	54.91	160	57.5	518	66.33	388	88.93	360	94.36	561	96.15	579
51.06	455	43.18	340	49.76	612	60.39	356	62.35	804	64.45	683	72.59	779
63.09	272	43.29	339	45.77	549	54.86	95	71.52	659	75.98	688	80.91	563
77.85	293	65.58	225	59.64	727	65.95	0	97.67	669	101.69	785	108.12	481
79.13	196	67.37	248	69.38	473	73.74	137	96.49	586	104.1	346	108.25	-218
80.12	429	64.42	130	68.02	502	70.93	0	90.3	498	98.83	648	92.42	651
78.36	-51	58.12	110	52.52	604	60.3	-132	90.06	409	89.82	249	88.27	273

Appendix 5-13: Simulator experiment - Instructions

Institute for Transport Studies, University of Leeds

VALIDATION EXPERIMENT

INSTRUCTIONS

We would like you to drive on a single carriageway A road as you would normally drive in real life. The test road is 3 miles long including straight and curved road sections and we would like you to repeat it three times. Between each run we would be grateful if you could fill in a questionnaire regarding simulator sickness. You will have a practice run in the beginning, around 6 min. and the test run will last approximately 40 minutes. After the three runs you will have to fill in another questionnaire regarding the realism of the simulator. If you feel uncomfortable for any reason please let me know.

Appendix 5-14: Simulator experiment - Wellbeing scale (Pre-tasks)

Institute for Transport Studies, University of Leeds

VALIDATION EXPERIMENT

Wellbeing Scale (**Pre Tasks**)

Subject ID .... Date: ....

Consider how well you are feeling now. From the list of symptoms below, please indicate the extent you are currently experiencing each:

	Extent (Circle your response)			
Symptom	None	Slight	Moderate	Severe
1. General discomfort	1	2	3	4
2. Fatigue	1	2	3	4
3. Headache	1	2	3	4
4. Eyestrain	1	2	3	4
5. Difficulty focusing	1	2	3	4
6. Increased salivation	1	2	3	4
7. Sweating	1	2	3	4
8. Nausea	1	2	3	4
9. Difficulty concentrating	1	2	3	4
10. Fullness of head	1	2	3	4
11. Blurred vision	1	2	3	4
12. Dizzy (eyes open)	1	2	3	4
13. Dizzy (eyes closed)	1	2	3	4
14. Vertigo	1	2	3	4
15. Stomach awareness	1	2	3	4
16. Burping	1	2	3	4

Appendix 5-14: Simulator experiment - Wellbeing scale

Institute for Transport Studies, University of Leeds

VALIDATION EXPERIMENT

Wellbeing Scale

Subject ID .... Test Run: .... Date: ....

Consider how well you are feeling now. From the list of symptoms below, please indicate the extent you are currently experiencing each:

	Extent (Circle your response)			
Symptom	None	Slight	Moderate	Severe
1. General discomfort	1	2	3	4
2. Fatigue	1	2	3	4
3. Headache	1	2	3	4
4. Eyestrain	1	2	3	4
5. Difficulty focusing	1	2	3	4
6. Increased salivation	1	2	3	4
7. Sweating	1	2	3	4
8. Nausea	1	2	3	4
9. Difficulty concentrating	1	2	3	4
10. Fullness of head	1	2	3	4
11. Blurred vision	1	2	3	4
12. Dizzy (eyes open)	1	2	3	4
13. Dizzy (eyes closed)	1	2	3	4
14. Vertigo	1	2	3	4
15. Stomach awareness	1	2	3	4
16. Burping	1	2	3	4

Appendix 5-15: Simulator experiment - Consent and payment forms

Institute for Transport Studies, University of Leeds

VALIDATION EXPERIMENT

CONSENT FORM

I ....of (address) ....
....have had the nature of the experiment explained to me by the experimenter ....

I understand I can withdraw from the experiment at any time.

I fully understand the nature of the experiment and agree to take part.

Signature: Date:

PAYMENT FORM

I .... have received the sum of £7 for completing the above experiment.

