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Design and Development of a Bus Simulator for Bus Driver Training

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ABSTRACT

The bus industry is plagued by high accident costs and risks of passenger injuries. A bus simulator may offer a method of reducing accident rates by delivering targeted training to bus drivers who are most at risk.

The first part of this thesis describes the design of the UK's first bus simulator, the fidelity of which was based on a thorough analysis of bus crashes. The second part describes the first studies in a multi-staged method to evaluate the training effectiveness of the simulator: face validity, effects of bus driver experience and stress on simulated performance and simulator sickness. This approach ensured that the ABS has a reasonable level of fidelity, is capable of eliciting behaviourally valid responses from bus drivers and is the first step is achieving training transfer effectiveness. The final study investigated the occurrence of self-bias in bus drivers. The conclusions drove the design of simulated scenarios to be used for bus driver training.

Keywords:
Bus, Simulator, Fidelity, Validity, Accidents, Driving, Stress, Training

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1.1 Introduction to Literature Review

In 2004, 2,978 people were killed and 204,432 were injured in traffic accidents in the UK (DFT, 2004). Many of these accidents involved people who drive as part of their occupation, with some estimates being as much as 30% (e.g. Broughton, Baughan, Pearce, Smith and Buckle (2003). Given that there are over 156,000 bus and coach drivers driving approximately 80,000 vehicles over 4.1 billion vehicle km in the UK every year (Confederation of Passenger Transport, 2005), clearly the passenger services industry is making a contribution to the high number of work related accidents. Although only 3% accidents on all trunk roads involve a bus or a coach, these accidents are likely to have a large number of casualties due to the number of passengers that these vehicles carry (Highways Agency, 2005) but this information is difficult to access given that it is not recorded by any central agency. However, it is known that in 2000, there were 149 people killed and 16,412 people injured in an accident involving a bus or coach (The Highways Agency, 2005). Although poor road and vehicle conditions may be partly to blame, Sabey and Staughton (1975) suggested that human behaviour accounted for approximately 90% of the causes of all accidents. Of these accidents, Lewin (1982) claims that 85-90% could have been avoided if the drivers involved had been routinely alert, safe and skilful.
This problem has been recognised by Arriva Bus UK, a major player in the passenger services industry, who in 2001 spent over £15 million to cover the cost of bus accident repairs and litigation. As a company, Arriva Bus UK has approximately 18,000 incidents on the road every year. While there are several proactive risk schemes with the aim of reducing accidents in place across Arriva Bus UK, for example a psychometric test for predicting bus driver behaviour (Garwood and Dorn, 2004) and a bus driving skills CD-Rom that is designed to raise bus drivers awareness of their own skills (see Dorn, Garwood and Muncie, 2002), to date it is too early to evaluate the effectiveness of these measures on accident rates.

With regards to bus drivers, Arriva Bus UK consider that high accident rates may be attributed to poor driver behaviour and insufficient training in the skills required to effectively drive a bus. To explain, the passenger services industry is plagued by the problem of driver shortages and high staff turnover, which in turn exacerbates the problem of driver shortage and creates an urgent need to recruit and train new bus drivers. New recruits receive approximately two weeks of classroom-based and in vehicle training in a driving school (Foran, 2002). Once they have passed their test, there follows a stage of confidence building, where the driver learns to apply their new skills in everyday traffic under the guidance of a mentor before they are put in sole charge of a vehicle. Arriva Bus UK recognises that during this stage of skills consolidation (Anderson, 1983) it is vital to encourage safe driving strategies to reduce risk taking and involvement in accidents. However, due to driver shortages the mentor period only lasts between 1 day and 2 weeks depending on the resources available.

Moreover the mentor drivers are not trained to conduct the supervision of novice drivers (Carney, 2002). While novice bus drivers have mastered the techniques of manoeuvring a bus when they pass their PCV driving test, there is little opportunity to provide driver training in work conditions; hazard perception skills and decision-making whilst driving a bus full of passengers in dense urban traffic is quite different to the training and testing regime for PCV licence acquisition. Therefore novice bus drivers are often ill-equipped to deal with driving for work under demanding conditions despite having passed their PCV test.

One way to reduce the problem of accident rates is to introduce a safe, cost effective method of increasing a bus driver's prior knowledge and skills. There have been a number of successful interventions aimed at increasing novice driver's risk awareness using PC or simulator based training products (e.g. Fisher et al, 2002; Regan et al, 1999). There is every reason to suggest that the same will hold true for novice bus drivers. A bus simulator is a useful tool to train drivers in critical traffic conditions that are rarely encountered in traditional in-vehicle training, but are events that may lead to bus incidents (Dorn et al., 2002). Importantly, simulator-based training can be delivered without risk to bus drivers, their passengers and vehicles.

The chapters that follow provide a theoretical background for the development of a bus driver training simulator for improving skills and reducing accidents. The first section introduces some of the known factors that contribute to accidents, particularly driver stress and skill deficits due to driver age and experience. It is important to understand the relevance of the literature to bus driving so that the driver characteristics that may lead to higher risk of bus accidents can be considered. This is followed by an account of the contribution of current driver training methods to improve driver behaviour and accident rates using simulator based training. Next, issues in the development of simulators are considered in terms of optimising the transfer of skills learned in the simulator to the operational environment. This is to ensure that the design and construction of the bus simulator proceeds in accordance with bus driver training needs and that the training scenarios implemented in the simulator are representative of typical bus driving. Finally, methods for evaluating the effectiveness of simulators are considered. The conclusions drawn from the literature review will direct the aims of the current research, which is to ensure that the bus drivers' behaviour in the simulator is consistent with driving a bus in the real world so that the simulator is fit for purpose.

1.2 Bus Driver Behaviour and Training

1.2.1 Bus Driver Risk Taking

Bus drivers have the responsibility for assuring the safety of their passengers but bus driver risk taking compromises the safety of other road users and passengers (Mizra et al, 1999; Hamed et al, 2000). For example, Mizra et al (1999) highlighted the prevalence of risk taking and poor decision-making amongst Karachian bus drivers. Although bus drivers did not break the speed limit, the behaviours observed included racing, overtaking and cutting up other vehicles; continuing through red traffic lights, stopping in the centre of the road or too far away from the pavement so that passengers had to negotiate traffic to get to the pavement; double parking at bus stops, stopping before or after bus stops and not stopping completely at bus stops so that passengers were forced to alight while the vehicle was in motion. This behaviour persisted in spite of the presence of traffic police, and in some cases was observed to be worse. In a survey-based study of 179 bus drivers by Hamed et al (2000), self-reported behaviour confirmed Mizra et al's observations that although bus drivers were aware that long shifts, eating, smoking and drinking while driving and jumping red lights increased their risk of being involved in an accident, they still took risks. For example, 35% of bus drivers admitted to jumping red lights. In addition to this, they defined a good driver as one who minimises travel time by overtaking other drivers and by speeding. The survey also revealed that passengers perceived these behaviours were a threat to their personal safety and considered bus drivers to be high risk takers.

Although both of these studies were conducted outside the UK, comparable behaviours can be seen on British roads. In the UK, there are strict traffic laws in place to protect the safety of road users, but traffic offences are regularly committed by drivers, including bus drivers. Simply having traffic rules and regulations are not deterrents for risky behaviour. Perhaps then bus drivers have insufficient knowledge of the highway code. For example, Katwal and Kamalanabhan (2001) found that accident involved bus drivers had a poorer knowledge of road and traffic rules than their accident free colleagues, suggesting a training need. Alternatively, perhaps driver characteristics are important factors in predicting risk taking. For example, Sullman et al (2003) surveyed New Zealand truck drivers (who share similar organisational problems to bus drivers) and found that a driver's age and experience was highly correlated with traffic violations, risk-taking and speed. Traffic violations were found to be the single most significant predictor of accidents. Perhaps then bus driver's believe that they have sufficient skills to be able to take risks without having an accident (Groeger & Brown, 1989; Svenson, 1981; Svenson, Fischhoff, & MacGregor, 1985) when compared with the average driver (McKenna, 1993; Svenson, 1981; Svenson, Fischhoff, & MacGregor, 1985). Alternatively, bus driver risk-taking may be attributed to immaturity or a lack of bus driving experience. More experienced bus drivers may have a better understanding of the safety culture within the organisation or may have been involved in accidents before and so are aware of the consequences of engaging in risky behaviour. While the role of age and experience on bus driving has received little attention, research on car drivers show significant age and experience related differences in driver characteristics and driving behaviour. The effects of age and experience as predictors of accidents will be discussed in the following sections to provide a background for the implications of this literature for bus drivers.

1.2.2 Age and Experience as Predictors of Accidents

Age and experience are most commonly used as predictors of accidents. As a rule there is a general decline in accident rates with experience (Evans & Courtney, 1985; Peck, 1993) but the relationship between accident frequency and annual mileage is not proportional (Maycock, Lockwood and Lester, 1991). Various researchers concur that younger drivers have the highest risk of being involved in an accident (Evans and

Courtney, 1985, Kweon and Kockelman, 2003) but when driving exposure in terms of annual mileage is considered, both young and old drivers have the highest accident rates when compared with middle aged drivers (Abdel-Aty et al, 1998; Chipman et al, 1992; Lockwood and Lester, 1991; Ryan, Legge, and Rosman, 1998). However, the nature and circumstances of traffic accidents are different for drivers of different ages (Boyce and Geller, 2002; Clarke, Ward and Jones, 1998; Cooper, 1990; Evans and Wasielewski, 1982; McGwin and Brown, 1999). For example, younger drivers are more likely to be involved in accidents late at night, older drivers are more likely to suffer from impairments due to illness and middle-aged drivers are more often involved in alcohol-related accidents (McGwin and Brown, 1999).

It is particularly important for the present research to understand the mechanisms underlying these differential accident rates. One hypothesis for the high accident rate of novice drivers is that they are deficient in a number of driving-related skills. Support for this stems from Drummond's (1989) review of the literature on novice driver performance issues. Drummond concluded that, in comparison to more experienced drivers, novices suffer from deficits in sensation, perception, cognitive processing, psychomotor abilities, selective abilities, selective attention, and knowledge of driving. More specifically, several studies have shown that experienced and expert car drivers detect hazards more accurately and faster than novice car drivers (McKenna and Crick, 1991; 1994) and that risk perception (the ability to detect, perceive and assess the degree of risk in driving); attentional control (the ability to prioritise attention), time-sharing (the ability to share limited attention between multiple competing tasks) and calibration (the ability to moderate task demands according to one's own performance capabilities) are important skills that are often lacking in novice car drivers (Triggs, 1994). However, older drivers may also suffer from perceptual and cognitive skill losses that may compromise safety while driving (McKnight and McKnight, 1999; Mercier et al, 1997). For example, age-related changes in the ability to plan and execute driving manoeuvres due to cognitive and motor slowing, and the fact that older drivers require more information to make decisions compared to the younger drivers, may make unexpected emergency events particularly difficult for older drivers (Lee et al, 2003). Research shows that some older drivers are aware of their deficits and compensate by driving slowly and conservatively, and take fewer risks (McGwin and Brown, 1999; Ryan et al, 1998). However, the compensatory mechanisms used by older drivers may not be particularly helpful during emergency events that require sudden responses. Critical events demand speed of information-processing and fast motor responses, as well as increased attentional capacity. Deficits in these skills may place older drivers at risk in traffic situations requiring immediate and accurate responses.

The fact that younger drivers are predisposed to increased risk of accident involvement is attributed by some researchers to immaturity and lack of experience rather than deliberate thrill-seeking and risk taking. For example, McKnight and McKnight (2003) analysed accidents involving drivers under 20 years old and concluded that the majority of accidents resulted from failure to deploy routine safe operating practices and failure to recognise danger. Cognitive explanations suggest that inexperienced drivers have impoverished mental models of the traffic environment. For example, Underwood et al (2002) found that novice drivers have an impoverished mental model of what is likely to happen on dual carriageways, whereas experienced drivers have a richer mental

model of driving on these kinds of roads. Usually a driver's mental model will develop as they encounter these kinds of roads and assimilate experiences. Indeed, Bailley, Bellet and Goupil (2003) examined the quality of driver's models of the traffic environment in terms of the accuracy of information available to them. They compared different driver groups according to their amount of driving experience and measured the quantity of cognitive resources available to them while watching a counterbalanced sequence of 40 traffic scenes when sharing attention with a secondary mental arithmetic task. Half of the drivers took part in the mental arithmetic task. At the end of each scene both groups had to decide whether something had changed in the traffic scene or not and identify the location and nature of the change. The experimental changes were made either to the road infrastructure or to the events. The results indicated that experienced drivers were better at detecting changes across all conditions. While modification detection was impaired in the dual task condition for all groups, it was more markedly impaired for novice drivers. Experienced drivers were better at detecting both events and infrastructure changes. For all drivers event detection was less impaired by interference from a secondary task than detecting changes to the road infrastructure was. Experienced drivers were better at detecting changes in events that occurred 0-25m from their position. However changes beyond 25m were detected equally well by both groups. However in the presence of a distracter experienced drivers were better at detecting changes up to 50m, beyond which detecting changes in the presence of a distracter was the same for both groups.
This research has important implications for bus driving in situations where the driver has little time to detect and react to changes in their immediate environment, especially if they are distracted by passengers in the cab or from the stress of dealing with conflicting information whilst driving. It also shows that that the level of experience of the driver may also be a factor in whether a high-risk incident results in a near miss or an accident.

So far, the previous literature on experience and risk in car drivers has focussed on the differences between older and younger drivers. However it is not clear of the relevance of this literature in the context of bus driving. The difference between car drivers and bus drivers is that most bus drivers have already had several years experience driving a car before they take their PCV licence. However, previous car driving experience has not been found to influence bus accident liability in a Swedish sample of bus driver (Wahlberg, 2005). Therefore, the mechanism for risk taking in novice bus drivers may be quite different to the mechanism for risk taking in novice car drivers. For example, some studies show that risky behaviour in both novice and experienced drivers is due to allocating insufficient cognitive resources to the driving task (e.g. Horswill and McKenna, 1999). Novice bus drivers may not be motivated to devote their attention to the driving task if they fail to perceive that the driving task is cognitively demanding and potentially dangerous.

1.2.3 Self-bias

There is a strong tendency for drivers to regard themselves as more skilful. Less at risk and less risky than the average driver (Groeger & Brown, 1989; Mathews and Moran, 1986; McKenna, 1993; Svenson, 1981; Svenson, Fischhoff, & MacGregor, 1985;

Walton & Bathurst, 1998). Therefore unrealistic skill evaluation may be the reason why some bus drivers engage in risk taking. Studies show that self-assessment of risk depends on perceiving a particular event as risky by attributing an estimation of danger to it (Groeger and Chapman, 1990). As such, there are known individual differences in the level of risk perception and risky situations that drivers expose themselves to. It has been reported that a driver's sex, age and experience has a profound effect on self-assessment of risk (DeJoy, 1992; Gregerson, 1996; Groger and Brown, 1989; Massie, 1995; Mathews and Moran, 1986). For example, it has been demonstrated that learner drivers overestimate their own skill when compared with their instructor's ratings of their ability (Hall and West, 1996). It is also well known that younger male drivers tend to overestimate their own skill in relation to their actual ability (Gregerson, 1996; Mathews and Moran, 1986) and also perceive their chances of being involved in an accident as significantly lower than their peers and middle-aged drivers (Finn and Bragg, 1986). Consequently a high degree of optimism could encourage inexperienced drivers to perform driving manoeuvres for which they have inadequate skills. Although positive self-bias decreases with age it still persists in older drivers (Finn and Bragg, 1986; Holland, 1993; Mathews and Moran, 1986). Middle-aged drivers perceived their chances of being involved in an accident as comparable to their peers but lower than younger drivers (Finn and Bragg, 1986). Older drivers (+70) on the other hand were less confident in their own abilities in comparison with younger drivers but felt more competent than other drivers in their own age bracket (Holland, 1993). In other words, older drivers may feel that they are 'not bad for their age'. Hence an older driver may feel very much in control while driving because they have successfully negotiated tricky situations before and may not be aware that their judgements are impaired. The potential influence of positive self bias is attenuated (but not extinguished) at least in drivers over 50 years old who had been involved in an accident, who had less self-bias than those who had not been involved in an accident (Mathews and Moran, 1986).

As the evidence suggests, there is a general tendency for drivers of all ages to underestimate the risks associated with driving and to overestimate their driving skills and that this positive self-bias even persists in drivers who have had a previous accident. There is reason to suppose that the same phenomenon holds true for bus drivers. This would have implications for the design of a bus driver training programme. A successful safety intervention must involve a systematic method of de-biasing an individual driver's perception of risk. It must be capable of revealing deficits in an individual's skill in order to attenuate a driver's natural self-bias. This is particularly true for drivers who have had little experience, because although they have learned the necessary skills to drive a vehicle, they have not yet learned the perceptual and decision-making skills to maintain safe distances, recognise potential hazards and avoid them (Aphaloe et al, 1987).

In summary, age-related differences in driving behaviour can be partly explained by differences in experience. Young and inexperienced drivers appear to possess insufficient knowledge and resources driving that may impact on their ability to predict and anticipate hazardous situations. Additionally, very inexperienced drivers may also lack the skill to perform manoeuvres with the degree of autonomy that experienced drivers are capable of, which compounds the problem (Gregerson, 1996; Ivancic and Hesketh, 2000). Furthermore, over optimistic beliefs about their own ability can lead to risk taking and over exposure to risky situations which they are not skilled to deal with, hence their over representation in the accident statistics. As a driver's knowledge and understanding develops with increased experience in traffic, they are better able to anticipate hazards and appreciate the consequences of their behaviour, which results in fewer accidents. More experienced drivers may then have developed more elaborate mental models of the driving environment through having greater experience in traffic and may be more aware of their own performance limitations and so have more realistic expectations of their ability. Experienced driver may be better able to predict the consequences of their own behaviour on safety and hence have lower accident rates. However in very old drivers the positive effect that experience has on safety is compromised by age-related declines in physical and cognitive abilities. Some older drivers compensate by reducing the amount of driving they do, but in cases where the benefit of increased experience no longer compensates for deficits, accident risk is higher.

1.2.4 Training Cognitive Skills

Since experience plays a large part in driver behaviour, bus driver training then cannot be discussed without reference to models of learning and skill acquisition. To begin with, Amalberti and Wibaux (1995) view cognitive and manual skill deficits as problems in the acquisition of expertise. For example, a procedure which is learned but never practised will not become a skill as practice is required to consolidate knowledge and to enable the trainee to develop their understanding of system limitations and their own performance limits and to improve their confidence in what they do. They discuss the difference between novice and experienced pilots and consider that less experience pilots hold a poor mental representation of what they know how to do and what not to do in certain situations. They attribute risk taking during the phase of confidence building to poor knowledge of the task. They conclude that if effort can be put into training at this stage, then the pilots are less likely to 'experiment' while they are operating an aircraft and thus there is less chance of them making mistakes that may lead to accidents.

The discussion of the study above shows that there may be some parallels between pilot training and bus driver training in terms of skill acquisition. According to cognitive accounts of skill development, it is probable that the difference between novice and experienced bus drivers can be attributed to the development of a procedural understanding of the driving task (Anderson, 1983). Models of skilled performance also provide some insight into why more experienced drivers still have accidents. To explain, Fitts and Posner (1967) propose that skilled performance is spatially and temporarily organised, is goal-directed and uses feedback to correct errors, unless there is insufficient time for detection and correction to occur. Here the distinction between accidents due to skill deficits and accidents due to inappropriate driver behaviour is clear. In the case of bus driving, the skills set incorporates perceptual motor skills in the form of procedural knowledge for operating the bus and decision-making skills in traffic which are dependant on depth of declarative knowledge and breadth of cognitive skills. For example, the correct procedure at bus stop is as follows: On approach check mirrors for passengers standing, check the location of the bus stop, lift foot gently off accelerator while covering the brake, gradually decrease speed, check mirrors, stop 6-12 inches parallel to the kerb, put gear in neutral, apply the handbrake, check vehicle length and height of kerb, open the doors, before departing check mirrors, close doors, select gear, conduct an all round scan, identify an appropriate opportunity to pull into the traffic flow, indicate, release handbrake, check mirrors, smoothly accelerate away. Accidents could occur if a bus driver failed to follow the correct procedure. However, while driving a bus engaging in risky behaviours such as driving at high speeds and leaving short headways can leave the driver with little time to react to changes in their immediate roadway environment. This could also increase their chance of being involved in an accident. The difference in underlying cognitive and decision-making mechanisms has different training implications. In the former case, procedural training could correct any skills deficits that may lead to accidents, while de-biasing a driver attitude to risk may be a more effective method of accident prevention in the latter case.

Anderson (1983) sees skill acquisition as synonymous with problem-solving. According to this view, cognitive skills involve effectively translating information into a response, which involves the acquisition of a set of domain-specific rules which allow the solution of a problem. Although learning is considered to be a continual process, theorists often divide the learning process into phases or stages of skill acquisition (Anderson, 1983; Fitts and Posner, 1967; Schneider and Schiffrin, 1977). These staged learning models are grounded in the process of assimilation and accommodation. Firstly, as the trainee is introduced to the task and learns the basic rules and requirements, they develop a declarative encoding of the skill. Performance in this declarative stage is generally slow and error prone and is demanding in terms of attention, memory and reasoning and requires spatial, verbal and numerical ability (Ackerman, 1988). During the second stage of knowledge compilation, errors in the trainee's initial understanding are detected and eliminated and associations between task-elements are strengthened with practice until the trainee can perform the task successfully. At this stage progress is determined largely by individual differences in perceptual speed (Ackerman, 1988). The skill then reaches a stable state in the final stage, where procedural knowledge means that the task can be performed automatically and quickly and the trainee's confidence is increased. Differences in responding and encoding predict the outcome of performance at this stage (Ackerman, 1988). Ackerman and Kyllonen (1991) developed a model of skilled performance acquisition based on Andersons Advance Computer Tutoring (ACT*) Theory. According to these researchers, information presented to the trainee is deposited into working memory that is capable of holding only a few facts and procedural skills at a time. Strategic or procedural knowledge is related to the information in working memory retrieved from either declarative memory or procedural memory. Trainees then execute a motor programme in response to this information. The model shows that any individual differences in depth of declarative knowledge, breadth of procedural skills, working memory capacity and speed of information processing can influence the response.

Given the dynamic nature of attentional demands over the course of learning a new skill set, there must be a trade-off between the influences of ability and motivation, even within the context of a single training session. This was investigated by Kanfer and Ackerman (1989) who examined the effectiveness of different training approaches, goal-setting interventions and general intellectual ability on learning a simulated air traffic controller task. Students received procedural and declarative training and then had to perform a transfer task plus goal-setting. They found that when learners were under high attentional demands (transfer task after procedural pre-training plus a performance goal) lower ability learners were impeding in acquiring skills in the full task. However, when demand for attention was low (transfer after declarative pre-training plus a performance goal) low ability students performed almost as well as their high ability colleagues. The authors concluded that goal setting is optimal for high ability students under high attentional demands or for low ability students with low attentional demands. However it is detrimental to performance in low ability students when they are already occupied. The results of this study emphasise the importance of tailoring the training so that as the student progresses through the training programme they are only asked to assimilate new information appropriate to their stage of learning. For example, Staplin and Dowdell (2001) outlined a staged learning model for training novice driver situational awareness. The first stage they describe is learning to control a vehicle and the development of understanding of how their actions affect the motion and orientation of the vehicle. Secondly the driver's contextual understanding of safety rules is developed so that they learn to relate particular signs and warnings to different hazards and road features. Then follows the ability to anticipate others actions and visualise their own actions as perceived by others. Designed in this way the training programme enables the driver to develop an understanding of the risks of possible behavioural choices, without being too demanding of the students' limited cognitive resources.

The implication of the previous literature for the development of a bus driver training programme then is that it should be flexible enough to accommodate a range of aptitudes to ensure that training will transfer to the operational environment. It is therefore important to consider the range of talent with which the training programme must cope, especially since the focus on individual differences becomes more important as the trainee progress from a novice level of task performance through to a skilled expert (Kanfer and Ackerman, 1989; Taatgen, 2002). Therefore in skills training, the way in which a task is structured, the amount of domain specific information available and the way in which procedural rules are presented to the learner are significant to learning (Colley and Beech, 1989).