Signature: Date:

Appendix 5-16: Simulator experiment - Post-experiment questionnaire

Institute for Transport Studies, University of Leeds

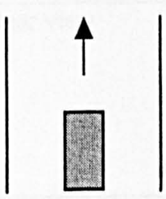
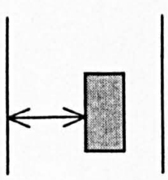
VALIDATION EXPERIMENT

DATA SHEET 3: POST-EXPERIMENT QUESTIONNAIRE

Sub No: .... Date:..................

The aim of this experiment was to assess the validity of the Leeds Advanced Driving Simulator. This will be achieved by investigating the longitudinal and lateral control of the simulated vehicle (i.e. the speed of the vehicle as it moves from a point A (start of the test road) to a point B (end of the test road) and the position of the vehicle inbetween the white lines of the left roadedge line and the centre line as it moves from point A to point B, respectively). This questionnaire is the last part of your contribution to this experiment. Your opinion will considerably help us to further improve the realism of our simulator, therefore I would appreciate if you could carefully fill in the questionnaire by circling a number on the rating scale (1 to 5).

Realism of the longitudinal and lateral control of the simulated vehicle

Overall journey		**Rating scale**		
1. Longitudinal control of the simulator	a1) How easy was controlling the speed of the simulator on straight road sections?	Very easy	1 2 3 4 5	Very difficult
	a2) How realistic was it driving on straight road sections (in terms of speed)?	Not at all	1 2 3 4 5	Very much
	b1) How easy was controlling the speed of the simulator on curved road sections?	Very easy	1 2 3 4 5	Very difficult
	b2) How realistic was it driving on curved road sections (in terms of speed)?	Not at all	1 2 3 4 5	Very much
2. Lateral control of the simulator	a1) How easy was controlling the lateral position of the simulator on straight road sections?	Very easy	1 2 3 4 5	Very difficult
	a2) How realistic was it driving on straight road sections (in terms of lateral position)?	Not at all	1 2 3 4 5	Very much
	b1) How easy was controlling the lateral position of the simulator on curved road sections?	Very easy	1 2 3 4 5	Very difficult
	b2) How realistic was it driving on curved road sections (in terms of lateral position)?	Not at all	1 2 3 4 5	Very much
3. Steering wheel	How realistic did you find the feeling of the steering wheel?	Not at all	1 2 3 4 5	Very much
4. Braking	How realistic did you think the brakes felt?	Not at all	1 2 3 4 5	Very much

Realism of other aspects of the simulator

Overall journey		**Rating scale**		
1. Monotony	How did you find the overall driving task?	Not at all monotonous	1 2 3 4 5	Very monotonous
2. Oncoming traffic	When driving on <u>straight</u> sections do you think the oncoming traffic, made you a1) increase your speed a2) decrease your speed	Not at all	1 2 3 4 5	Very much
	a3) had no effect on your speed b1) drive closer to the left roadedge line b2) drivecloser to the centre line	Not at all	1 2 3 4 5	Very much
	b3) had no effect on your lateral position			
	When driving on <u>curved</u> sections, do you think the oncoming traffic, made you a) increase your speed b) decrease your speed	Not at all	1 2 3 4 5	Very much
	c) had no affect in your speed b1) drive closer to the left roadedge line b2) drive closer to the centre line	Not at all	1 2 3 4 5	Very much
	b3) had no effect on your lateral position			
4. Rear view	a) Did you use the rear-view mirror when driving?	Not at all	1 2 3 4 5	Very much
	b) Did you use the right-hand wing mirror when driving?	Not at all	1 2 3 4 5	Very much

Any other comments

Please add any other comments which you think would be useful to us.

Appendix 6

Table 6-1 Subjects' individual characteristics by age category and occupation

Subjects' individual characteristics		Age category of Male (M) and Female (F) subjects in years								Total (N=100)	
		20-25		26-30		31-40		>40			
		M	F	M	F	M	F	M	F	M	F
Occupation	student	1	1	5	6	4	2	0	0	21	22
	researcher	4	2	6	5	4	2	2	1	16	10
	other	1	1	5	5	4	8	3	4	13	18

Table 6-2 Subjects' individual characteristics by age category and vision

Subjects' individual characteristics		Age category of Male (M) and Female (F) subjects in years								Total (N=100)	
		20-25		26-30		31-40		>40			
		M	F	M	F	M	F	M	F	M	F
Vision	glasses	6	5	4	7	3	3	4	2	17	17
	contact lenses	1	2	3	3	0	1	0	0	4	6
	nothing	1	1	9	6	9	8	1	3	29	27

Table 6-3 Subjects' individual characteristics by age category and advertisment

Subjects' individual characteristics		Age category of Male (M) and Female (F) subjects in years								Total (N=100)	
		20-25		26-30		31-40		>40			
		M	F	M	F	M	F	M	F	M	F
Where subjects found out about the experiment	Uni of Leeds	1	7	10	8	8	7	1	1	31	23
	Sports Centre	2	0	0	0	0	0	0	0	2	0
	Friend	3	5	6	7	4	5	4	4	17	21
	Leeds Met Uni	0	5	0	1	0	0	0	0	0	6

Table 6-4 Subjects' individual characteristics by age category and number of years holding a driving license

Subjects' individual characteristics		Age category of Male (M) and Female (F) subjects in years								Total (N=100)	
		20-25		26-30		31-40		>40 years			
		M	F	M	F	M	F	M	F	M	F
Dr. Lic. (years)	3-5	7	8	2	0	3	0	3	0	15	8
	6-10	10	9	10	10	0	1	0	0	20	20
	>10	0	0	4	6	9	11	2	5	15	22

Table 6-5 Subjects' individual characteristics by age category and mileage driven per year

Subjects' individual characteristics		Age category of Male (M) and Female (F) subjects in years								Total (N=100)	
		20-25		26-30		31-40		>40 years			
		M	F	M	F	M	F	M	F	M	F
Mileage driven per year	<5000	10	7	7	4	5	3	0	0	22	14
	5000-10000	4	7	4	6	4	5	2	1	14	19
	10001-15000	2	2	3	2	3	3	0	2	8	9
	>15000	1	1	2	4	0	1	3	2	6	8

Table 6-6 Subjects' individual characteristics by age category and advanced lessons

Subjects' individual characteristics		Age category of Male (M) and Female (F) subjects in years								Total (N=100)	
		20-25		26-30		31-40		>40 years			
		M	F	M	F	M	F	M	F	M	F
Adv. Les. (taken)	Yes	2	2	2	2	2	1	2	3	8	8
	no	15	1	14	14	10	11	3	2	42	42

Table 6-7 Subjects' individual characteristics by age category and familiarity with the simulator

Subjects' individual characteristics		Age category of Male (M) and Female (F) subjects in years								Total (N=100)	
		20-25		26-30		31-40		>40 years			
		M	F	M	F	M	F	M	F	M	F
Simulator (driven before)	yes	3	5	4	5	4	3	2	1	13	14
	no	14	1	12	11	8	9	3	4	37	36

Table 6-8 Subjects' individual characteristics by age category and familiarity with computer/arcade games)

Subjects' individual characteristics		Age category of Male (M) and Female (F) subjects in years								Total (N=100)	
		20-25		26-30		31-40		>40 years			
		M	F	M	F	M	F	M	F	M	F
Familiarity with computer/ arcade games	not at all	0	7	4	7	6	8	2	4	12	26
	1/year	3	4	7	8	2	2	2	1	14	15
	1/month	9	3	3	0	3	0	1	0	16	3
	> 1/week	5	3	2	1	1	2	0	0	8	6