1.2.5 Bus Driver Stress

Another factor affecting bus driver safety is the issue of driver stress. A large number of studies have indicated that bus driving is a high-strain occupation characterised by high demands, low control and low support leading to a high risk of physical and mental occupational ill-health (Kompier et al., 1990). The effects of stress are cumulative; negative reactions to stressors gradually develop after continued exposure with insufficient time for recovery. The high work demands associated with being a bus driver has led to research into bus driver health and physiological stress (Carrere et al, 1991; Evans and Carrere, 1991; Netterstom and Hansen, 2000; Raggatt and Morrissey, 1997; Gobel et al, 1998) and how this is mediated by external demands such as traffic density (Evans and Carrere, 1991; Netterstom and Hansen, 2000); size of the bus being driven (Duffy and McGoldrick, 1990) and the need to be on time to pick up passengers

(Meijman and Kompier, 1998). Netterstrom and Hansen (2000) found that perceived control on the job affects the stress response; the higher the exposure to traffic congestion and the less control perceived by bus drivers, the more pronounced their psychophysiological stress response. Bus driver's mental well-being has also been shown to suffer, for example Evans (1994) reported that 13% of the sample of drivers in his study scored in the range equivalent to hospitalised psychiatric patients as a consequence of work-related stress.

Previous research has suggested a link between stress and accident involvement. The occurrence of stressful life events requires psychological readjustment and during this process, driving performance may be impaired and lead to accidents. For example, Finch and Smith (1970) found that 80% of 25 drivers killed in road traffic accidents had experienced one or more significant stressors within a 24-hour period prior to the accident. Furthermore, McMurray (1970) demonstrated that the accident rates of people involved in divorce doubled during the six months before and after the divorce date and Selzer and Vinokur (1974) found that life changes and subjective stress was significantly correlated with accident rates. More recently, Hartley and Hassani (1994) compared driver stress scores with accident involvement rates between truck and car drivers in Australia. About one third of the truck drivers and about 40% of the car driver's accident and conviction rate were predicted by self-reported driver stress. Amongst bus drivers, Evans and colleagues (Evans and Courtney, 1985; Evans et al, 1987) found that emotional stability and personality-based stress responses are related to accident frequency and increased absenteeism.

There are several reasons why bus drivers may be vulnerable to stress. Work overload, time pressures and responsibility for people's lives are all potential sources of stress arising from factors intrinsic to the job of being a bus driver. For example, when drivers have to cope with traffic congestion, distractions from passengers and the boredom of routes, it is likely that they become increasingly apprehensive, frustrated or angry and respond to traffic conditions with increasing aggression, anxiety and/or fatigue (see Matthews and Desmond, 1997). Bus driver stress may then be a matrix of feelings of aggression, irritation, anxiety, worry, impatience, fatigue and concerns about the behaviour of other drivers and can be explained by reference to the transactional theory of driver stress (Mathews et al., 1998). Here, problematic outcomes can be predicted by interactions between a driver's personality and perceived environmental demands. Within the transactional process, bus driving involves a balance between coping with time pressures and traffic situations and passengers needs. Bus drivers have to respond to schedules, rotating shift work and have little opportunity for autonomy or control over their pace of work. While driving, they also have to respond to incoming stimuli from the traffic environment, and react to potential hazards. Furthermore, bus drivers face contradictory demands, for example the need to drive safely and the need to be on time (Evans and Johansson, 1998). In response to bus driver stress, there are likely to be significant individual differences in the choice of driver coping strategy. The role of an individual's coping styles, such as a tendency to prioritise punctuality, safety or customer service while operating a bus mediates the link between work-demands and health (Meijman and Kompier, 1998). Since coping strategy selection depends on the driver's motivation and beliefs about the driving task, performance impairment is associated with the maladaptive strategy of downgrading of the goal of maintaining performance efficiency in favour of other competing goals such as sticking to a schedule (e.g. van der Hulst, Meijman and Rothengatter, 2001; Meijman, 1995; Meijman and Kompier, 1998). In this way, the bus driver's appraisal of job and driving-related events is likely to determine their level of subjective stress.

1.3 Driver Education and Training: Developing a Drivers Experience

1.3.1 An Evaluation of Current Driver Training Methods

Since driver behaviour plays a central role in traffic safety then, creating changes in driver behaviour is likely to reduce traffic accidents. The main aim of a bus driver training programme currently is to develop a driver's skill so they can safely negotiate their way in traffic. Recently researchers have also identified three major areas in which skills can be developed that will enhance a drivers overall ability: realistic risk perception skills, which allows the driver to estimate their probability of having an accident; decision-making skills, which allows the driver to decide what action they should take in different circumstances; and vehicle handling skills, which enables the driver to effectively implement their desired action (e.g. Jorgensen, 1993; Wilde, 1982). Traditionally driver training has focussed on developing vehicle handling skills alone. A novice driver must demonstrate that they can competently manoeuvre a vehicle before they are awarded a licence to drive. Since 2002 hazard perception skills have been included in novice driver training curricula in the UK and the driver must demonstrate competence in their ability to identify and anticipate potentially dangerous situations before they are awarded a licence (McKenna and Crick, 1997). However once on the road, the accident statistics still show that novice drivers have the highest accident rates and the literature reviewed in the previous sections shows that novice drivers lack many of the appropriate skills and behaviours that more experienced drivers have. Is the problem attributable to inadequate training?

There are four possible methods for assessing driver training currently employed by researchers in the field: qualitative feedback about the training course, accident rates, simulated-driving performance and on-road performance. Qualitative feedback regarding the impact of the training programme is a relatively simple evaluation method, however the impact of training on actual performance cannot be confidently assessed using this method because the reliability and validity of subjective statements is questionable. Road tests are considered by some researchers (e.g. Roenker et al, 2003) to be the best measure of driver performance but have the drawback of inconsistencies in administration and scoring. On the other hand, driving simulators offer experimental control but often lack validity. Another disadvantage is that simulator based methods may cause nausea, especially in older drivers (e.g. Hagenmeyer and Sommer, 2004). Both methods have the disadvantage of being too costly and time consuming for assessing large fleets of drivers. Crash history, although it is a fairly insensitive measure of driving performance itself provides the ultimate evaluation of driver training since the uppermost goal of driver training is to improve safety and reduce accident rates (Elvik and Vaa, 2004). In addition to these methods,

Hatakka et al (2002) propose that the social and cultural environment should be examined to determine whether the driver is supported in driving safely, for example young drivers may be encouraged by their peers to take risks.
It is clear that the focus of training currently received should be examined given that only one level of behaviour, vehicle manoeuvring is currently considered. Then the provision of training materials should be evaluated in terms of their effectiveness to support learning at each level. Finally, the role of self-evaluative and reflective skills in the implementation of the idea of life-long learning in traffic should be considered along with the most effective method of teaching these skills and whether it is possible to teach them all and whether the learning process can be supported in an effective way. The question is whether current driver training methods are adequate and if not what should be the focus of new driver training methods.

1.3.1.1 Novice Driver Training

Although attempts to train vehicle handling skills in a driving simulator have been made (Hoskovec & Stikar, 1971; Uhr et al, 2003), only the study by Uhr et al (2003) demonstrates that training vehicle handling skills in a driving simulator can transfer to real world driving performance. Researchers reviewing novice driver training methods agree that programmes focussing on improving vehicle handling skills are not effective in reducing accident rates (Christie 2001; Elvik and Vaa, 2004; Engstron, 2003) and may even exacerbate the problem by encouraging drivers to accept risks due to increased confidence in their own skill (Gregerson, 1996; Hall and West, 1996; Ivancic, and Hesketh, 2000). For example, Gregersen (1996) investigated the relative effects of two types of training programme on young males driving ability. The programmes were skills training in which drivers practiced certain manoeuvres and insight training in which drivers were trained to critically assess their driving ability. Analysis revealed that there was no difference between actual driving skills for both groups of drivers; however skill training produced a false estimation of ability compared with insight training. Elvik and Vaa (2004) concluded that accident rates actually increased in groups of novice car drivers who received additional skills-based training.
While basic control skills are undoubtedly pre-requisites for safe driving, it is now believed that the ability to apply higher order skills, for example hazard perception, risk perception and insight contributes more towards reducing crash risk for drivers (Ranney, 1994; Triggs, 1994).

A number of groups have taken advantage of technology advancements to develop interventions that focus on increasing a novice driver's experience in traffic in order to develop their hazard perception and awareness of risk (e.g. Allen et al, 2001; Allen et al, 2003, Allen et al, 2004; Allen et al, 2005; Fisher et al, 1998; Fisher et al, 2000; Fisher et al, 2002; Regan et al, 1998; Regan et al, 1999; Regan et al, 2000). The training is conducted either in a driving simulator or by using CD-Rom products, and targets the need to search for potential hazards. For example, Allen et al (2003, 2004, 2005) delivered standardised training to over 500 high school students using three configurations of a low cost driving simulator. One third of students were trained using a simulator with a cab with actual steering, brake and throttle controls and a wide field of view (135°). One third of students were trained with a desktop simulator with a wide field of view and the final third of students were trained on a single monitor desktop system. The training programme included an orientation to brief the students on traffic signs and signals and the issues involved in safe driving. They then drove scenarios that included hazardous roadway and traffic situations requiring psychomotor and cognitive skills. The success of the training programme was measured as the number of trials the students had to perform in the simulator in order to reach a pre-determined level of competence in accidents, average speed, turn signal errors, instances of hard braking and hard cornering, and TTC. The data showed significant improvements across trials with regards to speed violations, turn signal use and accident frequency for all simulator configurations. Average speed and TTC measures were combined to provide and indication of conservative (low speed, larger TTC) and aggressive driving (high speed, smaller TTC). The results showed that there was an initial increase in aggression at the start of the training programme and then a decline in aggressive behaviour as students approached the sixth trial. Qualitative feedback indicated that the students enjoyed participating in the training. The studies demonstrate the potential value of driving simulators for novice driver training. However, the drawback is that it is not yet clear whether performance improvement within the simulator then transfers to the real world driving task and whether this type of training has any impact on real world accident rates in novice car drivers, although Allen and his colleagues are awaiting the accumulation of adequate accident data from the cohorts used in their studies.

Fisher et al (2004) evaluated two forms of risk perception training: Avoidance learning, in which a driver is required to take remedial action to avoid a collision (Fuller, 1988) and mediated learning, which is designed to reinforce anticipatory skills (Wallace and Regan, 1998). The effect of training was assessed by comparing the two trained groups and a control group who had not received any training on a simulated driving task. The results indicated that drivers who had received training drove more cautiously in terms of their speed and braking behaviour in potentially hazardous situations, namely when their vision of approaching vehicles and pedestrians crossing the road was obscured by a truck. Trained drivers also drove more cautiously when the threat was not so obvious, for example by driving more slowly when approaching unobstructed pedestrian crossings. However, risk awareness training did not influence the way in which the drivers negotiated lane changes as they manoeuvred past obstructions, for example drivers pulled out too late past a parked vehicle. The results of this study are encouraging because it shows that PC-based risk awareness training can increase a novice driver's knowledge of hazards; however it also highlights the importance of supplementing hazard perception training with appropriate vehicle handling experience. In support of this, Fisher et al (2000) also showed that PC-based risk awareness training encouraged safer driving behaviour in high- risk traffic situations, as measured in a driving simulator.

Regan et al (1998) also attempted to train attentional control in novice car drivers using the variable priority technique. In the variable priority treatment group, drivers had to split their attention 50/50, 66/33 or 33/66 between two concurrent tasks: maintaining a safe headway from a car in front and performing a mental arithmetic task. Their performance was then compared to that of an untrained control group on a simulated driving task in which they had to respond to different speed limits. The results show that the variable priority group had greater acceleration and faster reaction times to the brake and accelerator when they changed speed. There were no differences between the trained and untrained groups in their ability to maintain a safe headway. The results show that attentional control training may improve a novice driver's ability to detect and respond to changes in the roadway environment.

Hatakka et al (2002) claim that motivational and attitudinal factors are just as important to performance as adequate psychomotor skills and physiological functions because skills for manoeuvring the vehicle are applied in the context of higher level goals and motivation, which may influence the chance of a driver engaging in risk taking behaviours. They describe the GADGET model of driver training that comprises four hierarchical levels of behaviour that govern the driving task: goals for life and skills for living, goals and context of driving, mastery of traffic situations and vehicle manoeuvring. They also describe three goals for training which include basic knowledge and skills, knowledge and skills concerning risk increasing factors and skills for self-evaluation. Table 1 provides a summary of the GADGET framework described by Hatakka et al (2002) with the example of a young driver who goes clubbing regularly as a lifestyle choice. This driver may drive under the influence of alcohol it may be due to not understanding the detrimental effect of alcohol on skill or the driver may only be concerned with being caught by the police and not consider the possibility of having an accident.

Table 1 GADGET Model

Hierarchical level of behaviour	**Knowledge and skills**	**Risk increasing factors**	**Self-evaluation**
Goals for life and skills for living	lifestyle	acceptance of risks	personal skills for impulse control
Goals and context of driving	effects of social pressure in car	social context and company	typical risky driving motives
Mastery of traffic situations	anticipation of events	risk increasing driving style	realistic self evaluation
Vehicle manoeuvring	control of direction and position	unsuitable speed adjustment	awareness of strong and weak points of basic manoeuvring skills

The development of training materials that covered most of the GADGET matrix was described in two studies: one by Dols et al (2001) and another by Falkmer and Gregerson (2003). The training syllabus was delivered using a driving simulator and provided practical training in vehicle handling skills, hazard perception, self-evaluation and insight. In their study, Falkmer and Gregerson (2003) delivered training using a low-cost and a medium cost driving simulator and then compared the trainee's performance to an untrained control on several transfer tasks in a driving simulator. Their results showed that the trainees who used the medium cost simulator had better lateral control of their vehicle, drove more slowly through fog and left longer headways and had greater minimum time-to-collisions than the low-cost simulator trained group and the control group. Their interpretation of these results was that simulator training offered some benefits over traditional driver training and education methods, but they did not consider in detail what they thought the benefits were. The study design suggests that if this was the case then better performance would also be seen in the low-cost simulator trained group. However, since there were no differences between the low-cost simulator group and the untrained group the results of this study may be better interpreted with reference to the fidelity of the driving simulators used to deliver the training. It would have been better to consider pre- and post-training performance to determine whether training per se or simulator fidelity influenced driving performance and to consider the effects on real world driving performance. Therefore the results of this particular study are inconclusive.

To summarise, the research shows that groups of novice drivers that have been trained perform better than their untrained colleagues in simulated driving tasks that require them to detect, perceive and respond to hazards. Yet, it must not be forgotten that novice drivers also need to develop appropriate vehicle handling techniques in response to these hazards. To explain, the basic manoeuvres for operating a vehicle have to be relatively automatic or they will require conscious attention, which will leave little capacity to observe and predict the behaviour of other road users (see Anderson, 1983; Fitts and Posner, 1967; Schneider and Schiffrin, 1977). However, it is essential that training does not create the impression that driving is essentially a manoeuvring task because having overconfidence in technical skills may encourage risk-taking and may be detrimental to performance in hazardous situations (Dorn and Brown, 2004; Gregerson, 1996). The traditional focus of driver education methods is to focus on developing a driver's knowledge of traffic rules and their ability to perceive and predict the behaviour of other road users. For instance, in comparison to novice drivers, experienced road users have learned to recognise risks, threats and problems and how to avoid them, as well as mastering the skills needed for everyday driving. However, training, testing and modifying skills for mastering traffic situations is not sufficient in itself. This because driving is self-paced so the driver is free to choose the demands that they impose on their skills, for example by increasing the difficulty of the driving task by using a mobile phone. The driver then needs to be aware of their personal skills and limitations and how this might affect their safety. If a safety intervention fails to produce a safe driving strategy, then additional skills training will not compensate for this lack of safety orientation. In response to this, Hatakka et al (2002) proposed two additional levels that driver education and training should address. The first relates to the goals and contexts of driving, in other words, the driver decides for what, where, with whom, with what and what time they will drive. For example, older drivers drive for work, while younger drivers drive more often at weekends for leisure with their peers (McGwin and Brown, 1999). Hatakka et al stress the importance of thoroughly planning a trip by estimating travel times, selecting the easiest routes and the most suitable time to drive to make it less demanding. They also stress how social pressures may influence driving behaviour. They argue that drivers should be taught planning techniques and should be informed of the affect of peer pressure on driving performance. The highest level refers to the impact of the driver's personal lifestyle choices, motives and goals on their driving behaviour. They consider risk-taking behaviour to be a developmental need and that young drivers in particular should be supported while they develop safer driving habits. Driver education at this level should then encourage a driver to reflect and evaluate their own lifestyle, with a focus on

increasing a driver's awareness of their propensity for risk taking connected with life goals and the relationship between risks and consequences.
Although the investigation by Falkmer and Gregerson (2003) shows some improvements in simulated driving performance after training based on this model, the results appear to be no better than improvements shown by other researchers (e.g. Fisher et al 2004), plus the results may be a confound of the fidelity of the simulator used in training rather than the training material itself. Unfortunately the impact of novice driver training on accident rates is not evaluated in any of these studies.

1.3.1.2 Older Driver Training

A few interventions have aimed to improve cognitive skills in older drivers. Roenker et al (2003) compared the performance of 456 older drivers (aged 48-94) after they had received one of two training methods: simulator training and general speed-of-processing training with the performance of a control group on simulated driving and on-road driving performance two weeks and 18 months post-training. The simulator training group received two 2-hour sessions that reviewed road traffic rules and regulations and included practicing scanning, crash avoidance and managing intersection techniques, followed by a 1-hour in-car demonstration of the necessary skills. The group that underwent speed-of-processing training were required to identify a centrally located target and a peripheral target presented at intervals increasing up to 30 degree eccentricity. Trials were repeated at progressively faster presentation speeds and with distracters. The three groups were compared on dangerous manoeuvres, signal use, turning, changing lanes and interaction with other traffic. The authors concluded that simulator training improved behaviours that were practiced during the training sessions, such as turn signal use, turning and interaction with other traffic. Speed-of-processing training improved behaviours that involved scanning a visual scene, detecting and reacting to changes in the environment and also reduced the likelihood of the driver performing a dangerous manoeuvre. However, the benefits of training were short-lived as performance differences had disappeared 18 months post-training. Nevertheless, the results are promising as they indicate that the driving skills of elderly drivers can be improved but training must be ongoing if these skills are to be maintained. Again very few studies have investigated the benefit of training in terms of accident reduction in older drivers. However, Elvik and Vaa (2004) reviewed two studies conducted by Jenke (1994) and McKnight, Simone and Weidman (1982) in the USA which consisted of theory, lessons and optional driving tests in the older drivers' local neighbourhood in order to teach behaviour that is optimally adapted to local traffic. They concluded that this type of training was ineffective in reducing accidents in older drivers.

1.3.1.3 Professional Driver Training

As a group, professionally trained drivers are more experienced than other drivers, which ought to imply lower accident rates. However, company car drivers have an increased likelihood of accident involvement (Broughton et al, 2003). To date there have been few publications of controlled experiments to test the effect of countermeasures on safety. Two exceptions are Machin (2003) who studied the effects of fatigue management training in coach drivers, Gregerson, Brehmer and Moren (1996) who compared four different countermeasures for reducing the crash involvement of company car drivers against a control group. In Gregerson's study, five groups of 900 drivers participated in either 1) group discussions in which drivers themselves are responsible for identifying behaviours that could cause problems and that they will be responsible for changing 2) campaigns that included the use of videos, pamphlets and meetings that focussed on seasonal problems in driving 3) a bonus scheme in which monetary points were earned or deducted from groups of drivers depending on crash frequency and severity 4) a driver training programme that concentrated on manoeuvring, skid training and feedback on a commentary drive or 5) the control group who had no intervention. Gregerson et al evaluated the effect of each of the four countermeasures on crash risk per 10,000 kilometres and crash costs over the two years preceding and following the interventions. The results show statistically significant improvements in crash risk following driver training (-16%), group discussions (-20%) and bonuses (-32%). presumably because these measures provided the driver with the opportunity to reflect on their own behaviour and skills and to make changes. However there was an increase in crashes in the group where campaigns were used (+36%). Crash costs were reduced in all four test groups but not the control. The drawback with this study is that there is no indication of the relative costs of the interventions implemented and the relative savings made and there was no discussion of the more qualitative outcomes or other predicted benefits, such as fuel savings, better attitude or safety culture.

In contrast, Machin (2003) conducted a qualitative evaluation of a fatigue management training programme but did not compare accident rates to an untrained control group. Seventeen coach drivers were presented with realistic job situations and a number of possible coping responses and were encouraged to evaluate the effectiveness of each coping strategy. They were then asked to generate their own effective ways of coping in response to difficult working situations that they might face in the following weeks and to think of any obstacles that might stop them from implementing them. Four weeks later the coach drivers themselves evaluated the training in a follow up session in which they described how the training had benefited them. The drivers discussed specific incidents that occurred since their training program, how they had responded to those incidents, what the outcome was, and how the material they had learnt in their training program had assisted them. Firstly, the results indicated that drivers favoured the use of positive task focussed and reappraisal coping responses even before training had been implemented. Although many of the drivers reported that the training had helped them to be more aware of how they responded to difficult work situations, and had also influenced them towards responding with task-focused and reappraisal strategies no attempt was made to compare the use of coping responses before and after training. A post-training evaluation questionnaire assessed drivers' reactions (self-efficacy and motivation), drivers' intentions for using the skills learned during training, and seven separate, in-training transfer enhancing activities that influence transfer of training. Drivers reported positive reactions in terms of having a strong desire to use the training and high confidence to use the skills they had acquired and also strong intentions to use what they learned on the job. The evaluation also indicated that they have a reasonably strong commitment to using their skills on the job; however their commitment to using the training was less than their desire to do so. Ten months later Machin (2001) conducted a follow up telephone interview with nine of the drivers. The results of the evaluation of the in-training transfer enhancing activities suggested that the course and the materials were relevant, although it did not cover some issues that drivers perceived to be important; the amount of feedback was sufficient, and that goal setting was covered sufficiently although more practice at using the skills could have been provided. Most of the drivers felt that training only slightly or moderately prepared them for the problems they faced after training and commented that this was because they felt they were already competent at dealing effectively with problems. The major obstacle to transferring their training to the workplace that the drivers reported was the lack of recognition they received for using their training on the job. They felt that they would benefit from improved communication with management. This suggests the importance of creating a supportive training environment.

Other methods to improve driver training and crash risk have shown a mixed response. Elvik and Vaa (2004) reviewed several methods of professional driver training. They found that more stringent driving tests did not affect accident rates, whilst skills-based skid training actually increased accident rates in ambulance, HGV and car drivers. However, courses in defensive driving reduced accidents by 20%. There is now a body of evidence that some skills training may not be beneficial for road safety. Even specific skills training such as skid control and braking techniques have failed to find measurable improvements in accident rates. For example, in skid pad training, Katila et al, (1996) found that young drivers failed to understand that the purpose of training was to avoid a skid rather than be able to control it. This is particularly important given that an overestimation of driving skill may lead to increased risk of accidents (Gregersen, 1994). Ludwig and Geller (2000) implemented and evaluated a range of safety behaviour change countermeasures amongst pizza delivery drivers over a 10 year period. The countermeasures were group awareness sessions and a promise card, a mandatory turn signal use policy, assigned versus participatory goal-setting and feedback, group goal setting with public individual feedback, public individual feedback with competition, static versus dynamic goal-setting and community change agents. Their focus of evaluation was on seatbelt wearing, signalling and stopping at intersections, but not accident rates. Unfortunately Ludwig and Geller did not conduct any hypothesis testing but they did conclude that behaviour change countermeasures should offer support for involvement, should foster peer support and should provide on-going feedback to participants. Unfortunately these studies do not show how driver training directly improves driving performance.

Simulator-based training is a relatively new approach to professional driver training but is an alternative to traditional in-car training which has demonstrated changes in driver behaviour. For example, Matsunaga et al (2000) compared pre and post training performance at intersections both in a simulator and on-road in five drivers who received training in behaviour at intersections with or without the use of feedback. In the simulator, the frequency and duration of stopping at intersections was better if the driver had been allowed to compare their own driving performance with the recommended driving behaviour at intersections. This highlights the importance of providing feedback in training. On the real road test the frequency and duration of stopping at intersections increased after training, showing that training in the simulator had transferred. In another simulator-based study by Uhr et al (2003), the effect of real world training and simulator training on the performance of truck drivers on a reversing task was compared. Both groups received basic instruction and real world performance assessment. One group then practiced the manoeuvre in a real truck, the other group practised in a simulated truck and they then performed the reversing task again in a real truck. Both groups showed improvements on the real world task after training, although the simulator trained group took longer to perform the assessment tasks. They attributed this to the fact that it was more difficult to perform the task in the simulator because it was more responsive to feedback from the steering wheel.

Lang, Neukum and Krueger (2005) described the development of a motion-based simulator with a wide field of view that was designed to deliver simulator based training to novice police drivers. 44 male and female trainees in teams of two completed five trials in simulated rural, urban and motorway settings under the direction of a police driving instructor. Police experts then rated video recordings of the five trials, paying particular attention to speed choice, overtaking, team work, lane keeping, communicating their intentions to other drivers, headway, negotiating right of way, using irregular lanes and clearing traffic. Experts gave significantly higher ratings to performance on the final trial in comparison to the first trial indicating that performance had improved as training had progressed. The trainees considered the simulator to be an accurate representation of police driving and were highly motivated to use the simulator. Further work is underway to examine whether performance improvements transfer to the real world.

Brock, Jacobs, Van Cott, Mccauley and Norstrom (2001) described a number of bus simulators that are currently being used to supplement bus driver training in the USA. However, to date no evaluations other than collecting drivers' opinions and reporting positive feedback have taken place. Other researchers describe the development of truck simulators to train vehicle control skills (Meyer et al., 2001; Monin, 2004; Parkes, 2003; Parkes and Rau, 2004; Parkes and Reed, 2005). Parkes and Reed (2005) analysed the efficiency and acceptability of the TRUCKSIM, which is a motion-based truck simulator that currently delivers training designed to encourage fuel-efficient driving. 400 truck drivers volunteered to drive a simulated route. They then took part in the training programme. This comprised a video orientation that explained the principles and application of fuel-efficient driving strategies. These strategies included keeping the engine RPM in the green band of the RPM gauge by selecting an appropriate gear and accelerator position for the conditions, using gravity rather than the accelerator to build speed on downhill sections, to block change gears when appropriate, and avoiding harsh braking or acceleration. The video considered the benefits of traffic awareness and forward planning to keep the vehicle moving efficiently as far as possible. The drivers then had the opportunity to demonstrate these principles in a simulated fuel efficiency exercise, which took place along a 20-minute route in rural, urban and motorway sections. The measures of interest were: time to complete the task, the number of gear changes shown, and the apparent fuel usage. The results indicated that after fuel efficiency training there was a 6% decrease in time taken to complete the route, 11% decrease in gear changes and a significant decrease (3.5%) in fuel consumption in rural settings. The results are promising as they show that truck drivers, who share similar working conditions with bus drivers show performance improvements within a simulated environment after appropriate simulator based training. However, further research is needed to investigate whether this type of training transfers to the real environment.

In addition to the studies cited in the academic literature, there have also been several unpublished accounts of the successful use of simulators for professional driver training. For example, Trevino (2000) claims that the number accidents involving police drivers at intersections dropped from 58 to 15 between 1999 and 2000. The dramatic decline was attributed to the acquisition of a fixed-based police driver training simulator. Wetzel (2000) makes similar claims that New Jersey Transit has benefited by including 3 days of simulator-based training in their 17-day bus driver training programme. The benefits seen include training and testing time decreased from 19 to 18 days, which equates to an annual saving of £375,000 and an accident reduction from 42.6 accidents per million miles in 1994 to 34.1 per million miles in 1998.

The table below shows a summary of the contents of the driver training methods reviewed in this chapter and also the techniques used to evaluate the benefits of the training. Driver training is intended to give drivers a lower accident rate than they would have otherwise had, and speed up the decrease in the accident rate that occurs as drivers become more experienced (Elvik and Vaa, 2004). Considering the importance of driver training, it is necessary to systematically investigate the impact of different driver training programmes on driver performance and accidents.

Table 2 Summary of Driver Education and Training Methods and Evaluation

Authors	Target Population	Training Method	Evaluation Method				Scope of the Training Syllabus											
							Vehicle Handling			Traffic Mastery			Goals for Driving			Skills for Life		
			Qualitative	Simulator	On-road	Accidents	K&S	RF	SE	K&S	RF	SE	K&S	RF	SE	K&S	RF	SE
Hoskovec & Stikar (1971)	Novice car drivers	simulator					*	*										
Uhr et al (2003)	Novice car drivers	simulator			*		*		*									
		On road			*		*		*									
Regan et al (2000)	novice car drivers	CD-Rom, Driver-ZED		*						*	*	*						
Fisher et al (1998)	novice car drivers	PC-Based		*						*	*	*						
Regan et al (1998)	novice car drivers	Variable priority, simulator		*									*					
Regan et al (1999)	novice car drivers	CD-Rom, Driver-ZED		*						*	*	*						
Fisher et al (2002)	novice car drivers	CD-Rom, Driver-ZED		*						*	*	*						
Staplin & Dowell (2001)	Novice car drivers	simulator		N/A	N/A	N/A	*	*	*	*	*	*						
McCormack (2003)	Novice car drivers	simulator		N/A	N/A	N/A			*	*	*	*						
Allen et al (2004)	Novice car drivers,	simulator		*			*	*	*	*	*	*						

Dols et al (2000)	Novice car drivers	TRAINER tools, simulator		N/A	N/A	N/A	*	*	*	*	*	*	*	*	*	*	*	*
Falkmer & Gregersen (2003)	Novice car drivers	TRAINER tools simulator		*			*	*	*	*	*	*	*	*	*	*	*	*
Gregerson (1996)	Young car drivers	On-road					*	*	*									
Ivancic & Hesketh (2000)	Young car drivers	simulator based error training		*			*	*	*	*	*	*						
		simulator based error-less training		*			*	*		*	*							
Roenker et al (2003)	elderly car drivers	speed-of-processing PC based			*											*		
		simulator			*		*	*	*	*	*	*						
Jenke (1994)	elderly car drivers	Theory, on-road, test				*	*	*	*	*	*	*						
McKnight et al (1982)	elderly car drivers	Theory, on-road, test				*	*	*	*	*	*	*						
Trevino (2000)	Police drivers	simulator				*	*	*	*	*	*	*						
Lang et al (2005)	Novice police drivers	simulator	*	*			*	*	*	*	*	*	*	*	*	*	*	*
Wetzel (2000)	Bus drivers	simulator				*	*	*	*	*	*	*						
Meyer et al (2001)	Tractor-trailer drivers	simulator		*	*		*	*	*									
Brock et al (2001)	Bus drivers	simulator		N/A	N/A	N/A	*	*	*	*	*	*						

Gregersen et al (1996)	Company car drivers	Skills training, on-road				*	*	*	*									
		Group discussions				*							*	*	*	*	*	*
		Campaigns				*	*	*		*	*							
		Incentive scheme				*			*			*			*			*
Ludvig & Geller (2000)	Pizza delivery	Multiple intervention		N/A	N/A	N/A	*	*	*	*	*	*	*	*	*	*	*	*
Machin (2001,2003)	Coach drivers		*														*	*
Monin (2003)	Truck drivers	Simulator	*				*	*	*									
Parkes & Reed (2005)	Truck drivers	Simulator	*	*			*	*	*	*	*	*	*	*	*	*	*	*
Uhr et al (2003)	Experienced truck drivers	simulator			*		*		*									
		on-road			*		*		*									

Key:

K&S – Knowledge and Skills
RF – Risk Increasing Factors
SE – Self Evaluation

1.4 A New Direction in Bus Driver Training and Education

Simulators have been used for training operators of many different devices including tanks, planes and nuclear reactors dating back to World War 2 (Emery et al, 1999). Truck and driving simulators have been developed to train operators of police vehicles (GE Capital I-Sim, 2002; FAAC, Inc, 2002), tractor trailers (GE Capital I-Sim, 2002), snowplows (FAAC, Inc., 2002) and a host of other vehicles in both civilian and military sectors.

Given the factors that may impede performance improvements and the training design necessary to overcome these difficulties, it seems that computer-aided instruction devices capable of delivering individualised instruction to allow learners to progress at their own pace and to provide performance feedback are particularly suited to this kind of training application. Indeed, the use of flight simulators in training can have considerable benefits in terms of performance improvement (Lintern et al., 1990). It seems reasonable then that the introduction of a driving simulator in bus driver training could have a considerable benefit on safety.

1.4.1 The Advantages of the Use of Simulators for Bus Driver Training

1.4.1.1 Introduction to Training Simulators

Training is the systematic approach to learning that consists of multiple phases including specification of task requirements, learning objectives and the design of the learning environment including consideration for measuring performance and providing practice and feedback (Salas, Bowers and Rhodenizer, 1998). During training, bus drivers must have the opportunity to learn and practice their new skills in a context that provides essential performance cues and ensures the safety of the instructor and student. (See Salas, Bowers and Rhodenizer, 1998). Training devices are developed to support clear training objectives, which may involve a combination of cognitive, perceptual, procedural, psychomotor, and decision-making processes, depending on the task. The primary aim of training devices is to provide information needed to develop these specific skills. Training simulators therefore serve two main functions: to present information that is required in training and to incorporate features to facilitate and enhance practice and learning (Flexman and Stark, 1987). Training simulators are synthetic environments designed to provide task information rather than to support real operational functions.

1.4.1.2 A Comparison of Training Simulators with other Training Devices and Equipment

The primary function of the training simulator is to display information relating to system performance in response to control inputs. The simulator incorporates controls and displays that have the level of fidelity required to support learning at cognitive and psychomotor levels, whereas displays and controls are only represented in abstract form in low-level training devices (Flexman and Stark, 1989). Simulators use computers that store data that represents the dynamics of the system being simulated and the cues necessary for task performance, including visual and auditory information. When an input is made the effects are computed in relation to other control and environmental conditions and are translated into an output. The response of a system to a control input or other external influence is a function of many factors. It is important that users can understand and learn to control the influences of the system. The simulator organises and processes these factors to represent the dynamic response of the real system. Simulators are capable of providing immediate feedback on correct and incorrect responses. Therefore it is easier to establish causal relationships in a simulator.

Driving consists of making skilled and properly timed actions based on sound judgements and decisions under varying road and traffic conditions. Often in the real world situations happen so quickly that it is difficult to anticipate events. Simulators can be operated faster or slower than real time to allow time to anticipate events by recognising patterns of stimuli in different combinations.
Training simulators are characterised by the capability of controlling the information that supports practice for the purpose of facilitating and enhancing learning in the most efficient manner. The simulator supports practice by providing controls and information required to perform different tasks and presents the exact training setting needed to facilitate learning at each stage of skill development. In addition to this, simulators can provide supplementary cues that may enhance skill acquisition (Chechile, Fleischman and Scidoski, 1986; Lintern, 1991;Lintern, Roscoe and Sivier, 1990; Roscoe, 1991).
The training environment is controlled through instructor intervention whether this is real or represented by a computer. Briefing instructions and demonstrations can be automated which confers the advantage of standardisation to show all trainees the effects of specific conditions and optimum task performance and to reduce instructor's workload. Task conditions can be presented in a standardised format so that trainees are systematically exposed to task conditions graduated in difficulty in relation to their skill development, which means that trainees can pace their own learning. Traditional bus driver training is designed to introduce the knowledge, skills and procedures needed to drive the bus under normal operating conditions (Foran, 2002). Exposure to abnormal, unusual and hazardous situations tends to be avoided for safety reasons, so the events that often lead to bus accidents are rarely encountered in training (Muncie and Dorn, 2003). Simulator technology is capable of simulating adverse conditions to train bus drivers in the level of skill required to respond effectively to dangerous situations. Consequently, realistic training tasks can be experienced without the dangers of being in real traffic on the road. Similarly, practical, economic and safety reasons limit the amount of training a bus driver has in coping with malfunctions. Simulators are ideal environments to safely practice the skills needed to deal with malfunctions, for instance brake failure. Another issue that is particularly pertinent to bus driving is the conflict between prioritising the availability of buses for training versus the need to have enough buses available to run scheduled routes. A whole-task bus simulator solves this conflict because a simulator is intended solely for training.
Detailed training performance measurement is possible when simulators are used so it is possible to measure trainee performance objectively and reliably in ways that are ruled out on the road. Performance can be measured in terms of speed, accuracy and output.

Performance assessment in real systems tends to be based on subjective evaluations that compare the student's overall performance to that of an expert. The instructor rarely has access to specific parameters that pertain to performance. The simulator, on the other hand, collects and stores data relating to overall performance and also individual response parameters. Using such performance measurement capabilities it is possible to rate performance of the student with respect to task demands. It is also possible to determine whether the student is ready to progress from one task to another. This requires insight into the way complex skills are developed and correlating various parameters with performance in various tasks and sub tasks can do this. Another function of performance assessment is to scale individual performance against the trainee population and identify and diagnose the cause of sub standard or incorrect performance. Another outcome of precise and reliable performance measurement is the potential to provide training feedback by which extensive information on performance can be provided either in real-time or after completion of the training segment. Although there are part-task simulators available for training (Sanders, 1991), simulators are generally designed to support whole task rather than part task training, because they allow practice in the same conditions of workload, stress and time pressures typical of the job for which they are training. Simulators can provide the setting in which prior training in individual skills and skill elements are integrated and assessed. For instance, driving simulators have previously been used to test hazard perception skills and can be used to assess the benefits of experience and training on driving skills (Dorn and Barker, 2004; Dorn 2005; McKenna and Crick, 1994). To exemplify, Dorn and Barker (2004) demonstrated that professionally trained police drivers were more likely to reduce their speed in response to hazards, adopted a more central lane position to get a clearer view of the road, and were more cautious when overtaking and when following a lead vehicle when compared with untrained drivers. McKenna and Crick (1994) also used a simulator based hazard perception test to discriminate between age-matched trained and untrained police drivers. To follow on from these studies, a bus simulator that approximates real life may be successfully used to train and test hazard perception and decision-making skills that are necessary for bus driving.

1.4.2 Current Concerns Regarding the Use of Simulators for Training

At face value, a bus simulator has great potential as a time saving and cost-effective method of developing a driver's experience with decision-making in traffic. However, there are risks involved in developing a bus driver-training simulator. The risk stems from there being a relatively immature technology base. Hence the simulator could have features that induce physical discomfort, for example simulator sickness and artefacts within the training scenarios that could create a negative transfer of training. Technology limitations that may affect training include inadequate resolution of the visual display (Falmer et al, 1999), low update and refresh rates (Watson et al., 1998) and low performance motion platforms that either provide false cues or suffer from excessive lags. Such limitations compromise the validity of the simulator in that drivers may behave differently than they do in the operational environment. One of the most significant concerns is that perceptual distortions and cue conflicts due to technology limitations may lead to simulator sickness (e.g. McCauley, 1984; Sharkey & McCawley, 1992). Simulator sickness is a form of motion sickness thought to arise from the visual-vestibular conflict induced by vection (apparent motion) in a simulator. Although vection contributes to the perceived realism of the simulation, it is also the basis for the sensory conflict when the motion perceived visually is not corroborated by the vestibular system. Common symptoms reported include nausea, disorientation and occulomotor discomfort such as eyestrain, blurred vision and eye fatigue (Casali, 1986; Kennedy et al., 1992; Mourant & Thattacheny, 2000). Watson (1995) found that simulator sickness does not account for a significant amount of variance in driving performance, however experiencing the uncomfortable symptoms of simulator sickness may result in lower initial acceptance or avoidance of the simulator altogether. The issue of simulator sickness is particularly pertinent to bus driver training due to the age of the trainee population. This is because the likelihood of suffering from simulator sickness is thought to vary as a function of age (Liu, Miyazaki and Watson, 1999) and experience with the operational vehicle (Kolasinski, 1995). For example, the attrition rate due to sickness in simulator studies involving older drivers is very high indeed (Hagenmeyer and Sommer, 2004). However, short exposure times have been recommended to minimise discomfort (Brock et. al., 2001) and participants can adapt to the sensory conflict on repeated exposure to the simulator (Watson, 1995). To date, very few studies have examined the effectiveness of training transfer from a driving simulator to a real vehicle (Uhr et. al., 2003; Allen et. al., 2003) as compared to the number of studies that focus on design research related to improving simulation technology and system components (e.g. Jameson, 2001; Kapetein et al., 1996; Kappe et al., 1999; Reymond and Kemeny, 1999; Staplin, 1996). The worst-case scenario is that cue conflicts due to technology limitations could result in negative transfer to the operational environment. It is therefore important to conduct research related to the training effectiveness of the simulator.

To summarise, training simulators are generally designed to replace the need for training in the real vehicle because they can support training in a wide range of skills and functions that is simply not possible to achieve on the road (e.g. emergency procedures). However, the purpose of the bus simulator is to supplement not replace existing skill-based in-vehicle bus driver training by providing a safer, more economical and more convenient alternative to training in the operational vehicle. This is because of the concern that current technology limitations and the possibility of simulator sickness may affect training transfer to the operational environment. It is therefore important to evaluate the training effectiveness of the simulator as well as its safety during its use.

1.5 Fidelity and Validity in the Design of Training Simulators

The simulation approach to bus driver training is very promising. However, while there are clear standards for the licensing of simulators in aviation training as yet there are no widely accepted standards and methodology for the design and evaluation of driving simulators. Hence there is little information to guide the design specifications of simulators for driver training. The key, therefore, is to identify what information skilled drivers use to control a moving vehicle. If this limited set of information can be selected from a perfectly simulated roadway it may be possible to identify and implement the minimal perceptual requirements needed to guide the design of more cost effective vehicle simulators. In the simulator, all aspects of the system-user interface relevant to learning must be included but their relevance must be established before the simulator is designed.

The traditional approach to simulator development is to duplicate the physical characteristics of the real vehicle being simulated to maximise fidelity. This incorporates the 3D representation of the driver's environment and also the software that produces the correct vehicle dynamics for particular conditions, vehicle configurations and vehicle systems. The level of physical fidelity required is related to the type of task to be trained, the proficiency level of the trainee, the difference between criterion performance and maximum performance and the method of instruction. A common conception is that the closer a simulator replicates its real world counterpart the greater its presumed validity. In this sense, a moving-base driving simulator is often assumed to have greater physical validity than a fixed-base simulator. However, too much emphasis is placed on simulator fidelity, as no level of physical validity is useful to training if behavioural validity cannot be established. Accordingly, a less sophisticated simulator may have more behavioural validity than a more sophisticated one with greater physical validity and so will prove more useful for behavioural research (Triggs, 1996). Indeed, Bailey (1993) and Wickens and Andre (1994) found that users of simulator systems do not always prefer the system that supports the best performance.

The motivation to duplicate the appearance and feel of the vehicle can be very compelling. However it is of paramount importance that driving behaviour is sufficiently similar in real-life and simulated conditions. Validation then is a critical issue in establishing the credibility of simulator based training. Validation can involve evaluating simulator component response characteristics, driver response characteristics and overall driver/simulator performance. Evaluating simulator response characteristics includes ensuring vehicle dynamics produce accurate simulated vehicle responses and that the responses of the various simulator-cuing devices (e.g. vision, motion, sound, control force) are accurate. Driver responses include their subjective reactions, (which is often referred to as fidelity in the literature) and objective behavioural measures, including perceptual responses and decision-making. The overall driver/simulator performance can be evaluated in terms of responses to events and inputs and through demonstration of training transfer or proficiency testing to real world performance.

With that in mind, it is important to gain a thorough understanding of the bus driving task and to understand the personality and temperamental characteristics, and the skills and ability of the population to be trained to ensure that the training programme is tailored to the needs of the trainees (Hayes and Singer, 1989; Salas, Bowers and Rodenizer, 1998). An individual's skills, attitudes and motivation are as important as their stage of training (Alessi, 1988; Hayes and Singer, 1989).

2 Fidelity in Training Simulators

2.1 Introduction

One of the major issues surrounding the development of training simulators is the issue of fidelity. Historically there has been a heavy investment in technologies to create virtual environments to match operational ones. While high capital and operational costs of military and commercial aircraft can justify high costs of simulator training, the cost and operation of motor vehicles cannot. These budget constraints have therefore prompted simulator builders to opt to reduce costs by reducing fidelity, for example by eliminating elements of the vehicle cab or reducing the quality of the motion, sound or graphics. Although such designs reduce costs, it can cause problems for training effectiveness if vital elements are overlooked. Therefore before building a bus simulator for bus driver training, the cost/fidelity trade off must consider all the elements of the system.

The work described herein analyzes simulator fidelity issues and discusses fidelity requirements for driver training. An extensive literature review was performed on the general topic of simulator fidelity issues. Given the paucity of research on fidelity of driver training simulators, the aviation literature will be used to guide the research into the development of the bus simulator for driver training.

2.2 Definitions of Fidelity

2.2.1 Definitions currently offered in the Simulation Literature

The issue of simulator fidelity has been discussed and studied for over 30 years, and there is still no consensus on a definition. During this time, the term has been used in a variety of ways and to refer to many different aspects of simulation. Attempts to make the term less vague have caused a proliferation of definitions. Lane and Alluisi (1992), for example, identified at least 22 different definitions used in the literature to refer to different kinds of fidelity. A sample of the different kinds of fidelity mentioned in the literature includes: objective fidelity, perceptual fidelity, equipment fidelity, environmental fidelity, psychological fidelity, cognitive fidelity, task fidelity, experiential fidelity, physical fidelity and functional fidelity (AGARD, 1980; Allen, Buffardi & Hays, 1991; Hansen and Jakobsen, 1993; Hays and Singer, 1989; Kaiser and Schroeder, 2003; Prothero et. al., 1995, Stoffregen, Nelson and Papulayan, 1999). Each of these kinds of fidelity could be appropriate for a particular application, but not all are generally applied to all simulations.

In 1999, the Simulation Interoperability Standards Organisation (SISO) adopted the following formal definition of fidelity:

"Fidelity is defined as the degree to which a model or simulation reproduces the state and behaviour of a real world object or the perception of a real world object, feature, condition, or chosen standard in a measurable or perceivable manner; a measure of realism of a model or simulation; faithfulness."

"The methods, metrics, and descriptions of models or simulations used to compare those methods or simulations to their real world referents or to other simulations in terms of accuracy, scope, resolution, level of abstraction and repeatability."

This two-part definition is equivalent to Hays and Singer's (1989) two aspects of simulator fidelity: physical fidelity and functional fidelity. Physical fidelity is a measure of the physical characteristics of the simulator and functional fidelity is the informational or stimulus and response options of the equipment. Fidelity can therefore characterise the representations of a model, a simulation, the data used by a simulation or an exercise. Fidelity should generally be described with respect to the measures, standards or perceptions used in assessing or stating it. Each of the fidelity types has different implications for the applications that employ these representations. In 1980, the Advisory Group for Aerospace Research & Design (AGARD) distinguished between two classes of flight simulator depending on the nature of the cues they provide.

"Equipment cues provide a duplication of the appearance and feel of the operational equipment (the aircraft), i.e., the static and internal dynamic characteristics such as the size, shape, location, and colour of controls and displays, including controller force and displacement characteristics."

"Environment cues provide a duplication of environment and motion through the environment."

Fidelity is then a function of the degree to which the equipment and environmental cues relate to those of the real aircraft. A distinction between the real cues, measured objectively, and the cues the pilot subjectively experiences, provides the following definitions for two types of fidelity (AGARD, 1980):

"Objective Fidelity provides an engineering standard and is the degree to which a simulator would be observed to reproduce its real-life counterpart aircraft, in flight, if its form, substance, and behaviour were sensed and recorded by a non-physiological instrumentation system onboard the simulator. By including both equipment and environmental cues, this definition can encompass all pertinent dynamic cue timing and synchronization aspects of simulator fidelity."

"Perceptual Fidelity provides a psychological/ physiological standard and is the degree to which the flight crew subjective perceives the simulator to reproduce its real-life counterpart aircraft, in flight, in the operational task situation. The requirement that the operational equipment be considered in the context of the task situation ensures that not only cue timing and synchronization, but also cue priority effects, are taken into account."