Table 6-9 Correlation Coefficients

	CONLP_CU	CONLP_ST	CONS_CU	CONS_STR	REALP_CU	REALP_ST
CONLP_CU	1.0000	.3576	.3261	.2059	-.1529	-.0982
	(97)	(97)	(96)	(97)	(97)	(97)
	P= .	P= .000	P= .001	P= .043	P= .135	P= .338
CONLP_ST	.3576	1.0000	.1571	.4321	-.0767	-.2582
	(97)	(97)	(96)	(97)	(97)	(97)
	P= .000	P= .	P= .126	P= .000	P= .455	P= .011
CONS_CU	.3261	.1571	1.0000	.3255	-.1644	-.1973
	(96)	(96)	(96)	(96)	(96)	(96)
	P= .001	P= .126	P= .	P= .001	P= .109	P= .054
CONS_STR	.2059	.4321	.3255	1.0000	-.1667	-.2292
	(97)	(97)	(96)	(97)	(97)	(97)
	P= .043	P= .000	P= .001	P= .	P= .103	P= .024
REALP_CU	-.1529	-.0767	-.1644	-.1667	1.0000	.4083
	(97)	(97)	(96)	(97)	(97)	(97)
	P= .135	P= .455	P= .109	P= .103	P= .	P= .000
REALP_ST	-.0982	-.2582	-.1973	-.2292	.4083	1.0000
	(97)	(97)	(96)	(97)	(97)	(97)
	P= .338	P= .011	P= .054	P= .024	P= .000	P= .
REAS_CU	-.2075	-.0447	-.1356	-.1409	.3084	.1708
	(97)	(97)	(96)	(97)	(97)	(97)
	P= .041	P= .664	P= .188	P= .169	P= .002	P= .094
REAS_ST	-.0189	-.1366	-.3556	-.3331	.2813	.4166
	(97)	(97)	(96)	(97)	(97)	(97)
	P= .855	P= .182	P= .000	P= .001	P= .005	P= .000
SP_STR	.1153	.2535	.1104	.1236	-.0822	.0215
	(97)	(97)	(96)	(97)	(97)	(97)
	P= .261	P= .012	P= .284	P= .228	P= .423	P= .835
SPEED_CU	.0478	.1933	.0823	.1249	-.1319	.0272
	(97)	(97)	(96)	(97)	(97)	(97)
	P= .642	P= .058	P= .426	P= .223	P= .198	P= .792
LP_CURV	.0206	-.0093	.0768	.1808	-.0216	.1362
	(97)	(97)	(96)	(97)	(97)	(97)
	P= .841	P= .928	P= .457	P= .076	P= .834	P= .184
LP_STR	-.0209	.1360	.1405	.2162	-.0173	.0409
	(97)	(97)	(96)	(97)	(97)	(97)
	P= .839	P= .184	P= .172	P= .033	P= .866	P= .691
AGE	.1681	-.1060	.0803	-.1471	-.0692	-.0616
	(97)	(97)	(96)	(97)	(97)	(97)
	P= .100	P= .301	P= .437	P= .151	P= .500	P= .549
DRI_LIC	.1591	-.0996	.0931	-.2008	-.1180	.0357
	(97)	(97)	(96)	(97)	(97)	(97)
	P= .119	P= .332	P= .367	P= .049	P= .250	P= .729

	CONLP_CU	CONLP_ST	CONS_CU	CONS_STR	REALP_CU	REALP_ST
MILEAGE	-.1288	-.0904	-.0885	-.1710	.2341	.1639
	(97)	(97)	(96)	(97)	(97)	(97)
	P= .208	P= .379	P= .391	P= .094	P= .021	P= .109
SEX	.0707	-.0228	.2256	.0178	.0680	-.1958
	(97)	(97)	(96)	(97)	(97)	(97)
	P= .492	P= .825	P= .027	P= .863	P= .508	P= .055
BRAKING	-.2199	-.1290	-.1717	-.1659	.0525	.1680
	(97)	(97)	(96)	(97)	(97)	(97)
	P= .030	P= .208	P= .094	P= .104	P= .610	P= .100
STEERING	-.2182	-.3840	-.2350	-.2362	.2689	.1892
	(97)	(97)	(96)	(97)	(97)	(97)
	P= .032	P= .000	P= .021	P= .020	P= .008	P= .063