Objective fidelity encompasses the physical and functional aspects of the simulation described by Hays and Singer (1989). Perceptual fidelity also encompasses physical, functional fidelity but also includes psychological fidelity (user's acceptance of the simulator).

A more recent definition of fidelity is that of Kaiser and Schroeder (2003) who recognise four types of fidelity that are relevant to flight simulation:

- Physical fidelity: "to what extent does the simulator's displays, controls and other physical components look and feel like the actual aircraft?"
- Visual fidelity: "to what extent does the visual scene resemble that seen through the cockpit window?"
- Motion fidelity: "to what extent does the motion-induced forces experienced in the simulator reflect those of the actual flight environment?"
- Cognitive fidelity: "to what extent does the simulator environment engage the pilot in the same sort of cognitive activities as the actual modern flight deck?"

These fidelity distinctions could equally be applied to ground vehicle simulation in the following way:

- Physical fidelity: "to what extent does the simulator's displays, controls and other physical components look and feel like the actual vehicle?"
- Visual fidelity: "to what extent does the visual scene resemble that seen through the windscreen of the actual vehicle?"
- Motion fidelity: "to what extent does the motion-induced forces experienced in the simulator reflect those experienced in the actual vehicle?"
- Cognitive fidelity: "to what extent does the simulator environment engage the pilot in the same sort of cognitive activities as the actual traffic environment?"

The basic connotation of simulator fidelity is clear even when there are differences of opinion about its precise definition. The concept of simulation fidelity has to do with how well simulation responses and results correspond to what the simulation represents and involves both an objective assessment of performance and a subjective evaluative component. From these definitions then we can begin to distinguish between simulators that have low, medium and high levels of fidelity.

2.2.2 Fixed-based or Moving-based simulators

It is important to distinguish between motion-base and fixed-base simulators. In the latter, drivers have the visual perception of motion without the physical sensation, whereas moving base simulators are equipped with hydraulics to provide drivers with the physical sensation of a moving vehicle. The introduction of motion platforms to provide physical movement in roll, pitch and yaw rotation as well as lateral, longitudinal and vertical translation further contributes to the perceived realism of the virtual environment, for example when braking or negotiating curves.

2.2.3 Low-fidelity simulators

Low fidelity simulators usually have a narrow field of view, limited visual fidelity and simple vehicle dynamics. The simplest low-fidelity simulators include arcade video games and desktop PC-driven driving games that are controlled by a keyboard, joystick or miniature steering wheel. Two other types of simulator also fit into this category: model board systems in which a miniature camera is installed in a small model and physically moves around a terrain board and PC based simulators which are essentially sophisticated video games with a steering wheel and pedals. Although these PC-based simulators operate in real time, they typically have a narrow field of view, limited visual fidelity and very simple vehicle dynamics. However, there is research to demonstrate that some skills training does transfer from low fidelity flight simulators to the real aircraft (e.g. Dennis and Harris, 1998; Gopher, 1994; Koonce and Bramble, 1998; Moroney, Hampton, Beirs and Kirton, 1994).

2.2.4 Medium fidelity simulators

It has been suggested that medium fidelity simulators might have larger field of views (120°-180°) and more sophisticated vehicle models and scenario effects, such as weather, road friction, day/night (Brock et al, 2001). They may have limited motion capability provided through g-seats, which provide motion cueing information through PC-controlled actuators which change the height of the seat, move the back-pad and seat-pad and adjust the tension on the harness and lap belt, but primarily drivers have the visual perception of motion without the physical sensation. These features require more powerful computers than low-end simulators.

2.2.5 High-fidelity simulators

High-fidelity simulators are often characterised by very sophisticated visual image generation systems, advanced vehicle dynamic models and complex motion bases to provide high fidelity real-time vehicle simulations. They typically have greater processing power than lower fidelity systems and of course cost more. Examples of high fidelity simulators are the Netherlands Organization for Applied Scientific Research, Human Factors Research Institute (TNO-HRFI), the Swedish National Road and Transport Research Institute (VTI) and National Advanced Driving Simulator (NADS) at the University of Iowa.

2.2.5.1 TNO Simulator

The TNO driving simulator, located in the Netherlands, is an interactive driving simulator that has a six-degrees-of freedom moving-base, computer-generated external imagery and has the capacity to process up to 254 independently moving vehicles within the simulation environment. The vehicle mock-up (either a BMW 318 or a DAF

CF 65.180) is positioned within a room containing a 200 by 35° cylindrical screen and the rear-view mirrors.

Figure 1 TNO Driving Simulator

2.2.5.2 VTI Simulator

The Swedish National Road and Transport Research Institute is home to the VTI driving simulators. Driving Simulator III is based on a real vehicle chassis, has advanced vehicle dynamics and a sophisticated motion system, which enables fast accelerations. The surroundings are simulated and displayed to the driver via three main screens and three rear view mirrors. A vibration table under the chassis simulates the motion effects of contact with the road surface, providing a more realistic driving experience.

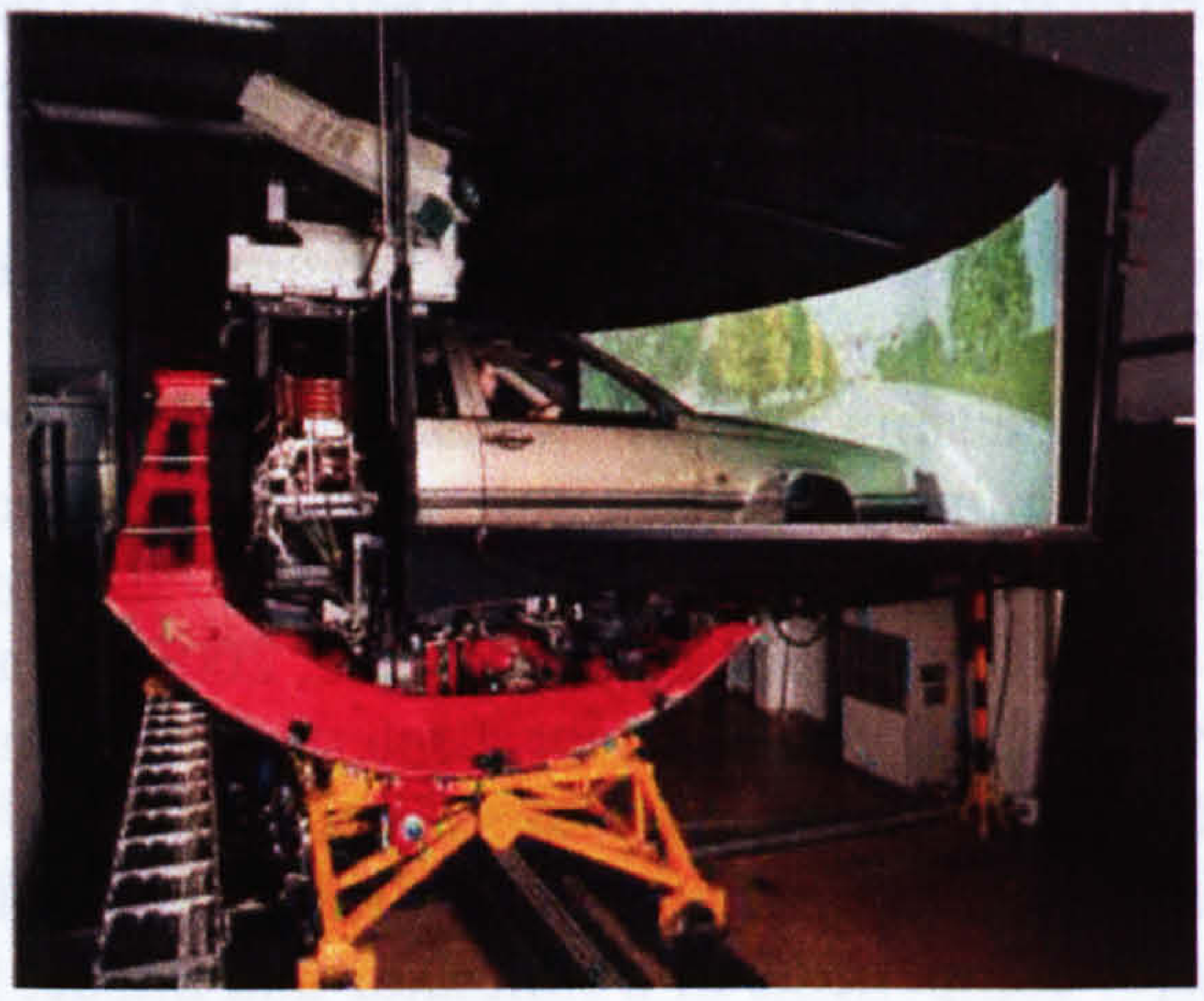


Figure 2 VTI Simulator

2.2.5.3 NADS Simulator

The NADS, located at the University of Iowa, is the most sophisticated ground vehicle simulator in the world. It consists of a large dome in which entire cars and the cabs of trucks and buses can be mounted. The vehicle cab subsystem currently consists of four vehicle cabs, configured to fit within the physical environment of the visual dome on the motion subsystem that provides 400 square meters of horizontal and longitudinal travel and nearly 360 degrees of rotation in either direction. Each cab retains the vehicle interior with few changes to the internal ergonomics and layout. The four vehicle cabs include a standard sedan (Chevrolet Malibu), a sports/utility vehicle (Jeep Cherokee), a midsize sedan (Ford Taurus), and a commercial truck cab (Freightliner). The vehicle cabs are equipped electronically and mechanically using instrumentation specific to their make and model. The vehicle is attached to a motorized turntable that allows the dome to rotate and simulate different driving conditions so that drivers experience highly realistic driving scenes, traffic sounds, and road conditions such as gravel and pot holes.

Figure 3 **NADS**

2.3 Simulator Categorisation: the distinction between fidelity and training effectiveness

At present the concept of fidelity is metric-free; the fidelity of a specific simulation cannot be located and assigned a numerical value (Lane & Alluisi, 1992). This means that you cannot simply select a simulator on the basis of its fidelity and expect it to have the correct requirements for training. For example, research has shown that the level of fidelity required for training depends on the type of task being trained and the vehicle being simulated (e.g. Caro, 1979; Kaiser and Schroeder, 2003; Longridge, T., Bürki-Cohen, J., Go, T., and Kendra, A., 2001; Taylor, Lintern and Talleur, 1995). Various attempts have been made to categorize simulators according to the fidelity of their components. With regard to flight simulator studies, Lintern and McMillan (1991) contend that the four major components of a simulator that impact training effectiveness in terms of their influence on design and production costs are: visual systems, whole-body motion cueing systems, vehicle dynamics and control systems. While the effects of manipulating the fidelity of these components has been fairly well documented in the aviation industry, to date there have been few studies to investigate the relative importance of the fidelity of the various components of driving simulators on transfer of training to the real world. This poses the problem that although simulators are vaguely categorised according to their level of fidelity, this does not help in the decision regarding which simulator is best for training.

2.3.1 Flight Simulator Categorisation

The Civil Aviation Safety Authority (2002) classifies aviation simulators into four categories (JAR-STD-1A). Certification and accreditation is made on the basis of checking the simulator performance requirements against a checklist of standards. The classification system specifies the tasks that can be trained on the simulator so that trainers can select the simulator that will best meet their training objectives.

2.3.1.1 Category A Synthetic Trainers

Category A simulators provide training in instrument flight procedures, limited navigation aid procedures, orientation and homing, and with the addition of special requirements can provide training in visual flight procedures. They require a cockpit enclosure, basic flight instrumentation, an automatic direction finder or VHF omni-directional range, aerodynamic simulation, aircraft controls, limited instructor facilities and a flight path display. The visual system must provide at least 45° horizontal FOV and 30° vertical FOV per pilot. Night scenes are acceptable. The response to control inputs should not be more than 300ms above those experienced on the real aircraft. Effects may be of a generic nature.

2.3.1.2 Category B Synthetic Trainers

Category B simulators provide additional training in instrument flight procedures and instrument cross-country navigation. With the addition of special requirements they can also provide training in visual flight procedures. These simulators require an automatic direction finder, VHF omni-directional range, instrument landing system and distance measuring equipment or Global Positioning System, a cockpit enclosure, full instrumentation and controls, realistic aerodynamic simulation and characteristics, full instructor facilities and a flight path display. Flight performance and systems characteristics must be validated against actual flight test data.

2.3.1.3 Category C Synthetic Trainers

Category C simulators provide a Category B standard synthetic trainer, plus simulation of a specific aircraft type, which is then assessed according to the operational standards applicable to flight simulators. Additional daylight/twilight and night visual displays are required projected via a collimated visual system that provides each pilot with 180° horizontal and 40°vertical FOV. Motion cues including wind shear should be provided by a six axis motion platform. Standard flight deck sounds and other limited audio cues, such as crashes and precipitation should also be provided. The response to control inputs should not be more than 150ms greater than those experienced in the real aircraft.

2.3.1.4 Category D Synthetic Trainers

Category D flight simulators offer the highest level of flight simulator performance. All sound and motion cues should be provided and tested to ensure they have comparable amplitude and frequency of flight deck noises, including engine and airframe sounds. The sounds should be co-ordinated with the required weather. Characteristic motion vibrations that result from the operation of the aeroplane, such as those indicating an event or aeroplane state that can be sensed from the flight deck must be present. The flight simulator must be programmed and instrumented so that the motion vibrations can be measured and compared to aeroplane data.

2.3.2 Driving Simulator Categorisation

Few attempts have been made to classify driving simulators. Notably, this issue was addressed in part by Brock, Jacobs, Van Cott, Mccauley and Norstrom (2001), who investigated the current use of bus simulators in bus driver training and recommended that bus simulators could be placed into the following three categories:

2.3.2.1 Level 1 Bus Simulator

Level 1 bus simulators use an open-loop video to display traffic and other instructional information. Typically there are several student stations in a classroom, each with a steering wheel, accelerator and brake pedals, and a rudimentary dashboard. In spite of this, the device is not interactive as the student's input into any of these controls will not produce any appreciable effect on the video display. The system is designed to train and tests very specific bus operator activities, for example reaction time and visual recognition. Stopping distances, road conditions, the relationship of speed to both, and the role of reaction time can be demonstrated and then practiced. The instructors can monitor and identify students who are not correctly responding as the scenarios play. The system effectively demonstrates the way a large transit bus behaves under varying conditions as well as how the student should operate such a large vehicle.

2.3.2.2 Level 2 Bus Simulator

Level 2 bus simulators use a model board system in which a miniature camera is installed in a small model of a bus that physically moves about on a small terrain board in an adjoining room. This system replicates the visual, auditory, and vibratory effects of driving a bus in an urban, crowded environment in order to train student operators to manoeuvre a transit bus in relatively tight situations. The system demonstrates basic manoeuvring of transit buses in typical urban areas. Skills such as approaching a bus stop, parking, tight turns, and backing can be taught to a single student without risk of damage to an actual bus or to platforms, other vehicles, or pedestrians.

2.3.2.3 Level 3 Bus Simulator

Level 3 bus simulators used the latest technology to deliver a full replication of the driving experience. Level 3 simulators were distinguished by having a larger field-of-view (FOV), with 180° forward, a vertical FOV of at least 45° and 60° to the rear. Mock ups of real bus cabs were included so that the mirrors in the simulated cab could be physically manipulated to reflect the image projected from behind. Additionally, more sophisticated vehicle models were used along with more complex environmental effects, for example weather, day-night, and road friction, and motion cues to replicate the look and feel of the outside world as seen by a driver looking out of the windows of a bus cab. The scenarios reflect the specific driving environment of the transit buses for which the operators are being trained. Therefore, the device provides high fidelity simulation of actual driving situations that trainees are likely to encounter upon completion of the training program.

All of the devices investigated by Brock et al (2001) trained some of the skills that transit bus operators needed, however no single simulator trained them all. While the categories offer an effective method of distinguishing between different types of training methodology; they do not allow scope for making the distinction between the variations that are often seen in 'level 3' type simulators. These categories also confuse the issue of the degree of simulation, the level of fidelity, the type of technology used and the types of task that can be trained on the simulator. The degree of simulation relates to the operational features provided in the simulator, for example motion, visual database, controls and so on. Thus it is possible to have part task and full-mission simulators; either of which could be high, low or medium fidelity (Parkes and Flint, 2004). For example, although the open-loop video of the level 1 simulator provides a high physical fidelity simulation of the visual environment, it has low functional fidelity because it is not interactive. Nevertheless, the categories provide a way of deciding which type of simulator might be suitable for a specific training need, which is a step in the right direction.

2.3.3 Driving Simulator Re-Classification

The message from the literature seems to be that simulator classification is difficult, especially for training simulators. It is not sufficient to say that a high fidelity simulator is better for training because it depends on the type of task being trained (Dennis and Harris, 1998; Hayes and Singer, 1989; Kaptein, Theeuwes, and van der Horst, 1996; Lintern and McMillan, 1993). Therefore a dynamic classification system that is task-dependent would serve trainers better because it would allow them to make more informed choices about the type of simulator that they require in order to meet their training objectives.

2.4 Fidelity in the Design of Training Simulators

2.4.1 Fidelity and Training Transfer

Training effectiveness is often equated with fidelity (Stoffregen, Nelson, Pagulayan, and Bardy, 1999). However, there is a growing body of evidence from the aviation literature that suggests deliberate departures from reality can improve the quality of pilot performance in flight simulators (Chechile, Fleischman and Scidoski, 1986; Lintern, Roscoe and Sivier, 1990; Roscoe, 1991). One further challenge concerns the degree to which virtual environments can be transformed from their normal appearance and behaviour of the real world in ways that might benefit training. For example matching the complexity of the task to the level that trainees can cope with is a central issue in education, and lower fidelity simulators may better serve novice trainees (Verstegen, 2004).

From an engineering standpoint, human beings are characterised as highly adaptable but limited capacity information processing systems capable of using only a fraction of the information available to us from the world at any one moment (Schneider and Shiffrin, 1977). Neither a novice nor an expert can respond to all of the information available in a task setting except in rare circumstances when task information is scarce or when complex patterns of information can be differentiated. Complex training environments may then compete for students' limited attention and memory while they are learning (Alessi, 1988; Chechile, Fleischman and Scidoski, 1986). Lintern (1991) argued that intentional departures from reality by abstracting or augmented displays might actually enhance skill acquisition by focussing the trainees' attention on task-related perceptual invariants and thus reduce distractions. Supporting evidence comes from Lintern, Roscoe and Sivier (1990) who demonstrated that transfer of landing skills from a flight simulator benefited from predictive augmentation and training without crosswind. Chechile, Fleischman and Scidoski (1986) studied divided attention in pilots and concluded that stimulus complexity primarily influences initial learning but as students develop automaticity, fidelity may increase without attention deficits. Alessi (1988) proposed an interaction between learning and fidelity and the instructional level of the trainee (figure 4).

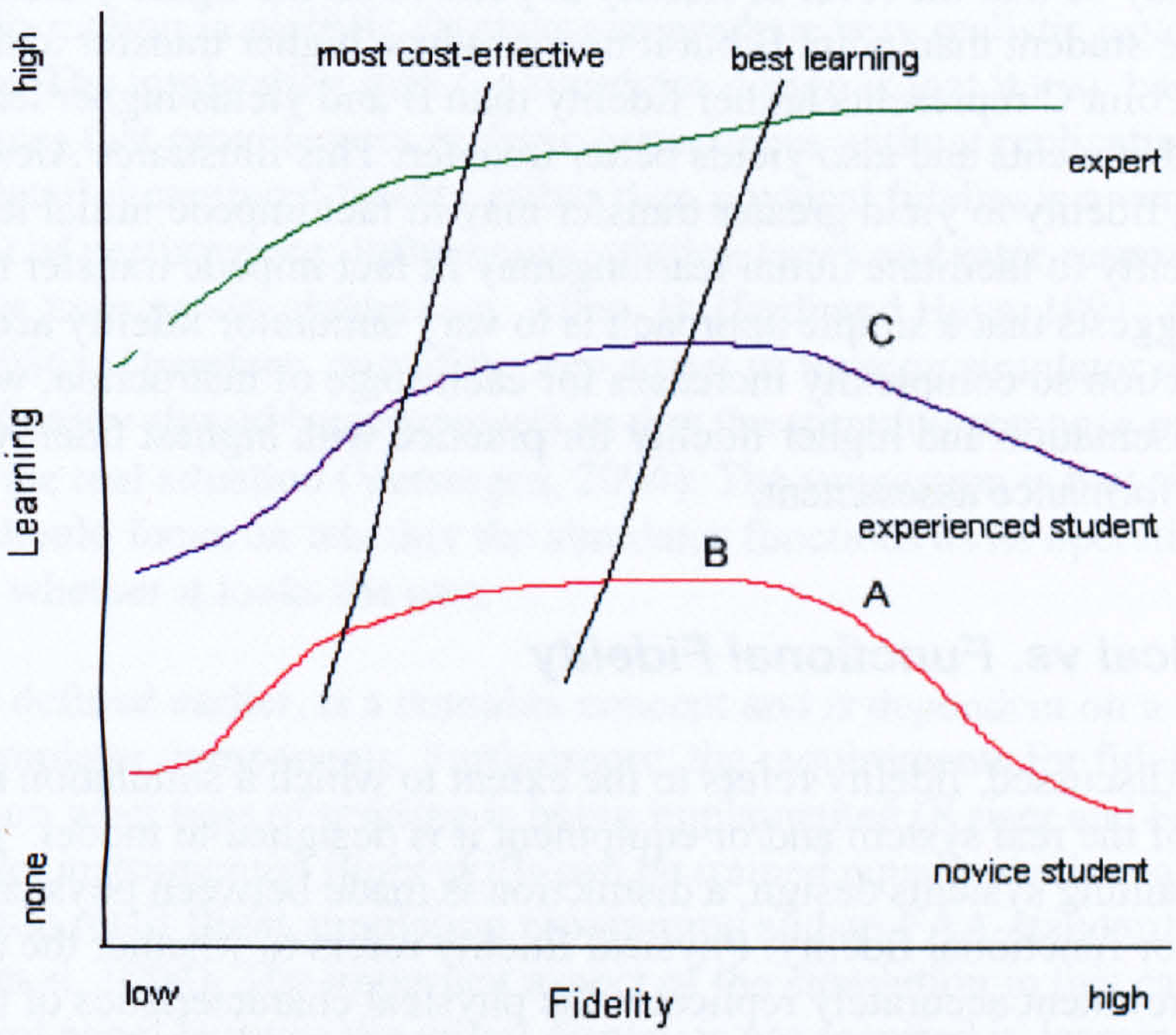


Figure 4 **Hypothesized Relationship between Fidelity and Learning (Alessi, 1988)**

The relationship between learning and fidelity is non-linear and depends on the instructional level of the student. For a novice student very low fidelity produces some learning but a slight increase in fidelity may yield better learning. A hypothetical example may be the difference in watching a video to teach hazard perception skills (such as the DVLA's Roadsense video, 2002) and a hazard perception PC-based interactive programme (such as Arriva's Risk Assessment CD-ROM, 2002). The same student might learn less from a high fidelity simulator and even less from the real vehicle which has the highest fidelity as the environment may be so stressful and confusing that their attention is directed elsewhere and learning may not occur (e.g. Chechile, Fleischman and Scidoski, 1986; Dorn and Mason, submitted). According to Alessi (1988), experienced students generally learn more than novices in higher fidelity environments such as simulators. For the expert a high fidelity vehicle may not be as effective as the real thing. Alessi gives the example of an experienced pilot learning to fly a new type of plane. The pilot is already proficient in flying skills but must familiarise his/her self with the specific controls and handling characteristics of the new type of plane. The equivalent in bus driving may be 'type training' in which a bus driver learns to handle a new model of bus. For increasingly sophisticated students the 'point of best learning' reflects increasing fidelity of instruction. However the line labelled 'most cost-effective' intersects the curves where they begin to exhibit diminishing returns. Beyond that point, great increases in fidelity are required to produce small increases in learning. Alessi (1988) argues that an efficient curriculum would train people along the most cost-effective line, gradually increasing fidelity as students increase their experience. Figure 4 depicts the effect of fidelity on learning but what about the effect of fidelity on transfer? The notion of transfer includes initial learning but also the degree of similarity between the training and operational environment as discussed. It may be that the level of fidelity at point A on the figure yields less initial learning for the student than point B but it may produce higher transfer to the real environment. Point C represents higher fidelity than B and yields higher learning for more advanced students and also yields better transfer. This illustrates Alessi's point that increasing fidelity to yield greater transfer may in fact impede initial learning, while decreasing fidelity to facilitate initial learning may in fact impede transfer to the real task. Alessi suggests that a simple approach is to vary simulator fidelity according to the stage of instruction so complexity increases for each stage of instruction, with lower fidelity for presentation and higher fidelity for practice with highest fidelity or the real vehicle for performance assessment.

2.4.2 Physical vs. Functional Fidelity

As previously discussed, fidelity refers to the extent to which a simulation matches the characteristic of the real system and/or equipment it is designed to model. With regards to fidelity in training systems design, a distinction is made between physical fidelity and psychological or functional fidelity. Physical fidelity refers to whether the training device or environment accurately replicates the physical characteristics of the real system, such as the controls, displays, and visual and audio cues. Functional fidelity is defined as the degree to which a simulation imitates the information and stimulus-response options that are present in the real world, for example the vehicle or road dynamics (Hayes and Singer, 1989). With perfect fidelity, a training environment (virtual or real) would be indistinguishable from the actual task environment. With this in mind, the concept of immersion, a state in which the user becomes part of the simulated world rather than the simulated world being a feature of the user's own world, has been a central feature of virtual reality systems. Prothero, Parker, Furness, and Wells (1995) argued that presence, the subjective feeling of 'being there', should be the sole criterion for the design of virtual environments. However, there are a number of philosophical as well as practical flaws to this assessment method, which are discussed by Stoffregen et al (1999). For example it is possible to feel 'present' in a simulated environment but still feel that it lacks credibility if the events experienced are not considered to be plausible. Consequently, it is not worth the effort of designing an experiment to test whether drivers mistakenly believe they are in a real vehicle. Instead, the question when designing virtual environments for training is the extent to which the virtual world must match the real world for training transfer to occur. Traditionally it was thought that the higher the correlation between the physical features of the simulated and natural environments, the greater the chance of generalising the experience from the simulator to the real world (Stoffregen et al 1999). The belief here is that if the user perceives a simulation as being more realistic, their behaviour is more likely to mimic that in the operational environment (Prothero et. al., 1995). It is true that the high degree of similarity in high fidelity simulators conveys a high degree of face validity and this face validity has played a major role in gaining acceptance from professional pilots for the use of flight simulators. For example, Wickens and Andre (1994) found evidence that pilots typically prefer "the bells and whistles" of a high fidelity system. However, many researchers have advocated a move away from the traditional emphasis on physical fidelity towards an emphasis on the psychological or functional aspects of fidelity (Baudhuin, 1987). For instance a simulator with high physical fidelity may not have the necessary capabilities and functionality to assess operator proficiency. Furthermore, the presentation of a limited amount of properly selected information in realistic displays can produce very realistic psychological experiences. The implication then for simulator design is that it may be possible to design devices that provide very realistic experiences without replicating the real world in perfect detail. Functional fidelity rather than physical fidelity is a very important determinant of performance, influencing solution times and inter-response times in maintenance training simulators (e.g. Allen, Buffardi and Hays, 1991; Allen, Hays and Buffardi, 1986). Therefore, one of the key issues in training simulator design is that functional fidelity should be guaranteed so that the stimulus-response relations are the same as in the real situation (Verstegen, 2004). The suggestion is that simulator designers should focus on whether the simulator functions as its operational counterpart rather than whether it looks the part.

Fidelity, as defined earlier, is a complex concept and is dependent on a variety of different simulator components. Furthermore, the requirements for fidelity change depending on what type of training is being implemented (Kaiser and Schroeder, 2003). For example, instrumented flight skills can be trained equally well on a low fidelity PC-based desktop retail flight simulation programme and an FAA-standard simulator (Moroney et al, 1994). The important aspect of the simulation in this case is the fidelity of the control panel because the visual display is not required in learning. This demonstrates that some similarities between the simulation and transfer environment are irrelevant to transfer and that simulators with lower levels of fidelity can be equally as effective in training (e.g. Gopher, 1994; Koonce and Bramble, 1998). Some groups of researchers have long supported the use of lower levels of fidelity depending on the goal of the simulation (e.g. Dennis and Harris, 1998; Gopher, 1994; Hays and Singer, 1989; Koonce and Bramble, 1998; Lintern and McMillan, 1993; Salas, Bowers and Rhodenizer, 1998). However, in full-mission flight simulations, higher levels of fidelity may be sought as the simulator needs to closely replicate the vehicle and task environment so that all relevant cues and elements of the tasks are available to the user to allow the transference of skills (Rehmann, Mitman and Reynolds, 1995). Hence, the level of fidelity needed to support learning should determine the level of fidelity built into the simulator rather than the preferences of the user (e.g. Wickens and Andre, 1994). It is therefore important to understand which aspects of fidelity are essential and which are secondary for training a specific set of tasks. For instance, if decision-making skills and tactics are being evaluated, then (based on lessons from the aviation literature) perhaps high fidelity in vehicle handling characteristics is not critical while on the other hand, if the primary interest is in the examination of manual-control skills, then it may be more important to have high fidelity vehicle handling characteristics than high fidelity environmental cues. These aspects of simulator fidelity support the general claim within the simulation community that fidelity requirements cannot be generally determined for different types of simulations and that the level of fidelity built into the simulator is dependent on the specific objective the simulation is intended to accomplish. Simply striving for high realism can drive the costs of training simulators sky high, but may add little value to training. Therefore, high realism should not necessarily be the goal of simulator designers, rather it is the level of fidelity required to support learning and transfer that should determine the level of fidelity built into the simulator (Alessi, 1988).

The review shows that the relationship between fidelity and training transfer is clearly complex and is mediated by the instructional level of the trainee. Intentional departures from reality can actually enhance learning, but too much departure from reality can impede transfer depending on the type of task being trained. The main questions arising from the discussion on fidelity are as follows:

- How low can the fidelity of the bus simulator be to enhance initial instruction without impeding transfer?
- Should the fidelity of the bus simulator be higher for more advanced students?
- What aspects of the bus simulator could be made more or less realistic to enhance training effectiveness?

To answer these questions the tasks to be trained must be identified and the instructional level of the trainees must be identified. Then the fidelity of the bus simulator can be defined to deliver simulated scenarios that will be most effective for training transfer to occur.

2.5 Level of Simulator Fidelity Required to Support Cognitive Skills Training

The guiding principle in the development of driver training simulators is to firstly identify the tasks that the simulator will support, and then to identify the information that skilled drivers use to complete these tasks so that the relevant cues are included in the simulator specification.

Uhr et al (2003) suggest that a hierarchical task analysis of the driving tasks to be trained should be conducted to ensure that the simulator has the correct level of fidelity to support learning. However, Triggs (1994) argued that a thorough 'bottom-up' analysis of all the tasks involved in driving would be time consuming and that a 'top-down' approach involving identification of the higher-order skills needed for decision-making, such as risk perception would provide enough detail to inform simulated scenarios for simulator based driver training in order to calibrate skills level and risk taking in novice drivers.

Regarding the development of a bus driver training simulator, the assumption is that novice bus drivers have already learned the skills necessary to manoeuvre a bus, for example pedal control and they are already experienced car drivers. However being able to drive a vehicle is not tantamount to being able to drive safely (Triggs, 1994). Rather, hazard perception and risk perception have been singled out as especially important skills when driving in very demanding scenarios (Ranney, 1994).

Hazard perception can be defined as the ability to recognise and anticipate dangerous traffic situations. Crick and Mckenna (1991) and Renge (2000) suggested that the concept of a mental model is useful for explaining driver's actions in a complex traffic environment. A mental model is an internal representation of a complex system, formed through experience and used to predict interactions within that system (Crick and McKenna, 1991; Johnson-Laird, 1983). Drivers who are better at hazard perception are described as having a more effective predictive mental model of the driving environment (McKenna and Horswill, 1999). Since novice bus drivers have had less contact with traffic and less time to develop and refine their mental models, they are therefore less able to correctly predict the development of traffic situations than experienced bus drivers (Vogel, Kircher, Alm, and Nilsson, 2003). Experienced drivers are more skilled at sampling visual information (Mourant and Rockwell, 1972) have a better understanding of other road users communicative signals (Renge, 2000) and can detect road hazards earlier than novice drivers (Crick and McKenna, 1991) and are more confident in their predictions (Vogel, Kircher, Alm, and Nilsson, 2003). When road users commit rule violations these skills are particularly important because the traffic situation then becomes less predictable. Therefore enabling novice bus drivers to develop more complex mental models of the traffic environment is likely to improve their hazard perception skills. However, it is not sufficient to just improve hazard perception skills in novice bus drivers since drivers tend to exhibit greater illusory biases with respect to their hazard perception skill compared with skill overall and vehicle-control skill (Horswill, Waylen and Tofield, 2004). There follows the danger that bus drivers would not take steps to protect themselves and their passengers from hazards if they are excessively optimistic in their appraisal of the risks associated with various events or situations. Therefore novice bus drivers' perception of risk must also be addressed in training, especially since recent evidence suggests that amount of car driving experience does not decrease the risk of bus collisions (Wahlberg, 2005). It appears that driving a bus may require a different set of abilities and skills than those acquired over time driving a car.

2.5.1 The Importance of a Visual Display

It is generally accepted that a visual system will increase the training value of a non-visual flight simulator (Hays, Jacobs, Prince and Salas, 1992) and that visual displays are more important than cockpit motion in flight simulators (O'Hare and Roscoe, 1990; Roscoe, 1991). However, Lintern and McMillan (1993) conclude that for flight simulators there is little evidence to suggest that high fidelity visual displays are more effective than low fidelity displays with regards to training transfer. On the other hand, Taylor, Lintern and Talleur (1995) collated the results from 31 advanced flight students tested in a transfer of training paradigm designed to test the effects of scene detail, FOV and amount of visual training in a simulator. They showed that subjects trained under a low scene detail and wide FOV (two channels vs. one) performed better than all other combinations. However subjects trained under low scene detail and narrow FOV performed more poorly than subjects trained under other combinations. The authors suggested that simulator designers should favour wide FOV over high scene complexity. However, flight training is very different from driver training so the results may only be applicable to flight simulators. For instance, Fisher, Laurie, Glaser, Connerney, Pollatsek, Duffy, and Brock (2002) argue that risk perception skills in driving depend mostly on visual scanning and cognitive analysis, hence visual cues may be more important in driver training than pilot training, while motion cues may be less important in driver training when compared with pilot training. However there has been little systematic research on the influence of visual displays on training transfer in driving simulators (e.g. Allen et. al, 2003; Jameson, 2001; Kaptein, Horst and Hoekstra, 1996; Kappé, Korteling and van der Erp, 1999; Staplin, 1996). Those that have been conducted will now be reviewed.

Visual systems are typically expressed in terms of their resolution, colour, field of view and scene complexity. Adequate resolution depth cues are required so that students can perceive depth in the scene, as well as self-motion and the motion of other vehicles (Farmerd , van Rooij, Riemersma, Jorna and Moraal, 1999; Kemeny, 1999; Stoner, 1995). For example, Staplin (1996) compared drivers' performance of a gap acceptance task in the real world and on a simulator with three different display resolutions and found that the higher the resolution the closer the driver's behaviour matched that of their real-life actions. Detection and recognition distance and conspicuousness are impaired as a function of the discrepancy between visual acuity and the resolution of the image display. Given this finding, it may be advisable to achieve the highest resolution available (Farmer et al, 1999). There are no studies on the effect of colour per se on training transfer, however a colour display may enhance the face validity of the simulator and may facilitate the saliency of objects in the display. High visual update and refresh rates are also necessary to display close-proximity moving models (Stoner, 1995) and to facilitate the acquisition of closed-loop control skills, of which driving is an example (Ricard, 1995). Farmer et al (1999) recommend that update and refresh rates should be equivalent at 60-75 hz, however the demands of generating images does not allow for frame rates as high as these. Watson et al (1998) reviewed the literature from a number of researchers and found that 6-10hz was an absolute minimum; 20hz is typical. There is some debate about the benefit that a wide field of view may have for driver training. Farmer et al (1999) argue that the field of view should match that of the user in the operational environment. Bus drivers are often required to make large head movements to scan for hazards when manoeuvring at bus stops, junctions and traffic lights, hence a wide field of view is required to support behaviour at these locations.

Allen and colleagues (2003; 2005) have investigated the effect of manipulating visual display on driver training. They trained over 400 high school students using three different display conditions: single monitor, three monitors and vehicle cab. After a brief orientation session that presented information on traffic rules and regulations the students completed six simulated trials of complex driving scenarios. Their performance was assessed in terms of the total number of accidents, turn signal errors, and instances of hard braking and hard cornering, average speed and average time-to-collision. The data showed that the learning trend across trials was significant for all variables. The results show that students driving the single monitor system generally drove more aggressively. They had higher speeds, harder braking and cornering, more turn signal errors, more accidents and smaller TTC than students driving the other simulator configurations. This was attributed to a limited field of view and poorer ability to judge speed. Students driving the cab simulator configuration were generally more conservative in terms of their speed, TTC and accidents, which was attributed to the more realistic display allowing better perception of speed, distance and closing rates when overtaking other vehicles. Braking and cornering was similar in the three-monitor simulator configuration and the cab mock-up but overall the single monitor configuration elicited the poorest performance which was attributed to a lack of peripheral cues since the other configurations supported detailed driving scenarios with a high level of fidelity. The implication here is that a wide field of view is better for training. However, the drawback with this study is that there is no clear information about the effects of field of view on driving skills transfer to the operational environment and whether this type of training has any impact on real world accident rates in novice car drivers.

Support for a wide field of view comes from validation studies that compare simulated driving performance to driving performance in the operational environment. Firstly, it is well established that the illusion of self-motion (vection) can be visually induced and can contribute to the fidelity of the simulator. Visual flow information, especially in the periphery can produce a sense of self-motion even in the absence of corresponding vestibular motion cues (Kaiser and Schroeder, 2003). A wide field of view and aspects of the visual display such as accurate texture gradation and object orientation help to generate the illusion of motion. Secondly, most researchers favour a wide field of view because it means that more peripheral cues are available to the trainee, which helps them control their vehicle (Allen et. al, 2003; Jameson, 2001; Kaptein, Horst and Hoekstra, 1996; Kappé, Korteling and van der Erp, 1999; Taylor, Lintern, and Talleur, 1995). For example, Kappé et al (1999) investigated the effects of horizontal field of view on drivers asked to perform a lane-keeping task whilst correcting for a slight side-wind. The results showed improved steering performance when the drivers experienced a wide field of view rather than a narrow field of view when resolution of the display was kept constant. Similarly, Jameson (2001) investigated the effect of field of view on the validity of speed choice and lane keeping by comparing real driving to driving in a simulator with three field of view conditions (50°, 120°, 230°). The results showed that widening field of view improved the validity of speed choice and lane keeping. Furthermore, Kaptein, Horst and Hoekstra (1996) attempted to identify the visual information required to successfully perform a braking manoeuvre by manipulating the complexity of the scene (simple, complex) and the field of view (40°, 120°) in the TNO fixed-based driving simulator. Participants were required to approach a parked vehicle and were instructed to brake at the last possible moment to avoid a collision. Drivers exhibited greater control in terms of time to collision estimates and controlling headway with a larger FOV, and the validity of the simulator was improved by widening FOV but not by increasing scenario complexity when the results were compared with real world trials.

Although the results of Kaptein et al's study indicate that wide field of view is more important than high scene detail for training simple vehicle control skills, generalising these results to more complex skills is problematic. This is because braking in a car is a relatively basic vehicle control skill. However if the driving task under investigation was more complex and required the driver to sample more information from their environment, for example to negotiate hazards, scene complexity may have had a larger effect on performance success. In spite of the paucity of research on scenario fidelity and training transfer; there is some evidence to suggest that the psychological fidelity of training scenarios improves training outcomes. To exemplify, Machin (2003) evaluated a coach driver fatigue-management training programme that used training materials that were directly related to the coach driver's usual tasks and so had a high level of psychological fidelity. The evaluation of the training indicated that coach drivers who perceived the situational exercises as most realistic reported better training outcomes. However this study used classroom-based exercises rather than simulator-based driver training to manage fatigue and so may not be generalisable. Since the Arriva bus simulator is intended to support training in complex skills such as hazard perception and decision-making, it is important that the scenarios reflect situations that the bus drivers are likely to encounter in the real world. It is also important that the scenarios have sufficient detail to have a high level of psychological fidelity to try and maximise training success. Therefore in the absence of adequate research on the subject of replicating the bus driver's immediate environment, previous research on driving simulator construction suggests that a bus simulator with as wide a field of view as possible is critical to enable the accurate performance of basic vehicle control skills. This would also provide for more complex visual scenarios necessary for training hazard perception skills for which bus drivers in particular frequently use their peripheral vision.

2.5.2 System and Hardware Responsiveness and Feedback

Many driving simulators, for example the NADS, TNO (Blaauw, 1982) and VTI (Alm, 1995) use a full size mock up of the interior of the type of vehicle it is replicating to try and motivate driver's usual behaviour. It is therefore vital to ensure that the electronic and mechanical equipment responds appropriately to the users inputs, since closed loop tasks, of which driving is an example, are more sensitive to decrements in system responsiveness (Watson, Walker, Ribarsky, and Spaulding, 1998). It is crucial to performance that drivers receive immediate feedback about the effect of certain inputs on their environment. Thus when the driver accelerates, brakes or turns, the visual display must change accordingly. System responsiveness fluctuates over time depending on the level of detail used in the visual display (Watson et al, 1998). For example high complexity scenes with large numbers of polygons/triangles take longer to render than low complexity scenes with fewer polygons/triangles. It is therefore important that the ABS has sufficient RAM to cope with rendering detailed images. This is because simulators with a refresh rate of less than 20 frames a second may compromise the ability to give instantaneous feedback to trainees (Farmer et al, 1999), and reduced system responsiveness may reduce training effectiveness if the trainee learns to respond to inappropriate cues.

In real driving it is possible to perceive a lot about the surface friction of the road from the centrifugal force exerted by the wheel on the driver. In simulated driving this effect is replicated by providing steering feedback. Mourant and Sadhu (2002) compared participant's evaluations of spring-loaded and force feedback steering wheels and found that participants rated the force feedback steering wheel more highly in terms of realism, manoeuvrability and vehicle control. It seems reasonable that the ABS needs to have a sensitive and fast acting torque motor fitted to the steering column so that it is capable of representing the correct tactile feedback from interaction with the road surface. However, the influence of force feedback on training transfer has not yet been investigated.

2.5.3 Motion Platforms and Training Transfer

Although driving is considered to be primarily a visual task (Gibson, 1938; Fisher et. al., 2002), kinesthetic cues are used in a predictive way (Uhr et. al. 2003). Some high performance motion base systems have been used in the development of high fidelity research simulators, such as the NADS facility. However, the market for driving simulators for training purposes will not accommodate the size, weight, cost and complexity of a full motion base in contrast to funding available for research based driving simulators for use by major organisations. The following section will discuss the impact of motion platforms on simulator fidelity and transfer of training.

Drawing from research conducted in the aviation industry, the importance of motion cueing depends on the task being trained and the type of aircraft being simulated. For example, Caro (1979) reviewed training transfer studies in the aviation industry involving simulators with motion platforms and concluded that motion platforms are only beneficial for training tasks that have motion as their primary cue. The motion cue must be sufficient to alert the pilot for action but the magnitude of the motion cue is less important than the promptness of the motion. This is because lags would have an adverse affect on performance. JAA standards specify that for flight simulators this should be no more than 150ms. Caro (1979) suggested that rather than ask whether motion is needed for flight training, the question should be 'for what training is motion needed?'

To explain, pilots perform tasks involving two main types of motion. Manoeuvre motion is the motion associated with pilot initiated flight path changes and is therefore of low frequency and low gain. As the pilot is initiating the input and has planned for the onset of motion prior to the event, manoeuvre motion cueing may not be crucial. On the other hand, disturbance motion is when an external influence creates a motion that causes deviation from the flight path and requires a corrective action by the pilot. Wind-shear, gust and turbulence and emergency conditions such as engine failure are typical sources of disturbance motion. Since pilots are generally unprepared for the onset of disturbance motion their reaction relies heavily on motion cueing; pilots directly sense accelerations and use kinaesthetic feedback to modify their control strategy and hence the way they fly the aircraft (Keirl, Cook and White, 1995). This effect is likely to be amplified in highly manoeuvrable aircraft or when performing high gain flight tasks. For example, a fighter jet will tend to require far more disturbance corrections than a more stable commercial aircraft, but makes use of reduced stability to follow more aggressive flight path profiles. Such aircraft may benefit from simulators that have a motion platform, but empirically there is little supporting evidence. Similarly, it is debatable whether motion cueing would enhance low gain task performance or would benefit training in large slow-manoeuvring airliners designed to be inherently stable even during transient manoeuvres. Research findings that fuel this debate include work by Soparkar and Reid (2003) who investigated the effects of simulator motion on several aircraft handling tasks. They compared pilots' subjective preferences on a fixed-base simulator with a low washout and a high washout motion simulator and found that pilots generally preferred motion to no motion. However, performance measurements and work load information was not taken, so there is no way of knowing whether motion cueing actually enhanced performance. Conversely, Bürki-Cohen, Boothe and Soja (2000) found that the absence of motion did not affect pilots' subjective perception of both pilot flying and pilot non-flying with regards to simulator comfort or acceptance and found no effect of motion on evaluation and training progress in a flight simulator. They used a quasi-transfer method to train and test experienced pilots with and without motion cueing. They used a 30-passenger Turboprop aircraft simulator and the selected manoeuvre was a take-off in low visibility, with or without an engine failure. The dependent measures were rejected take-offs (RTO's), continued take-off (V1/R cut) and workload measures. They found that the pilots' performance in terms of RTO's and workload measures were the same in non-motion and motion conditions. With regard to motion then, the aviation literature suggests that for certain tasks, flight training in fixed-base systems is just as effective as flight training in motion-based systems (Bürki-Cohen, et al., 2000; Koonce, 1979; O'Hare and Roscoe, 1990; Waag, 1981). However, the presence of motion may contribute to the fidelity of the aircraft being simulated, especially in small highly manoeuvrable aircraft (e.g. helicopters) and to enhance cues that inform pilots of engine failure (i.e. sudden yaw), rather than relying on visual cues alone (Longridge, Bürki-Cohen, Go, and Kendra, 2001).

Another consideration in the use of motion cueing is accommodating the size of a full motion based simulator, which can require a minimum room size of 30 x 30 x 60 feet (MPRI, 2004). A further problem is that the accelerations rendered in motion platforms are constrained by the physical limitations of actuators, which can conspire to generate unwanted motion cues that are not actually representative of actual flight or driving conditions. Caro (1979) stated that it is important for simulated motion cues to be generated with an accurate time relationship to the action of the controls and changes in the visual scene. Motion cues that are late or that result from spurious couplings in the mechanism can cause nausea (e.g. McCauley, 1984; Sharkey & McCawley, 1992) or decrease the psychological fidelity of the simulator, thus diminishing the users experience of the simulated environment, which may negatively affect its acceptance (AGARD, 1980). If the task being trained would benefit from motion cueing and hence a motion platform is being included in the simulator, it is important that the technology available is adequate so that cues presented to the user are timely and accurate. Considering driver training simulators, can a fighter jet be likened to a sports car and can a 30-passenger airliner be likened to a bus? While both ground vehicles and aircraft have six axes of motion: three rotational axes (pitch, roll and yaw) and three translational modes (X, Y, Z), ground vehicle dynamics are very different from those of a plane. The range of movement within each axis is more restricted in ground vehicles in comparison to aircraft. This requires specific platform designs and modes of operation. The first concern is that motion platform technology in the application of driving simulators is still in its infancy and to date is not adequate to provide the correct body motion cues that may benefit driver training. Secondly, motion cue and performance specifications are not directly transferable from flight to ground vehicle simulators. In the aviation industry, flight simulators have long been used to allow pilots to improve their flying skills. However, pilots are then expected to transfer directly from the simulator to the operational craft and perform at an acceptable level. Since the simulator is used as a substitute for the actual aircraft, it must be capable of supporting 100% transfer of performance to the aircraft. Anything less would compromise safety. This requirement dictates a level of fidelity above that necessary to achieve effective transfer of training (Burki-Cohen, Soja and Longridge, 2003). On the other hand, driving simulators are intended to supplement rather than replace training in the operational vehicle so it may only be necessary to incorporate the level of fidelity that is necessary for training transfer to occur. However, to date, there has been no quantitative analysis of the transfer of training from moving base and fixed-base driver training simulators.