	REAS_CU	REAS_ST	SP_STR	SPEED_CU	LP_CURV	LP_STR
CONLP_CU	-.2075	-.0189	.1153	.0478	.0206	-.0209
	(97)	(97)	(97)	(97)	(97)	(97)
	P= .041	P= .855	P= .261	P= .642	P= .841	P= .839
CONLP_ST	-.0447	-.1366	.2535	.1933	-.0093	.1360
	(97)	(97)	(97)	(97)	(97)	(97)
	P= .664	P= .182	P= .012	P= .058	P= .928	P= .184
CONS_CU	-.1356	-.3556	.1104	.0823	.0768	.1405
	(96)	(96)	(96)	(96)	(96)	(96)
	P= .188	P= .000	P= .284	P= .426	P= .457	P= .172
CONS_STR	-.1409	-.3331	.1236	.1249	.1808	.2162
	(97)	(97)	(97)	(97)	(97)	(97)
	P= .169	P= .001	P= .228	P= .223	P= .076	P= .033
REALP_CU	.3084	.2813	-.0822	-.1319	-.0216	-.0173
	(97)	(97)	(97)	(97)	(97)	(97)
	P= .002	P= .005	P= .423	P= .198	P= .834	P= .866
REALP_ST	.1708	.4166	.0215	.0272	.1362	.0409
	(97)	(97)	(97)	(97)	(97)	(97)
	P= .094	P= .000	P= .835	P= .792	P= .184	P= .691
REAS_CU	1.0000	.4425	-.0914	-.1548	.0984	.0590
	(97)	(97)	(97)	(97)	(97)	(97)
	P= .	P= .000	P= .373	P= .130	P= .338	P= .566
REAS_ST	.4425	1.0000	-.0313	-.0451	.0360	-.0414
	(97)	(97)	(97)	(97)	(97)	(97)
	P= .000	P= .	P= .761	P= .661	P= .726	P= .687
SP_STR	-.0914	-.0313	1.0000	.8187	.0638	.1363
	(97)	(97)	(97)	(97)	(97)	(97)
	P= .373	P= .761	P= .	P= .000	P= .534	P= .183
SPEED_CU	-.1548	-.0451	.8187	1.0000	.0172	.0737
	(97)	(97)	(97)	(97)	(97)	(97)
	P= .130	P= .661	P= .000	P= .	P= .867	P= .473

	REAS_CU	REAS_ST	SP_STR	SPEED_CU	LP_CURV	LP_STR
LP_CURV	.0984 (97) P= .338	.0360 (97) P= .726	.0638 (97) P= .534	.0172 (97) P= .867	1.0000 (97) P= .	.7973 (97) P= .000
LP_STR	.0590 (97) P= .566	-.0414 (97) P= .687	.1363 (97) P= .183	.0737 (97) P= .473	.7973 (97) P= .000	1.0000 (97) P= .
AGE	.0394 (97) P= .701	.0703 (97) P= .494	-.2206 (97) P= .030	-.2739 (97) P= .007	.1404 (97) P= .170	.0906 (97) P= .377
DRI_LIC	-.0299 (97) P= .771	.0668 (97) P= .515	-.0814 (97) P= .428	-.2250 (97) P= .027	.2268 (97) P= .026	.1754 (97) P= .086
MILEAGE	-.0042 (97) P= .967	.2011 (97) P= .048	-.0741 (97) P= .471	-.1122 (97) P= .274	.1424 (97) P= .164	.0776 (97) P= .450
SEX	.0399 (97) P= .698	-.0556 (97) P= .589	-.0297 (97) P= .773	-.2379 (97) P= .019	-.1974 (97) P= .053	-.1139 (97) P= .267
BRAKING	.0322 (97) P= .754	.1952 (97) P= .055	.0488 (97) P= .635	-.0545 (97) P= .596	-.0898 (97) P= .382	.0605 (97) P= .556
STEERING	.1885 (97) P= .064	.3026 (97) P= .003	-.1317 (97) P= .198	-.1640 (97) P= .109	-.2046 (97) P= .044	-.2273 (97) P= .025