In parallel with researchers in the aviation industry, driving simulator researchers and developers are divided about whether motion capability is necessary for all applications. Evidence from simulator studies indicates that motion systems are more important for tasks involving lateral control of the vehicle than longitudinal control (Reymond and Kemeny, 1999). For instance, the increased variation in steering behaviour seen in fixed-based simulators when compared with real world driving is often attributed to an absence of kinaesthetic information (e.g. Blaauw, 1982; Harms, 1996; Reymond and Kemeny, 1999). Korteling and Sluimer (1999) propose that lane-changing manoeuvres require a minimum of 1 DF motion to provide kinaesthetic cues on lateral accelerations. On the other hand, Alm (1995) concluded that motion systems have no real impact on the overall behavioural validity of the simulator. Indeed, of the validation studies reviewed for this thesis, only two fixed based simulators were not valid and this was attributed to poor visual display systems and not the absence of a motion system. However, the additional cues provided by motion platforms can improve the face validity of the simulator. For example, in Alm's (1995) study, driving on curves was rated as better when the motion system was switched on. Alms (1995) also concluded that the motion base on the VTI simulator was actually effective for reducing nausea effects from the simulated environment.

Although evidence indicates that drivers (like pilots) share a preference for motion platforms, increased psychological fidelity alone does not justify the additional expense of a motion platform. Instead, the need to simulate motion cues should depend on whether the objective of the training is motion-related. If the task to be trained has motion as its primary cue then motion cues should be accurately represented in the driving simulator. However, the main aim of the ABS is to support training of cognitive skills, such as hazard perception that relies heavily on visual scanning (Fisher et al., 2002). Since there is no evidence to suggest that hazard perception training would benefit from the presence of motion cueing, it is more important to invest in a high fidelity visual display system rather than compromise with a low performance motion platform and risk providing false cues to the trainee, which could result in negative transfer. With respect to the fidelity required for training needs, the cost of investing in a high-performance motion system is too high to justify for use in the ABS. Plus, fixed-base simulators have been shown to have good relative validity in terms of driver behaviour (Allen et al., 2003).

2.6 Recommendations for the Fidelity of the Arriva Bus Simulator

The following recommendations for the fidelity of the Arriva Bus Simulator are made on the basis of the current literature review.
Bus drivers need to sample from a wide field of view (FOV) when turning and pulling into bus stops. Therefore the simulator's visual display needed to present 180° FOV for these events to be recreated accurately. Further support for a Wide FOV comes from the work of Kaptein, Horst and Hoekstra (1996) in a comparison of braking performance across simulated and real world trials. The results suggested that a wide FOV is essential for validity purposes. Given that braking manoeuvres is also a key feature of bus driving behaviour at bus stops and junctions it is clear that a wide FOV is necessary

for training purposes. Other important features to consider in the design of a bus simulator are high-resolution depth cues, critical for many driving manoeuvres (Staplin, 1996; Kemeny, 1999). High visual update and refresh rates are necessary to display close proximity moving models, such as other vehicles (Stoner, 1995). It is particularly important to have a good visual resolution for simulated bus driving for accurate detection of events, especially in the distance. Although, high scene detail contributes to the realism of the visual environment, the amount of interactive objects that can be programmed is limited because the update rate of the visual scene slows down when there are many complex 3D models to build in rapid succession. The complexity of the simulated environment then is a compromise between an optimal update rate and a high fidelity interactive environment. With regards to the use of a motion platform, the aviation literature indicates that manoeuvres, procedures and flight scenarios can all be effectively trained on a fixed-base flight simulator (O'Hare and Roscoe, 1990; Waag, 1981). There is insufficient research on the use of motion platforms in driving simulators to conclude that there would be any measurable training benefit for the additional expense incurred by including a motion system in a bus simulator. Therefore the bus simulator should probably be a fixed based system, built to present a wide field of view and provide high resolution to facilitate the visual detail required for training hazard perception in bus drivers.

3 Validation Methods for Simulators

3.1 Concept of Validity in Simulator Research

Simulators must be valid to be useful in human factors research and training. It is sometimes difficult to ascertain which kind of validity researchers in driving simulation are assessing as the terminology is inconsistent (Blana, 1996).

The dictionary of Human Factors defines validity as: the degree to which a test or other measurement device really measures what it was designed to measure (James and Strandler, 1993). However, for some researchers the definition of the word validity can differ depending on the context or application in which it is used. For instance, Korteling and Sluimer (1999) argue that this definition, which stems from the field of human performance assessment, does not adequately cover the meaning of validity in simulator research because simulators are not strictly used as measurement or test devices. Instead they suggest that the validity of simulators should be conceived as the degree to which they fulfil their purpose. This means that research simulators should support an adequate exploration of specific research questions. For training simulators, this can be defined as the attainment of certain training objectives.

For training simulators, validity is supposed to reflect the quality of the simulator as a training device (Rose et al., 1987). This means that the validity of a training simulator is task dependent (Kaptein, Theeuwes, and van der Horst, 1996). Validity in terms of task dependency is associated with the level of fidelity of the simulator and the extent to which the cues provide adequate information to the driver for the purpose of completing a given task. An example of a simulator that is not valid for the task of negotiating a junction is a simulator that has a 90-degree lateral field of view in front projection simulating the scenario of a 4-way junction with a continuous cross-flow of traffic. The driver would not be able to see the traffic approaching from either side due to the geometry of the visual generation equipment and would not be able to perform the task. This simulator might however be considered valid for the successful completion of a serpentine course that traverses a road adequately depicted by the visual generation equipment. Another example might be a simple PC flight simulator that may be valid to train basic flight skills to novice pilots but may be invalid for conversion training of skilled pilots to another type of plane. In the same sense, a low-cost driving simulator may be valid to train for hazard perception in different traffic situations but may not be valid to train vehicle control skills. It is impossible to validate training effectiveness without first considering the training programme and the instruction process. The concept of validity is therefore linked to the functional characteristics of the simulator, such as its purpose (research or training), the tasks involved, the training method and the trainees (or research participants) involved. Therefore, the extent to which skills learned on the simulator are transferred to the real task is sometimes referred to as functional validity but is more commonly called transfer of training.

3.2 Terminology in Simulator Research and Training

It is important to identify what is meant by validity before attempting to measure the validity of a simulator.
The term face validity refers to the subjective assessment of the similarity between the simulator and real task environment (Blana, 1999). This is in contrast to a simulators' physical validity or physical fidelity. Jamson (1999) stated that physical validity measures the degree to which the simulator dynamics and visual system reproduce the vehicle being simulated and concerns the extent to which the simulator mimics its real world counterpart in terms of physical measurable characteristics (e.g. the actual resistance of the brake pedal).
If a driving simulator has face validity it means that the driver perceives that the simulator replicates the driving environment sufficiently to seem like a real vehicle (e.g. the simulator brake pedal appears to have the same resistance as a real brake pedal). Face validity is important for training simulators as it may affect how well the users of the simulator perform. Support for this comes from Korteling, Van der Bosch and Van Emmerik (1997) who found that participants in their experiments were more motivated to perform the simulated task when the simulator closely resembled the real situation. If the drivers do not accept the simulator as a valid measure of driving then their motivation to treat the simulator seriously may be diminished.
Behavioural validity, or functional fidelity, refers to a simulator's ability to induce the same response from a driver as would be performed in the same situation in real life in terms of their perceptual, cognitive and motor responses (Jamson, 1999). It is often presumed that behavioural validity incorporates physical validity. Thus, simulator studies often report the physical correspondence, and usually do not mention, let alone analyse, the behavioural correspondence between the simulator and real world system. In reality the two levels are not always related (Blaauw, 1982). In fact physical validity is neither a necessary nor sufficient condition for behavioural validity (Sanders, 1991).

Kaptein, Theeuwes, and van der Horst (1996) distinguish four different types of validity. These are absolute validity, relative validity, internal validity, and external validity. A simulator has absolute validity for a given task if the quantitative measurements of real life and simulator performance correspond exactly (Kaptein et al., 1996). To exemplify, a simulator has absolute validity for speed choice if an individual's mean speed is measured as 50 mph in both the simulator and in the real vehicle in an identical road environment. Harms (1996) found that the VTI simulator has absolute validity for speed choice.
On the other hand, relative validity refers to the qualitative correspondence of the performance measures of simulator and real driving. A simulator has relative validity if the same trend of an effect for a given task is seen within the simulator and in real life. For example a simulator has relative validity for speed choice if drivers choose a higher speed when they are on motorways than when they are on urban roads in both the simulator and the real road, although absolute driving speeds may be different (Kaptein et al, 1995). In cases when absolute validity is lacking it is possible to translate outcomes to the real scale through post data processing.
Kaptein et al (1995) also distinguish between internal validity and external validity. Internal validity refers to the relationship between the experimental manipulation and the observed effect. A simulator with internal validity allows researchers to exclusively associate a given effect on a person's driving with a specific cause. For

example, Riemersma et al (1990) found that that a speed reducing intervention led to a reduction in speed in both the simulator and on the road.
Kaptein at al (1995) argue that a simulator may have limited internal validity if behaviour is affected by physical limitations of the simulator. For example, if the simulator only has a 60° field-of-view, right and left turns are not possible because the driver is unable to see to the left or right to effectively monitor the flow of cross-traffic. External validity refers to experimental design in relation to a specific research question. It may concern the extent to which results obtained with specific participants under specific conditions during a specific time period can be generalized to other people, conditions and time periods. In other words, to what extent does behaviour in the simulator relate to real driving. Limitations to external validity may come about through a careless choice of test environment, such as road type (e.g. Godley et al., 2002) and selection of participants (e.g. Riemersma et al, 1990; Godley et al, 2002) or due to physical characteristics of the simulator for instance poor system responsiveness (e.g. Watson et al, 1998), restricted field-of-view (e.g. Kaptein et al, 1996) or inaccurate vehicle dynamics (e.g. Duncan, 1995; Harms, 1996) or the presence of delays in the visual display (e.g. Ricard, 1995).

3.3 Research Simulator Validation Methods

Research simulators are used in experimental situations to determine the effect of different system or environmental variables on human performance. This is because driving simulators are ideal alternatives to full-scale field trials (Riemersma et al., 1990). Data can then be used to predict or interpret performance on real-life equipment (Riemersma et al., 1990). The ability to elicit habitual and reflexive driving behaviours in a simulator allows research to be done in a safe environment without threat of environmental hazards and other vehicles. The simulator scenario can be repeated precisely each time for experimental control or can be altered to change test variables in order to update environmental or road conditions. Driving simulators can be used in the initial research efforts to provide a wealth of information and experience in a safe and relatively low cost environment. From then on field tests can be conducted with better focus of exploration within the problem space. This is particularly true when investigating the effects of impairments due to fatigue, drugs or alcohol when it is unsafe and unethical to use field trials (e.g. van der Hulst et al., 2001; Lenné et al., 2003; Thiffault & Bergeron, 2003). In addition to investigating the contribution of the psychological and physical capabilities of the road user to road safety, simulators can be used to evaluate the effect of the interaction of human operators to systems in the design phase, for instance in road design or in-car systems (e.g. Gugerty, 1997; Lui, 2003; Riemersma, 1990; Tornos, 1998). With simulator technology becoming ever more affordable and with more emphasis on behavioural factors, driving simulators offer the potential for making great contributions to road safety research at lower costs than was previously possible.

There are several ways in which a driving simulator can be validated. Allen, Buffardi, and Hays (1991) identified three methods of simulator validation. Firstly to validate absolute criteria for a given characteristic by traditional engineering methods, secondly to compare measurements obtained under real and simulated conditions and thirdly to compare simulated behaviour with real world results obtained under controlled observational conditions.

The first two methods relate to the issue of fidelity and involve measuring the physical aspects of the simulator and comparing them to the physical aspects of the real life system, for example resistance of the brake pedal. Differences would imply that the handling characteristics of the simulator are not the same as those in the real life system. The handling characteristics could then be assessed in an experiment where participants had to perform pre-determined tasks on the simulator and the real world equipment; differences in the handling characteristics could then be examined. These two approaches deal with the overall performance and the performance of the components of the simulator system. While these methods are the most precise and objective methods of validation in the field of simulator research, they exclude the performance of the driver. Therefore it is impossible to generalise to human task performance.

The third method to examine the correspondence of the driver's behaviour in the simulator system and the real world system was not fully described by Allen et al (1991). However, there are a large number of studies that investigate the correspondence of behaviour in simulated and real driving conditions during a specific task under the same road conditions. The sections that follow present several of these studies to illustrate methods that have been employed for the purpose of simulator validation. By no means should this be considered a complete review of all such studies on driving simulators.

3.3.1 Simulated vs. Real world Driving Performance

The method of simulator validation described in the following studies involves a group of participants who perform a task on the simulator. The same group (or different in some studies) then performs the same task on the real equipment. The correspondence of behaviour in the two groups is then assessed to establish whether the simulator has relative or absolute validity. Riemersma et al (1990) established the relative validity of the Daimler-Benz moving based simulator located in Berlin, Germany. The study evaluated whether new traffic calming measures had an effect on driver speed choice entering a village, in real and simulated driving. Speed measurements were taken on real traffic entering the town prior to the implementation of the signs and road markings. The speed measurements were repeated in the same locations after the speed reducing measurements had been introduced. For the simulation part of the study the landscape of the entrance to the village was recreated within the simulator. Speed reduction was evaluated for the cases of no speed reducing measures and with the speed reducing measures. In both simulator and real world trials, drivers reduced their speed and had lower speeds when entering the village in the presence of speed reducing measures than before the introduction of countermeasures. In both the simulator and real world trials speeds at the entrance to the village were very similar. The authors argued that the fact that drivers had similar speeds at the entrance to the village showed that the Daimler-Benz simulator had relative validity for the task studied, although approach speeds were found to be higher in the simulator and deceleration was greater in the simulator than in the real world trials.

Several validation studies have been completed investigating different aspects of the Leeds Advanced Driving Simulator (LADS). LADS is a fixed base simulator with a complete Rover 216GTi car for the user interface. A study by Carsten et al (1997) used a similar approach to that of the study by Riemersma et al (1990) described above. For this particular study speed and lateral position were measured at 21 different locations along an 8km section of road. A road with the same profile was then created within LADS. 100 participants then drove along the real and simulated routes in three traffic conditions (none, light, heavy), while the lane position and speed were recorded. Comparisons were then made between the real and simulated results. There were no significant differences in mean speed at the ten data collection points for the real and simulated routes for the three traffic conditions suggesting absolute validity with regard to speed. However, the lateral position data showed that drivers adopted different lateral positions in the simulator, which was attributed to reduced FOV in the simulator. The rank order of the ten lateral position measurements was similar for both systems and therefore the authors claimed relative validity for lateral position.

Blaauw (1982) studied driving experience and task demands in an instrumented vehicle and the TNO fixed-base simulator, which had the same mock-up and vehicle dynamics as the instrumented car. The participants (48 males, 24 novice and 24 experienced drivers) drove along a straight section of a 4-lane motorway under four conditions: (1) free driving in which no specific instructions were given; (2) forced lateral control in which they were told to concentrate on driving in a fixed position along the road; (3) forced longitudinal control in which they were told to drive at a constant 100km/hr and (4) forced lateral and longitudinal control in which they had to drive in a fixed position at a constant speed of 100km/hr along the road. Similar effects of driving experience and task demands were found in the simulator and instrumented car for lateral and longitudinal control. Variation in driving experience and task demands discriminated equally with respect to the variation in lateral position and steering wheel angle in both the simulator and the instrumented car. Overall, the simulator had good absolute and relative validity for longitudinal control but only relative validity for lateral vehicle control due to larger variations in the lateral position in the simulator. Again this was attributed to reduced FOV.

Tornros (1998) established the relative validity of the VTI driving simulator to determine whether it could be used in road tunnel design. Participants drove through a section of the Ekberg tunnel 12 times, twice in the left, middle and right lanes. The same route was replicated in the simulator. Speedometer information was only available for six of the trials. A methodological limitation was that all participants completed the in-car drive first so there may have been order effects that could have confounded the results. Mean speed was taken and distance to the sideline was measured. For the purpose of analysis lane position when the tunnel wall was to the left and then to the right was taken. Absolute validity for speed and lane position was not established but there was good relative validity for both speed and lane position. To expand, participants generally drove faster in the simulator (p<. 01) but in both the simulated and real tunnel speeds were slowest in the right lane (p<. 01). The effect of driving without access to speedometer information was the same in both the simulated tunnel and real tunnel in that participants drove faster when speedometer information was not available. On straight roads participants positioned themselves further from the sideline in the real tunnel than the simulated tunnel (p<. 001). Participants positioned themselves further away from the side of the tunnel when the tunnel wall was near in both the simulated tunnel and the real tunnel (p<. 001). There was no interaction between the two conditions indicating good relative validity for lane position. Similarly, for curved roads there was a significant effect of driving condition on lane position ($p < .001$) and a significant effect of tunnel wall ($p < .001$) but no interaction indicating good relative validity. The authors suggested that because participants completed the trials in the real tunnel first order effects might account for the lack of absolute validity.

The problem with comparing system performance and driver behaviour is that it is vital that the measures chosen to represent the driver's behaviour are appropriate (Fairclough, 2003). For example, it is clear that steering wheel angle is probably not the best way to validate speed choice on various types of road, rather speed would be an appropriate measure. However, if validating safe behaviour at traffic lights, it is unclear whether speed or steering wheel angle would be a more appropriate choice of measurement. This is because there is little knowledge about the relationship between system performance and driver behaviour.

3.3.2 Simulator-to-Simulator Method

Another method of validation is to compare performance across different simulators (e.g. with different field-of-views) or for different configurations within the same simulator (e.g. with/without a motion base). In this method one group executes a task on one simulator and another group performs the same task on another (usually degraded) simulator or one with a different (non-optimal) configuration. This method attributes differences in task performance to differences in simulator settings and is particularly useful for establishing the level of fidelity required to execute a given task. However, generalisations to the real world cannot be made unless comparisons are made with the real equipment.

Kaptein et al (1996) evaluated the visual information available to the driver in the TNO driving simulator to identify what information was critical to the driver's performance. In this study the effect of scene complexity and field of view were examined while subjects executed a braking manoeuvre. The subjects were told to refrain from braking until the last possible moment while approaching a parked vehicle so that a collision could be avoided. Driving performance varied only slightly with changes in field of view and scene complexity. Drivers did however exhibit better control with a larger field of view. Relative validity was found when the results of the field study were compared to the simulator study.

Alm (1995) compared data from real driving to performance data from the VTI simulator with and without kinaesthetic feedback provided by a motion base. Speed and speed variation and lateral lane position and lateral position variance were used as performance variables. Both relative and absolute validity was found for speed and lateral position, as there were no significant differences on average speed and lateral position for both environments.

Staplin (1996) reported a study investigating the effect of driver age on perceived safe minimum distance from oncoming traffic in the act of making a left-handed turn across the path of the oncoming traffic. The study included controlled field experiments as well as experiments for three different presentations of the visual environment: television, video projection, and cinematic. The effects of the differences in size and resolution on driving performance were evaluated along with the effect of driver age. The results obtained with the cinematic projection and those of the field experiments showed relative validity for the simulator over the different age groups. Not surprisingly, the results showed that both size and resolution were important factors to be considered in designing laboratory experiments to evaluate simulators.

3.3.3 Subjective Evaluations

Subjective evaluations may also be used to validate the simulator to measure face validity. For example, in addition to assessing behavioural validity, Blaauw (1982) elicited subjective evaluations of the TNO simulator using two questionnaires. One questionnaire assessed task difficulty in terms of attention and monotony on a continuous scale (0-100), and one assessed motion sickness and the realism of the simulator by asking participants to compare manoeuvres in the simulator and the instrumented car (multiple choice). Overall, all participants judged tasks in the simulator to be more difficult than the instrumented car (task difficulty, required attention and monotony) with the exception of longitudinal control (driving along the road with no other traffic). Experienced drivers generally rated the simulator more favourably than the novice drivers with the exception of monotony. Monotony was due to the lack of road signs, curvature, scenery and other traffic in the simulation. However the lack of complexity in the visual scene probably explains why there was no incidence of simulator sickness because of better refresh rates and reduced flickering of objects. Alm (1995) used the NASA-TLX (Hart & Staveleand, 1988) to measure workload and a questionnaire to measure the subjective realism of the VTI simulator with and without the moving base. The questionnaire was assessed on a seven-point scale (1=not at all and 7=very much) and included the questions: (1) How realistic was it to drive the simulator? (2) How realistic was it to drive the simulator on curvy parts of the road? (3) How realistic was it to drive the simulator on straight parts of the road? (4) Did you experience any nausea during the simulator trip?
The results of the NASA-TLX showed significantly higher mental workloads in the simulator compared to car driving. The simulator was more physically demanding, required greater effort, and was more frustrating than driving in the real road condition. The results of the questionnaire indicate that there was no difference in the ratings of realism when the moving base was off or on, however there was a tendency for participants to rate the simulator more favourably with the moving base on. Driving on curves was rated more positively when the moving base was on, but a motion base made no difference to the realism of driving on straight roads. Drivers felt more nauseous without the motion base. Alms concluded that the motion base was effective for reducing nausea effects from the simulated environment, helped keep the driver on a steady course in the road and was better for driving on curves. However, a poorly synchronised motion platform and visual display can increase nausea.

Riemersma et al. (1990) also asked their participants to complete a questionnaire that contained items concerned with evaluating the sense of reality conveyed by the simulator after they drove a simulated route. Generally subjective evaluations were favourable showing that the simulator had good face validity to real life.

However, the problem with using subjective criteria as a method of comparison is that this method assumes a priori that the user operates the simulator as if it were the real system. It requires users to make some kind of evaluative judgement based on comparing their mental representation of the performance of the real system and the simulator system, based on their inputs to the system (Mudd, 1968). For example if the user applies a force to the steering wheel they will see changes to the visual scene in proportion to that force and these changes will be the same in the simulator and the real world. Moreover, it is impossible to conclude that the simulator has good behavioural validity on the basis of users opinions. However, in conjunction with other methods face validity measurements can be useful (Korteling & Sluimer, 1999), especially for the design and construction of a simulator.

3.4 Training Simulators

Designing simulators that will deliver effective training is a long-standing goal for those who build and use them. Simulators can be used to train then test a drivers' ability to perceive and act upon simulated information, but the challenge is determining if the same driver will perform in a similar way to that of the real world. There is an underlying assumption that skills learned in a training environment will transfer to the active environment. For example, a pilot trained to land an aircraft in a flight simulator is expected to be able to competently land a real aircraft. However, training does not always involve learning a specific skill that is to be performed in a specific set of circumstances. The skill may need to be generalised to other tasks and situations. To exemplify, during the early stages of learning to drive a car, a novice driver will learn a specific set of responses to given stimuli, i.e. learning to select an appropriate gear to move away from a set of traffic lights. Without any further training, the trainee driver should be able to select an appropriate gear when driving in any car. The skill may then be generalized even more such that the driver can select gears appropriate for various other road and traffic conditions. Therefore it is not simply the specific behaviour that is learned but rather a behaviour that can be adapted to a range of relevant stimuli. Clearly the aim of any simulator-based training initiative is that the skills learned within the simulator are then transferred into the real vehicle.

The success of a training simulator then is measured by the effectiveness of subsequent performance on the actual task. This is known as transfer of training (ToT). Rolfe (1991) suggested that the issue of transfer of training is the key concept on which training within a flight simulator is based and defines it as the ability to acquire and maintain a skill in one situation that can be successfully carried over into another. Sanders (1991) suggests that the most useful validation method for a training simulator is to study transfer of training from the simulator to the real world to determine the extent that simulator training reduces the need for real-life trials.

The following section describes and discusses methodologies for measuring training transfer from simulated to real environments that were first described by Caro (1977) in a series of experiments commissioned by the United States air force.

3.5 Measuring Transfer of Training

Measuring driver training simulator effectiveness requires the collection of driver performance data. In order to observe the effects of simulator based training it is necessary to collect drivers' performance data before simulator training begins or to measure the performance of control groups who do not use simulators for comparison.

The effectiveness of a simulator is determined by the extent to which performance is improved on a real world driving task due to simulator training (Sanders, 1991). Proficiency at the task may be evaluated in terms of the amount, quality, or cost of learning or performing the task. As a final step in the experiment, the two groups' proficiency scores are compared with each other. According to Boldovici (1987), transfer can be:

Positive: learning is improved due to training via the simulator.
Negative: Training in the simulator somehow interferes with performing the new task.
Neutral: Training in the simulator has no discernible effect on performing the task.

Several objective measures have been introduced to quantify ToT (Ellis, 1965; Povenmire & Roscoe, 1971 Roscoe, 1971; Roscoe, 1980). In experiments using these measures the experimental group is trained on the simulator then after a time the group gets additional training on the real task until the real task performance of the group reaches a pre-determined level. The time needed for the experimental group to reach this level on the real task is compared to the time needed by the control group, who receives training on the real task only. Ellis (1965) described the basic computation for percentage of transfer (%T) as:

$$\%T = \frac{Tc - Te}{Tc} \times 100 \qquad (1)$$

Where:
Tc = Time, trials or errors needed for the control group to reach the criterion level
Te = Time, trials or errors needed for the experimental group to reach the criterion level after completing the simulator training programme

It can be seen from equation 1 that if %T of a simulator programme is 100% then no additional real task training is needed for the experimental group to reach the same performance level as the control group. When %T is 0% training on the simulator has no effect. %T can also be negative, which means that training on the simulator interferes with acquiring the skills necessary for completing the real task successfully (Ellis, 1965).
The major problem with this formula, as Roscoe (1980) noted, is that it does not take the amount of prior practice in the simulator into account and cannot be used to draw conclusions about the effectiveness of the simulator as a training device. To overcome this Povemire and Roscoe (1971) developed the Training Effectiveness Ratio (TER), which is computed in the following way:

$$TER = \frac{Tc - Te}{Ts} \qquad (2)$$

where:
Tc = Time or trials needed for the control group to reach the criterion level

Te = Time or trials needed for the experimental group to reach the criterion level after completing the simulator training programme
Ts = Time or trials spent by the experimental group in the simulator

From equation 2 it can be seen that a TER of 1.0 indicates that time savings for real task training are equal to the amount of time spent in the simulator. When TER is larger than 1.0 (Ts and Te are smaller than Tc), simulator training is more effective than training on the real task. When TER is lower than 1.0 then real task training is more effective, for example a TER of 0.5 means that every hour in the simulator saves half an hour in the real task. The simulator may still be beneficial for training if the cost of training in the real task environment is too high or its too dangerous. Generally simulator training is less costly than real task training, particularly for flight simulators. Roscoe (1980) developed the training cost ratio (TCR) and Cost effectiveness ratio (CER) to quantify the cost of the training device.
The computation for TCR is:

$$TCR = \frac{Cs}{Cc} \tag{3}$$

where:
Cs = financial cost of simulator group training (per unit time)
Cc = financial cost of control group training (per unit time) .

The Cost Effectiveness Ratio is produced by dividing the TER by the TCR:

$$CER = \frac{TER}{TCR} = \frac{Cc\,(Tc-Te)}{Ts \times Cs} \tag{4}$$

Cost effective training can be achieved with CER values of 1 or more. However if CER is less than 1, simulator training may still be beneficial for safety reasons. Values for CER, TER and %T change depending on the duration of simulator training. It is important to know how much time is saved in one training method for each successive increment of training using another method. At some point training on the simulator will no longer be an advantage because the effectiveness of simulator training will decrease with practice and it will be more cost effective to train on the real task. Figure 5 shows the TER and %T as a function of training time.

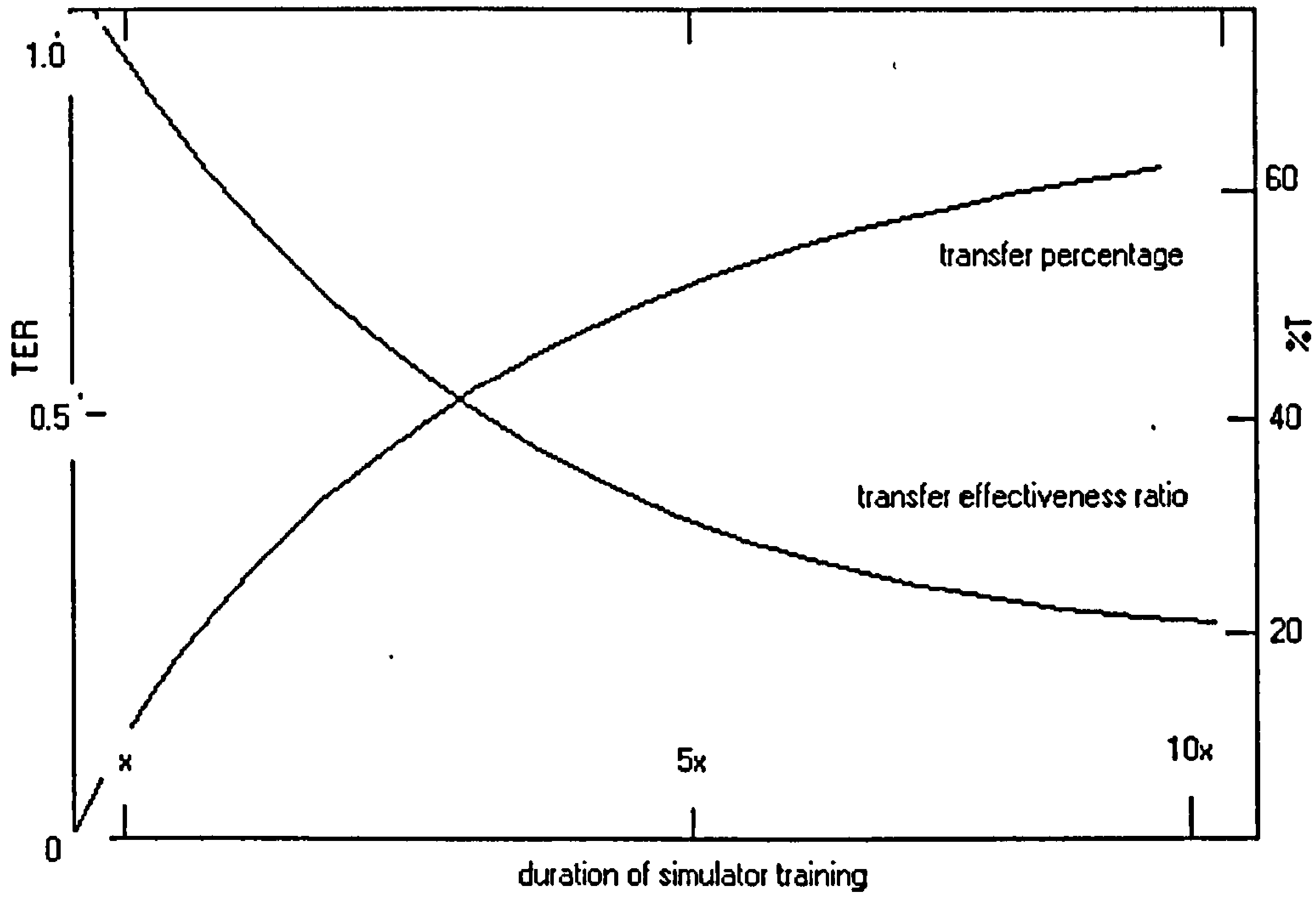


Figure 5 TER and %T as a Function of Duration of Training

The Incremental transfer Efficiency Ratio (ITER) was introduced so that the performance of one experimental group is compared with that of another experimental group with a different amount of simulator training. The ratio defines the extra time needed that the group with less simulator experience needs on the real task for them to reach the same level of performance as the group with more simulator experience. The formula is:

$$ITER = \frac{Te - x - Te}{X} \qquad (5)$$

where:
Te = time spent training on the simulator by the experimental group
Te-x = Time spent training on the simulator by another experimental group with x less training time
X = difference in training time on the simulator between the two experimental groups

ITER is a negatively decelerated function of simulator training time. The difference in the time needed to reach criterion performance on the real task will approach zero as a function of the amount of simulator training.

3.6 Training Simulator Validation Methods

Thurman and Dunlap (1999) reviewed the literature on simulator-based training and of the 103 articles retrieved only four articles presented information on training assessment and this was limited to trainee's opinions. They remarked that formal assessments of simulator-based training are not being conducted beyond simple utility evaluations. Hence little is known about how skills learned in the simulator are transferred from virtual environments to the operational environment (Uhr et al., 2003). Yet, there are a number of methods for evaluating simulator effectiveness, which can be divided into two distinct sets. Analytical models are based on analysing the properties of the simulator. The second set is based on performance evaluations conducted in the simulator.

3.7 Analytical Models

AGARD (1980) identified three main types of analytical models that may be used to evaluate flight simulators. The same principles may be applied to ground vehicle simulators.

Table 3 AGARD (1980) Analytical Models

Model	Method
Simulator Fidelity	Evaluation of the fidelity of the simulator compared with the real vehicle
Simulator Programme Analysis	Evaluation of the suitability of the training programme
Opinion Survey	Evaluation of the opinions of the operators, instructors, training specialists and students on the effectiveness of the simulator

3.7.1 Assessment of Fidelity Method

The fidelity assessment describes the degree of similarity between the simulator and the real world equipment. In this method experts compare the simulator and real equipment on physical aspects, for example the resistance of the pedals or grip of the tyres (e.g. Allen, Rosenthal and Chrstos, 1996; Allen, Rosenthal, Aponso, Klyde, Anderson, Hogue and Chrstos, 1997). According to Baudhuin (1987), the Nuclear Regulatory Commission (NRC) requires that all nuclear power facilities must have a "full-scope simulator" for initial and refresher training for all control room operator personnel. In short, the simulator must reproduce the operating characteristics of the actual plant....Transfer of training is indeed implied but appears not to be verified here." (p. 233)

This method of assessing face validity assumes that high fidelity leads to high transfer of skill and that when fidelity is low transfer is also low. However equating transfer of training with fidelity can lead to the development of unnecessarily complex and costly devices; a simulator can be a faithful copy of the real thing but that transfer still may not occur because the training is ineffective. The advantage of using this method is that it can be employed by anyone who is familiar with the real life equipment and does not require any groups of participants or objective measures. However it cannot be used to determine training effectiveness because this method does not involve measuring users' performance in relation to training objectives.

3.7.2 Utility Evaluation Method

Another method of assessing the validity of a training simulator is to analyse the way in which the simulator is used and to determine the extent to which specific training objectives are met using the simulator. Agard (1980) uses the term Simulator Programme Analysis. In this method subjective ratings are obtained from experts instructors who use the device then provide an assessment. Other methods include the amount of time the simulator is in use or whether instructors like the training programme (Adams, 1979). For example, Loftin and Patrick (1995) trained over 100 members of the ground-support team for the Hubble Space Telescope (HST) repair mission. The objective of the training was to familiarize ground-support controllers, engineers and technicians with the location, appearance, and operability of HST components in the space shuttle payload bay. It was hoped that this experience would help trainees to build mental models of system components and the correct interrelationships, provide procedural knowledge of tasks, and enhance the ability of ground-based flight controllers to interact effectively with the crew during the mission. Trainees were given 121 episodes where they were placed in an 'immersive virtual environment' simulation and instructed to perform the same kinds of tasks the repair crew were going to perform. Each training episode lasted on average 100 minutes (i.e., 40 minutes devoted to an immersive experience and 60 minutes of 'over-the- shoulder' observation). At the end of the HST repair mission, each participant was given a 'postflight' evaluation instrument. Loftin and Patrick (1995) reported that members of the ground support team believed that the training had a positive effect on their performance during the mission. It is evident from this example that these methods only provide a measure of acceptance of the simulator and do not provide adequate measures of training success. In other words, the simulator is considered to be successful if it is being used. Since trainees typically like the 'bells and whistles' of a high fidelity system (Wickens and Andre, 1994) those with higher fidelity are rated more highly than those with low fidelity. Although high fidelity simulators have played a major role in gaining acceptance from professional pilots for the use of flight simulators in training, ideally the value of the simulator should be determined by the trainees' performance and not by the performance of the simulator.

3.7.3 Opinion Survey

The opinion survey method requires trainees, instructors, specialists etc to give their opinion about the perceived training value of the simulator, the features of the simulator that contribute most to training transfer or the probable impact that simulator based training has on real task performance (Korteling and Sluimer, 1998). For example, Holzman, Cooper, Gaba, Philip, Small and Feinstein (1995) document a study in which they attempted to assess the utility of simulation for training anaesthesia crisis resource management (ACRM). In this study 68 anaesthesiologists and 4 nurse-anaesthetists participated in an ACRM training course held over a 2 ½-month period. The anaesthesia environment was a recreation of a real operating room using standard equipment and simulations. The task was to perform as close as possible to actual clinical interventions. The crisis scenarios included overdose of anaesthetic, oxygen source failure, cardiac arrest, malignant hyperthermia, tension pneumothorax, and complete power failure. Following the scenarios, participants were given detailed questionnaires to assess the training value of the setup. Over half of the participants felt that the course should be taken every 12 months, while another third felt that the course should be repeated every 24 months. Participants rated the potential benefit of this course for anesthesiologists to practice ACRM in a safely controlled simulated environment 'very highly'. A major drawback with this evaluation method is that it does not provide an adequate measure of training success, which would be better determined by objectively rating performance in the crisis scenarios. It is therefore not clear whether trainees would perform effectively in a real crisis.

The assumption behind opinion surveys is that the operator is able to objectively assess the various components of the simulator; however the people providing the evaluation may not understand how different cues contribute to learning. (Adams, 1979). The face validity data may therefore lead to erroneous conclusions about the requirements of the training simulator. Although this kind of data may be more useful when operational training or performance testing is not possible or if the simulator is under development, it is necessary to provide a more objective assessment of the usefulness of a simulator for training purposes.

3.8 Performance Evaluations

3.8.1 Transfer of Training (TOT) Method

Some training researchers believe that the TOT method is the only sufficient method for determining simulator training effectiveness (Bell & Waag, 1998). This method seeks to determine the effects of practicing one simulated task on the learning or performance of another separate, but similar task. Generally, assessing training effectiveness by the ToT method involves two groups: an experimental group and a control group. The experimental group is trained to criterion performance level on the simulator and is then trained on the real system till criterion level is reached. The control group is trained on the real equipment until criterion level is reached. Both groups are then tested on the real system (Bell and Waag, 1998; Boldovici, 1987). To exemplify, Lintern et al. (1990) gave one group of novice pilots two sessions on a low cost flight simulator before they commenced landing practice in a real plane. These students required fewer landings in the aeroplane compared to their control group who received no simulator training. Groups must be matched in terms of relevant prior training and experience (see Sanders, 1991).

The outcome of this method depends on the specific training programme included in the experimental set up, which involves the specified amount of training on the simulator, the training content, the training methods and the instructor. Other factors that may affect validity studies include having a small number of participants so that statistical comparisons are impossible, participants who are not matched in terms of experience (both in terms of experience with the real vehicle and the simulator), high costs of conducting such experiments (Meyer et al., 2001) and ceiling effects due to simplification of the experimental tasks or floor effects because they are too difficult. Also it may be unfair to exclude the control group from the simulator-training programme if the intention is to train critical safety skills. For example, a simulation is used to train the emergency procedures in the event of a meltdown in a nuclear plant. Unfortunately the control group, who did not receive any training and certainly have no opportunity to obtain on-the-job experience, is in jeopardy if a real crisis occurred because they may not have the skills to deal with the situation as competently as the simulator trained group.

Because of the limitations of a full TOT methodology, experiments of this kind may not always be conducted properly (Korteling & Sluimer, 1998) so several other methods for validating training simulators can be employed to overcome resource constraints.

3.8.2 Self-control Transfer Method

In the self-control transfer method, the experimental group serves as its own control. A group of participants already receiving real-task training would also receive simulator training for a time. Performance from the real task before simulator training begins is obtained and compared to performance data on the real task after simulator training has taken place. Differences in performance data are attributed to the effects of simulator training. However, the major problem with this design is the lack of a control group so conclusions about the simulators efficiency can only be tentatively drawn. Performance differences may be due to the confounding effects of skill decay if the time delay between real task training before and after simulator training is great or may be due to learning from the first test if the real task is standardised. The testing equipment might have changed or there may be methodological differences in measuring performance, which results in differences in performance data that are not due to simulator training. (e.g. Cummings, Rizzo, McGhee and Grant, 1998)

3.8.3 Pre-existing Control Transfer of Training Method

The pre-existing control transfer of training method is suited to cases where a new simulator or a new training programme is replacing an old one that has already been validated. In this method, the data from trainees' performance using the old simulator can be compared to data on trainees' performance that have been trained using the new simulator. The disadvantages of this method are that there is no way of randomising or matching participants across the two groups. This means that the experimental group may have different background training to the control group so differences in performance may be an artefact (e.g. Joab, Auzende, Futtersack, Bonnet and Le Leydour, 2002). Similarly, trainees in one of the groups may have dropped out due to poor performance, which will adversely affect the validity of the simulator because only the best trainees will be tested. Ideally, both sets of data should be obtained under the same conditions, which may not be the case if there is a long time interval between data collection.

3.8.4 Uncontrolled Transfer Method

In circumstances where a control group does not exist, for example in lunar landings or emergency situations, it is possible to determine the training effectiveness of the simulator by assessing whether trainees can perform the real task first time on the real system after being trained on the simulator. However it cannot be conclusively shown that performance is due to simulator training because there are no measures of baseline performance. For example trainees may accumulate relevant skills by operating real task equipment on the job, these skills might then enhance criterion performance on the real task. For example, a pilot who is forced to make an emergency landing for the first time may benefit from the experience of handling a plane under normal conditions.

An alternative is to compare performance on the real task with groups who have been trained using a different simulator or a group who had no simulator training. However, trainees are not matched or randomly assigned to groups, which might affect the measurement. Additionally, if there are long time intervals between data collection the criterion for correct performance might have changed. Therefore the method of data collection should be the same for both groups.

All of the methods described above involve collecting real life performance data. However, real life performance data is not always necessary for evaluation purposes. The following methods describe how the effectiveness of a training simulator can be assessed using only simulator performance data.

3.8.5 Backward Transfer of Training Method

In a backward transfer study a participant who has already demonstrated proficiency on the criterion task in the real task environment performs the same task in the simulator. This is likely to be an experienced driver. If an experienced driver can perform the task in the simulator then backward transfer is said to have occurred. However, drawing conclusions about the effectiveness of simulator training based on this method is risky because this method assumes a priori that the driver knows how to use the simulator (Adams, 1979; Mudd, 1968). In other words, the simulator provides cues to which the driver responds with the necessary behaviour to perform well. This does not mean that the cues are accurate or appropriate for learning the behaviour in the first place.

3.8.6 Simulator-to-Simulator Method (quasi-transfer-of-training)

The difference between a quasi-transfer of training (qToT) method and the ToT method is that in the former no training on the real equipment is given but in the latter it is. In qToT studies, the experimental group receives simulator training with one or more variables omitted. The control group is trained on the fully operational simulator, under the assumption that it resembles criterion performance on the real life task. The difference in performance reveals the relative contribution of the manipulated variable on the effectiveness of the simulator. However, the assumption that the fully operational simulator resembles the real life task is not tested and the fact that one group is assessed in non-optimal conditions is an immediate disadvantage. Strictly speaking this method is not a true reflection of training effectiveness. However it is extremely insightful in determining the relative contributions of different simulator components to training transfer.

3.8.7 Simulator Performance Improvement Method

In this method the performance of a trainee is measured after each training session. For example, Fisher et al (2002) found that PC-based risk awareness training improved novice drivers' performance in a driving simulator in comparison to novice drivers who had received no such training. If improvements are seen over several sessions then it is assumed that transfer to the real task will occur. However, it is wrong to assume that improvements in the simulator will lead to success on the real task. In fact negative transfer could occur. However, this method is useful because if no improvements are seen in the simulator then improvements are not expected in the real task trials.

3.8.8 Korteling and Sluimer's Method

Korteling and Sluimer (1998) described a method for evaluating a driving simulator. A group of novice drivers are trained in elementary tasks in a driving simulator (e.g. changing gear, force needed to attain a certain level of acceleration etc). After a few sessions trainees demonstrate their performance in a real car. Driving instructors then estimate the number of real lessons it would take for them to reach this level of performance in the real car. The independent variable is the amount of simulator practice or simulator characteristics, the dependent variable is the instructor's estimation about the number of lessons needed to reach this level of performance in a real car. The ratio of simulator lessons and the estimated equivalent indicates the training effectiveness ratio (TER). Using expert judgements may be less reliable than a full ToT, however there are advantages to applying several validation methods to one experiment, for example combining ToT with trainees' subjective evaluations to improve the effectiveness of simulator training.

3.9 ABS Validation Method

If no real-life trials are available for comparison, for example when simulating emergency procedures, subjective assessment techniques are the most easily applied in order to validate the simulator. However, due to the subjective nature of the judgements made and the related issues of reliability and validity, this type of simulator evaluation is of limited value in determining the effectiveness of the simulator as a training device as subjective methods may provide limited or false information about the functionality of the simulator (Adams, 1979). Ultimately trainee performance has to be measured and evaluated.

Behavioural validity is an important consideration when designing simulators for training because it is important to see whether the simulator elicits the same responses as its real world counterpart. The advantage of achieving behavioural validity is that there is then a direct relationship between the simulator and the real vehicle (Mudd, 1968). Since performance in the transfer environment is greatly influenced by the functional fidelity of the simulator (Allen, Hays and Buffardi, 1986), if the simulator operates as the real world equipment does, training effectiveness should be an outcome.

Major problems with establishing behavioural validity are often attributed to the realism of the visual display or motion and complex visual patterns, in other words the fidelity of the simulator, however behavioural validity does not always correspond to fidelity as departures from reality can improve training success (Roscoe, 1991). If the findings from the experiments conducted on new simulators are to inform real life situations, then it is important to know that the apparatus is eliciting similar responses from the operator as in the real world situation. For driving simulators, it needs to be shown that the particular simulator appropriately reproduces driving responses as they occur on the road.

The criteria for simulator validity is not always clear from the literature. Relative validity is clearly a necessary and sufficient requirement for a driving simulator. Whereas achieving absolute validity is not necessary for a simulator to be an effective training device. Even if no behavioural correspondence is found between the real task performance and simulator performance some researchers claim validity on the basis of qualitative statements (e.g. Wade & Hammond, 1998). However, this is not sufficient because the evaluators may not be able to objectively assess how the various components of the simulator contribute to validity for research or training purposes.

From a methodological stance, the ToT method described earlier often entails a great deal of time and expense and can be difficult to perform logistically (Meyer et al., 2001). In addition to this, there is no way of providing feedback that may help with simulator modifications. However, transfer of training evaluations have the advantage of being directly related to the training objectives. The results apply to a specific simulator configuration in combination with the use of specific training methods, including scenarios, instructions, exercises, feedback, trainee and instructor characteristics, the amount of training provided and the chosen experimental subtasks and task conditions. This may be a disadvantage however as validity is limited to the specific training programme that is being validated and not the validity of the simulator.