	AGE	DRI_LIC	MILEAGE	SEX	BRAKING	STEER.
CONLP_CU	.1681 (97) P= .100	.1591 (97) P= .119	-.1288 (97) P= .208	.0707 (97) P= .492	-.2199 (97) P= .030	-.2182 (97) P= .032
CONLP_ST	-.1060 (97) P= .301	-.0996 (97) P= .332	-.0904 (97) P= .379	-.0228 (97) P= .825	-.1290 (97) P= .208	-.3840 (97) P= .000
CONS_CU	.0803 (96) P= .437	.0931 (96) P= .367	-.0885 (96) P= .391	.2256 (96) P= .027	-.1717 (96) P= .094	-.2350 (96) P= .021
CONS_STR	-.1471 (97) P= .151	-.2008 (97) P= .049	-.1710 (97) P= .094	.0178 (97) P= .863	-.1659 (97) P= .104	-.2362 (97) P= .020
REALP_CU	-.0692 (97) P= .500	-.1180 (97) P= .250	.2341 (97) P= .021	.0680 (97) P= .508	.0525 (97) P= .610	.2689 (97) P= .008
REALP_ST	-.0616 (97) P= .549	.0357 (97) P= .729	.1639 (97) P= .109	-.1958 (97) P= .055	.1680 (97) P= .100	.1892 (97) P= .063

	AGE	DRI_LIC	MILEAGE	SEX	BRAKING	STEERING
REAS_CU	.0394 (97) P= .701	-.0299 (97) P= .771	-.0042 (97) P= .967	.0399 (97) P= .698	.0322 (97) P= .754	.1885 (97) P= .064
REAS_ST	.0703 (97) P= .494	.0668 (97) P= .515	.2011 (97) P= .048	-.0556 (97) P= .589	.1952 (97) P= .055	.3026 (97) P= .003
SP_STR	-.2206 (97) P= .030	-.0814 (97) P= .428	-.0741 (97) P= .471	-.0297 (97) P= .773	.0488 (97) P= .635	-.1317 (97) P= .198
SPEED_CU	-.2739 (97) P= .007	-.2250 (97) P= .027	-.1122 (97) P= .274	-.2379 (97) P= .019	-.0545 (97) P= .596	-.1640 (97) P= .109
LP_CURV	.1404 (97) P= .170	.2268 (97) P= .026	.1424 (97) P= .164	-.1974 (97) P= .053	-.0898 (97) P= .382	-.2046 (97) P= .044
LP_STR	.0906 (97) P= .377	.1754 (97) P= .086	.0776 (97) P= .450	-.1139 (97) P= .267	.0605 (97) P= .556	-.2273 (97) P= .025
AGE	1.0000 (97) P= .	.6517 (97) P= .000	.3331 (97) P= .001	.0326 (97) P= .751	-.1048 (97) P= .307	.0562 (97) P= .584
DRI_LIC	.6517 (97) P= .000	1.0000 (97) P= .	.2727 (97) P= .007	.0666 (97) P= .517	.0386 (97) P= .708	.0873 (97) P= .395
MILEAGE	.3331 (97) P= .001	.2727 (97) P= .007	1.0000 (97) P= .	-.0487 (97) P= .635	.0830 (97) P= .419	.0436 (97) P= .671
SEX	.0326 (97) P= .751	.0666 (97) P= .517	-.0487 (97) P= .635	1.0000 (97) P= .	.0193 (97) P= .851	.0520 (97) P= .613
BRAKING	-.1048 (97) P= .307	.0386 (97) P= .708	.0830 (97) P= .419	.0193 (97) P= .851	1.0000 (97) P= .	.1080 (97) P= .292
STEERING	.0562 (97) P= .584	.0873 (97) P= .395	.0436 (97) P= .671	.0520 (97) P= .613	.1080 (97) P= .292	1.0000 (97) P= .

(Coefficient / (Cases) / 2-tailed Significance)

" . " is printed if a coefficient cannot be computed