Taking this background knowledge of simulator validation into consideration, the goal of the bus simulator evaluation is to quantify the extent to which training using a bus simulator will lead to measurable improvements in performance. Since the ultimate end is to reduce bus accidents this could be measured in terms of accident rates. Undoubtedly the best way to validate the ABS is to conduct a training transfer study. However this may be more appropriate for established simulators and not for those under development, such as the ABS because there is the potential problem of committing considerable time and financial resources only to discover that the simulator lacks validity. It is therefore logical to consider a multistage evaluation approach whereby the ABS will be validated using a combination of methods, some of which have been previously described. The first stage is to conduct a face validity analysis to evaluate the realism of the ABS. The data from this stage will be used to identify what adjustments are necessary to bring about acceptable levels of simulation fidelity, and to decide whether the perceived value of the ABS is great enough to justify more resource-intensive evaluation. The second stage is to evaluate whether the simulation environment elicits a similar range of behavioural responses from the driver as might be expected in the real world situation. The question is whether drivers display behaviour that is concordant with expectations, which will support the validity of the simulation environment. On the other hand, if drivers display unexpected behaviours then the validity of the ABS is questionable. In addition to this, the simulator must be capable of differentiating between groups of bus drivers, for instance novice and experienced bus drivers who are expected to exhibit different patterns of behaviour according to the previous literature (e.g. Drummond, 1989; McGwin and Brown, 1999; McKenna and crick, 1991). Further to this is to test whether simulated driving is related to stress, workload, and fatigue in predictable ways based on the previous literature (e.g. Mathews, 2001; Mathews and Desmond, 2001). A third consideration is to evaluate the potential effects of simulator sickness on driver performance to determine whether simulator sickness will compromise the use of the ABS in training. The fourth stage involves investigating whether simulation based training improves performance within the simulation environment. This involves developing a scenario that must be completed before and after training, which is similar but not identical to the one practised during training. It also requires the development and use of measures that accurately reflect performance improvements, for example evidence of collision avoidance or reductions in speed. If significant performance improvements are seen before and after training, then this indicates that learning has occurred within the simulation environment and can be taken as further evidence for validity of the training simulator. Once the first evaluation stages have provided evidence that the simulation has sufficient fidelity, that it is judged to have potential training value, that it elicits similar behavioural responses to the real bus and that learning has occurred within the simulation environment. The final stage then is an investigation into transfer effectiveness. The question now is – does training transfer to the real environment?

Procedures for the conduction of transfer of training evaluations are well established in aviation (e.g. Caro, 1977 etc). However, evaluation of simulator training in the aviation industry focuses on cost benefits and the time saved to reach criterion performance in the real aircraft by using a flight simulator. The ABS however is not intended as a replacement to training in a real bus so the focus for training transfer effectiveness should be on specific learning outcomes, for example a reduction in accidents in the simulator trained group if training has transferred.

4 Thesis Aims and Objectives

The overall aim is to construct and validate a bus simulator that is capable of supporting safety training interventions in bus drivers. The first step in the development of the ABS was to identify the factors that may affect training transfer effectiveness. Figure 6 summarises the factors in the literature that were recognised as being important considerations in the design of the ABS.

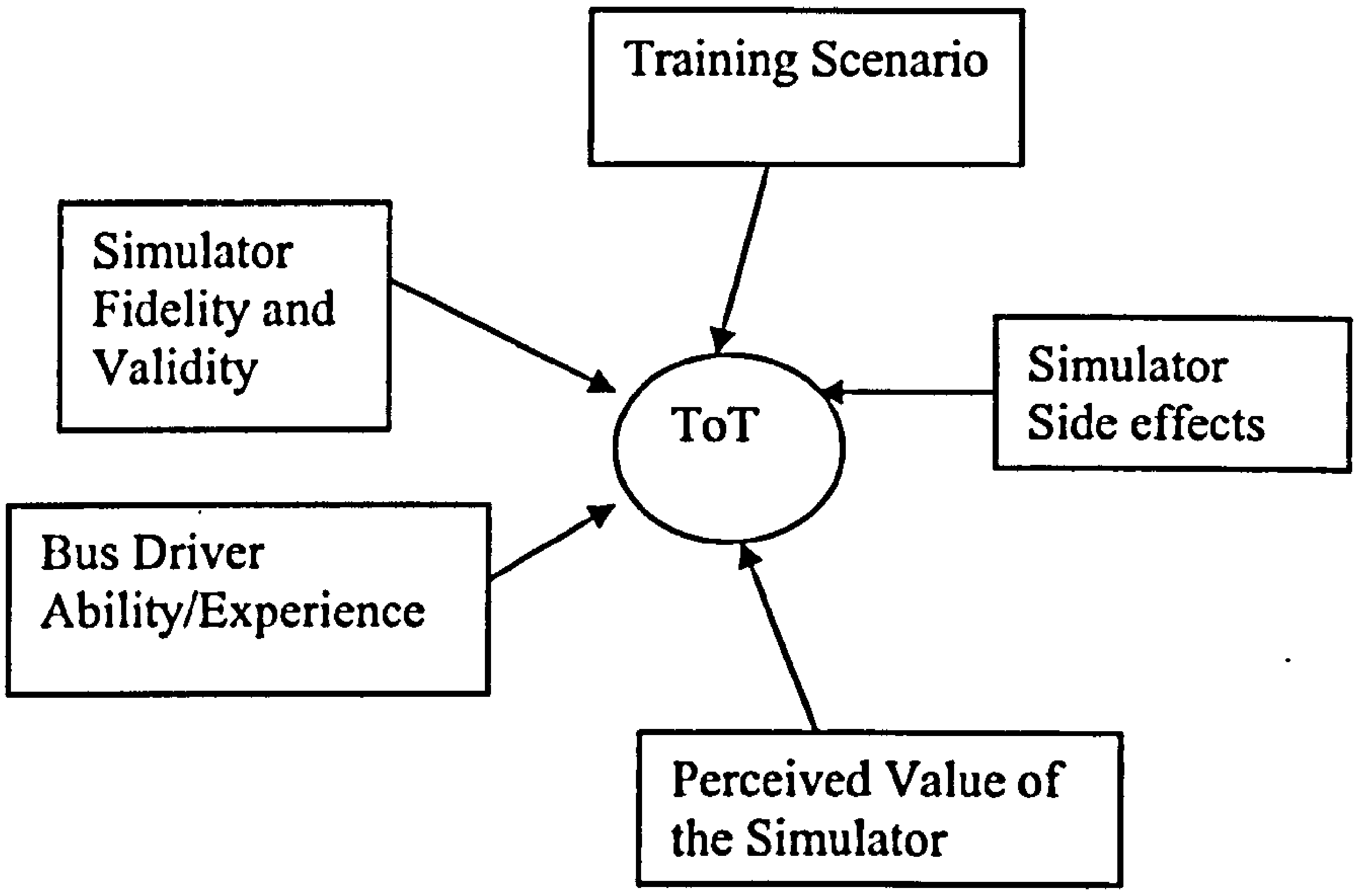


Figure 6 **Factors Affecting Training Transfer**

Firstly, it is important that the characteristics of the training programme, i.e. the scenarios and feedback are matched to the nature of the task being trained and to the ability of the trainee (Alessi, 1988; Salas, Bowers and Rhodenizer, 1998). Secondly, the level of fidelity built into the simulator must also be matched to the nature of the task being trained (Agard (1980, Alessi, 1988). Thirdly, trainee characteristics such as motivation, ability and prior experience (Alessi, 1988; Hays, Jacobs, Prince and Salas, 1992), and fourthly the perceived value of the simulator may also impact on training transfer (Agard, 1980). Finally, side effects such as simulator sickness may impede training transfer by affecting trainees' motivation to use the simulator, or by impairing the trainees' ability to drive safely after leaving the simulator, or causing negative transfer of training if the trainees adopt inappropriate behaviours in the simulator to try and alleviate symptoms.

The thesis is in two parts: part one is an investigation into bus driver training needs - the results of which will drive the design of the simulator and inform the development of training scenarios to improve bus driver safety. Part two describes the design of the bus simulator and the evaluation of its suitability for bus driver training.
The studies conducted in support of the aim are as follows:

1. To conduct an analysis of ARRIVA's accident database to identify the drivers who are most at risk of accidents and to identify the risky situations that may lead to bus accidents in order to inform the design of simulated scenarios for training purposes.
2. To design and construct the simulator hardware and software with sufficient fidelity needed to support bus driver training.
3. To compare simulated driving performance in novice and experienced bus drivers to demonstrate the behavioural validity of the simulator.
4. To assess the safety of the simulator with regards to simulator sickness.
5. To conduct an organisation-wide survey to determine whether self-bias is a feature of bus driver behaviour that may impact on training effectiveness.

5 Risk and Characteristics of Bus Crashes

5.1 Rationale

Bus accidents occur within a matrix of different temporal and environmental circumstances, at different locations and while performing different manoeuvres. The purpose of this study is to provide insight into the most problematic aspects of the driving environment and to identify the bus drivers who will benefit most from additional training. A further aim of this study is to determine whether the literature on novice car drivers can be applied to novice bus drivers by examining the age profiles of accident-involved novice and experienced bus drivers.

5.2 Age and Experience as Predictors of Accident Frequency

Associations between driver characteristics and accident involvement are well established. Two of the most persistently found predictors of accidents; age and experience will provide a good starting point to investigate crash risk in bus drivers, especially since this group has not been as well studied as car drivers. Age and experience are known to be major factors in the overrepresentation of novice drivers in road traffic collisions (Maycock, Lester and Lockwood, 1996) and are commonly used as predictors of crash frequency (e.g. Evans and Courtney, 1985). Indeed, some researchers claim that age and experience is more important than attitude when predicting accident rates (Assum, 1997). However one of the problems inherent in road traffic research is that age and experience are difficult to separate when investigating crash risk (Ryan, Legge, and Rosman, 1998; Mayhew and Simpson, 1990; Bierness, 1996). For age, earlier research shows that accident frequency falls with increasing age (Evans and Courtney, 1985). However, mileage adjusted accident risk declines with age but then rises for older drivers (Chipman et al, 1992; Maycock, Lockwood and Lester, 1991, Ryan, Legge, and Rosman, 1998). This is because older drivers tend to drive less frequently than younger drivers, which reduces their risk of being involved in an accident (Ryan, Legge, and Rosman, 1998). So, when exposure is also accounted for, the accident rates of the very young and very old drivers are comparable. This effect is thought to be due to physical and cognitive declines in older people and to increased risk-taking in younger drivers (Chipman et al, 1992; Clarke, Ward and Jones, 1998; McGwin and Brown, 1999). Experience is closely related to age but independently influences crash risk. Even limited driving experience has a major effect on road safety. For example, the disproportionately higher crash rate during the first year of car driving starts to decline after just a few months (Sagberg, 1998). For age and experience, Mayhew, Simpson and Pak (2003) found larger decreases in crash risk amongst younger novices compared with older novices during the first few months of driving. Greater declines in crash risk for younger novices may be due to greater initial risk taking in comparison to older novices so that their on-road driving experiences facilitates a more rapid learning of appropriate behaviour.

Comparing older and younger novice's crash risk then allows the relative contribution of age and experience to be considered. However, there is little known about the effects of age and experience on crash risk amongst professional drivers. Crash risk is generally greater for professional drivers even when taking into account their increased mileage (Broughton et al, 2003). Taking bus drivers as an example, Blom, Pokorny and van Leeuwen (1987) found that accident risk decreased with experience, especially over the first five years of bus driving. More recent research by Wahlberg (2005) showed that the risk of bus accidents decreases with age and experience, with experience as the strongest factor, carrying the effect. Although the effect of experience and age was strongest during the first years of bus driving, it still only accounted for an extremely small amount of variance, which indicates the importance of other factors in bus accidents. Furthermore, bus accident liability was not influenced by previous car driving experience although car driving experience was strongly correlated with age, indicating that bus driving is different from car driving. It is therefore not clear to what extent previous research on the relative contribution of age and experience on accident involvement can be applied to bus drivers and their crash risk.

5.3 Experience and Involvement in Different Types of Accident

Although this has not been previously investigated in bus drivers, there is some evidence to suggest that car drivers with different levels of experience are involved in different types of accident due to differences in the underlying etiologic factors for drivers in different age categories. For example, older car drivers are more likely to fail to stop for other traffic in right of way conflicts, and report failure to observe traffic signals and other vehicles and obstructions as the reason for their accidents (McGwin and Brown, 1999). Older drivers are also more likely to be involved in crashes at intersections and when turning, changing lanes and merging with traffic (Cooper, 1990; McGwin and Brown, 1999). Since the probability of being involved in an accident when turning at a junction depends on the size of the gap that a driver is willing to accept and the speed at which they cross the intersection (Alexander et al, 2002), this may be because older drivers have difficulty judging and responding to traffic flow due to perceptual and cognitive declines. Further to this, Keskinen, Ota and Katila (1998) proposed that older drivers themselves posed a hazard to other drivers because they were slower to accelerate and took longer to turn at junctions than younger drivers. On the other hand, young drivers are more likely to engage in risky behaviours, such as accepting smaller gaps when crossing traffic flow (Alexander et al 2002) and selecting higher speeds and closer following distances than middle aged and older drivers (Boyce and Geller, 2002; Evans and Wasielewski, 1982). Since Evans (1991) found that high speeds and close following distances are good predictors of vehicle crashes it is not surprising then that younger drivers have a high crash risk.

There is little research on the link between experience and sub categories of accidents in bus drivers. Therefore an analysis of the differences in bus accidents by experience may suggest aspects of the driving environment that pose a greater risk for different groups of bus drivers so that simulator-based scenarios can be presented to reduce the risks inherent in these situations during training.

5.4 Methodological Concerns When Analysing Accidents

The aim of the analysis then is to firstly investigate the role of bus drivers' age and experience in the frequency of bus accidents and to better understand the factors in the driving environment that are most problematic for bus drivers with different levels of experience. However traffic accident research can be problematic. For instance, Wahlberg (2003) reviewed a sample of studies investigating traffic accident predictors and identified three methodological shortcomings that were common in these studies: the uses of predictors such as personality or ability tests with low test-retest reliability; collection of data over too short a time period; and not differentiating between culpability for accidents (i.e at fault, not at fault). These studies may be limited by small sample sizes (e.g. Hancock et al, 1990). Other problems with data collection may include a lack of data regarding variables of interest, inconsistent data collection, sampling error and the use of self-reported crash data, which may be influenced by under reporting of minor incidents. Another problem in traffic accident predictor studies is that peoples' behaviour changes over time; what is measured at one point in time may not be as good a predictor at another time (McKenna, 1983). Many studies therefore use official accident databases in order to investigate the factors implicated in accident causation (e.g. Abdel-Aty, Chen, and Schott, 1998; Evans and Courtney, 1985; McGwin and Brown, 1999; Ryan, Legge, and Rosman, 1998). These databases have the advantage of being large and data is usually collected over a long time period so that appropriate statistical analysis can be used to draw reliable conclusions about traffic accident predictors. However, official data is not usually collected for research purposes and can be restricted, for instance if the data set is already categorised, or crash definitions are inconsistent. Under-reporting and various biases have been shown to exist (Harris, 1990). For example, minor accidents that do not involve the police or insurance company may not be reported. Moreover, culpability may not be recorded. Transportation company data on the other hand have the advantages of official archives, which are probably more complete (af Wåhlberg, 2002). Within companies though there may be additional problems. Accident data is often collected for insurance purposes with culpability being recorded to support the commercial operation of the company. Such databases are concerned with policies, claims and claimants rather than accident and driver characteristics. Arriva's collision database is different in that they have gathered detailed information about the characteristics of each collision and each driver for a number of years, including recorded culpability. A further advantage is that all incidents are reported and attributed to a particular driver, no matter how minor. This is due to a strictly adhered to company policy that all vehicles are checked at the start of each shift.

Given that Arriva's collision database is fairly comprehensive; the next step is to consider the best method to investigate crash risk according to driver's age and experience. There are many ways to assess the crash risk associated with different types of road user. Since conclusions on safety issues cannot be reliably drawn without exposure information (Evans, 1991, Wahlberg, 2005), crash rates are usually normalised against some measure of exposure.

Several researchers have suggested using induced exposure techniques to produce a relative risk ratio index (Cooper, 1990; Haight, 1973; Lyles, Stamatiadis and Lighthizer, 1991; Stamatiadis and Deacon, 1997). The calculation of crash risk used for the present study is a variant called quasi-induced exposure (Lyles et al, 1991; Stamatiadis and Deacon, 1997; Haight, 1973). Given an accident, risk is determined by calculating the ratio of responsible drivers divided by the proportion of non-responsible in each group. If data regarding culpable and non-culpable accidents is readily available, this method of risk ratio calculation offers the advantage over frequency information for determining the risk of accident culpability while controlling for differences in exposure between groups. The quasi-induced exposure method is based on the assumption that in two-vehicle crashes there is a driver who is responsible for the collision and that the second driver is selected randomly from the driving population (Carr, 1969; Haight, 1973). This method has the advantage of not having to ascertain the exact population of drivers, as accidents are used as the unit of analysis. Furthermore, the use of pairs of drivers from the same accident means that many environmental variables of interest are held constant. However, in the present study the drivers were not matched pairs because details of the second driver were not available. Therefore, the present analyses violated one of the assumptions of quasi-induced exposure, and thus introduced an unknown amount of error into the calculations. However, for a population of bus drivers, the use of pairs of drivers from the same accident is probably not that important. Firstly, many would have been car drivers, and thus not really comparable to the population of interest. Secondly the main purpose of this part of the method is to hold constant factors like time of day, where drivers probably differ a lot in their exposure due to characteristics like age (Stamatiadis and Deacon, 1997). However, the driving environment of bus drivers is much more standardized as they have much less choice concerning routes, time of day, type of vehicle etc. Therefore, it was not expected that the violation of the driver pair assumption would lead to any significant violation of the assumption of non-culpable drivers as a random sample of the population, which indicates the exposure of the class to which the driver belongs. Consequently, the analysis is not directly comparable to other methods of quasi-induced exposure and can only yield results that can be used for comparisons within the group. However, this is adequate for the main aims of the study which are: (a) to determine the relative contribution of age and experience on culpability for crashes; (b) to identify bus drivers training needs by investigating the circumstances in which the risk of being culpable for crashes is highest; and ultimately (c) to inform the design of simulator-based training scenarios.

5.5 Method

5.5.1 Accident Database

There are 121 Arriva depots throughout the UK and their incident database contains details of accidents involving Arriva buses. The database contains data relating to over 50 variables, some of which were of interest: incident type, accident location (road features), manoeuvres, weather conditions, road conditions, day of week, time of day, culpability and drivers length of service and age (Table 4).

Table 4 Categories of Interest from the Accident Database

Variable	Category
Incident type	Collision, passenger falls, luggage, fire, theft, vandalism, windscreen only
Manoeuvre	Stationary, slowing, accelerating, reversing, moving off, turning left, turning right, driving normally, changing lanes, overtaking, u-turn, evasive action, pulling into bus stop, pulling out of bus stop
Road Features	Bus stops, junctions, traffic lights, bus lanes, roundabouts, road works and pedestrian crossings.
Culpability	At-fault, not at-fault, part fault, vehicle defect, no knowledge of the incident.
Time of day	Split hourly i.e. up to 16.00hrs up to 17.00hrs into a 24-hour clock.
Day of week	Monday, Tuesday, Wednesday, Thursday, Friday, Saturday, Sunday
Drivers length of service	Calculated from their start date with Arriva.
Drivers age	Calculated from their birth date to the date of the incident
Weather conditions	Fine, raining, fog, mist, snowing, sleet, strong winds, freezing
Road conditions	Dry, wet, snow covered, icy, flooded, muddy, loose sand/gravel, pot holes, under repair, oil patches
Road Type	Motorway, dual carriageway, major, minor, country lane, public car park, private property, bus depot

5.5.2 Data Preparation

Incidents that occurred between 14th December 2000 and June 26th 2003 were selected. Only incidents that met the following criteria were included: Drivers were between 18 and 64, had 0-35 years service history with Arriva and details about the crash and culpability were complete. This left a total of 15100 collisions that were categorised according to three levels of culpability: number of at fault collisions (N=6230), number of part fault collisions (N=1422) and number of not at fault collisions (N=7448). Culpability is assigned on the basis of insurance claims settlements.

For some parts of the analysis, length of service (LOS) was categorised into 3 groups with equal proportions of drivers in each category: LOS1 (0-1 years); LOS2 (1 year and 1 month to 5 years), and LOS3 (over 5 years). Drivers in these categories will be referred to as novice bus drivers (LOS1), intermediately experienced bus drivers (LOS2), and experienced bus drivers (LOS3).

Table 5 Variables Included in the Analysis

Variable	Category
Incident type	Collision
Manoeuvre	Stationary, slowing, accelerating, reversing, moving off, turning left, turning right, driving normally, changing lanes, overtaking, u-turn, evasive action, pulling into bus stop, pulling out of bus stop
Road Features	Bus stops, junctions, traffic lights, bus lanes, roundabouts, road works and pedestrian crossings.
Weather conditions	Fine, raining, fog, mist, snowing, sleet, strong winds, freezing
Road conditions	Dry, wet, snow covered, icy, flooded, muddy, loose sand/gravel, pot holes, under repair, oil patches
Road Type	Motorway, dual carriageway, major, minor, country lane, public car park, private property, bus depot

5.5.3 Participants

There were 12, 224 bus drivers who had been involved in these crashes. The mean number of crashes per driver was 5.16. Drivers were aged between 18 – 64 years (mean = 42.8 years, SD = 10.8) and their length of service ranged from 1 month to 35 years (mean = 6.1 SD = 7.6). Information about driver's gender was not available, but almost all Arriva bus drivers are male.

5.5.4 Treatment of Results

The various crash categories were analysed by the use of percentages of total, which was compared between various levels of experience and age, and also concerning culpability. The latter analysis is of prime importance for training.
The data concerning age, experience and culpability may be explored by using correlations and risk ratio calculations.

5.5.4.1 Correlations

Pearson correlations were conducted between age and experience and the three measures of culpability: at fault, not at fault and part fault. In at fault collisions the bus driver was considered to be solely to blame for the crash. For not at fault collisions, the crash was deemed to be the fault of another road user. For part fault collisions, the bus driver contributed to the cause of the crash but another road user was also implicated. For each crash if a feature of a variable was present (e.g. sole responsibility), it was positively coded if not it was coded zero. This means that when correlations for sole responsibility were computed, both no responsibility and part responsibility crashes were coded zero.

A further culpability measure, All responsible crashes, was created which is the mirror of No responsibility; the sign of the correlation just needs to be reversed.

5.5.4.2 Risk Ratio Calculations

Two measures of risk were calculated:

Solely responsible: The risk of being the sole cause of an accident was calculated by dividing the frequency of at fault accidents with the frequency of not at fault accidents.

$$\text{Solely Responsible Risk Ratio} = \frac{\text{At Fault Accident}}{\text{Not At Fault Accident}}$$

All responsible: The risk of contributing to the cause of the accident was calculated by adding the frequencies of at fault and part fault accidents and then dividing by the frequency of not at fault accidents.

$$\text{All Responsible Risk Ratio} = \frac{\text{At Fault Accident} + \text{Part Fault Accident}}{\text{Not At Fault Accident}}$$

A ratio of 1 means that if drivers are involved in an accident the likelihood of them being responsible for causing the accident and the likelihood of them not being found at fault is the same; a ratio of less than 1 means that less than half of the drivers were the cause of the accident; and a ratio of more than 1 means that more than half of the drivers were the cause of the accident. These risk ratios can be calculated for defined categories of drivers, for example age groups, and comparisons thereafter be made between groups concerning the size of the ratios. The result is a measure of differences in accident-causing tendencies between groups. Also, accidents can be categorized by other characteristics and thereafter compared on the variables age and experience.

5.5.4.3 Chi2 Tests

Chi2 tests were conducted to determine whether there was any difference in the number of solely responsible and all responsible crashes for different groups of bus drivers.

5.5.4.4 T-tests

To understand the influence of age and experience, crashes were divided into groups depending on the road type, location and manoeuvre at the time of the crash. The mean age and mean experience for the drivers who were all responsible and not responsible was calculated and independent t-tests were conducted to test for any differences on these variables.

5.6 Results

5.6.1 Crashes

15100 crashes were suitable for inclusion in the analysis. There were 12,244 bus drivers who had been involved in these crashes. The analysis presented is based on collisions, so that any one driver may appear in the data more than once if they have been involved in multiple collisions within the time period of interest.
Table 6 and Figure 7 show the descriptive statistics for age and LOS by frequency of crash involvement.

Table 6 Bus Drivers' Mean Age and LOS

	Novice		Intermediate		Experienced	
	age	years service	age	years service	age	years service
Mean	38.5	0.43	40.5	2.6	48.7	14.2
Std. Deviation	10.5	.27	10.3	1.1	9.2	7.7
Minimum	18	.01	19	1.01	24	5.01
Maximum	64	1.0	64	5.0	64	35

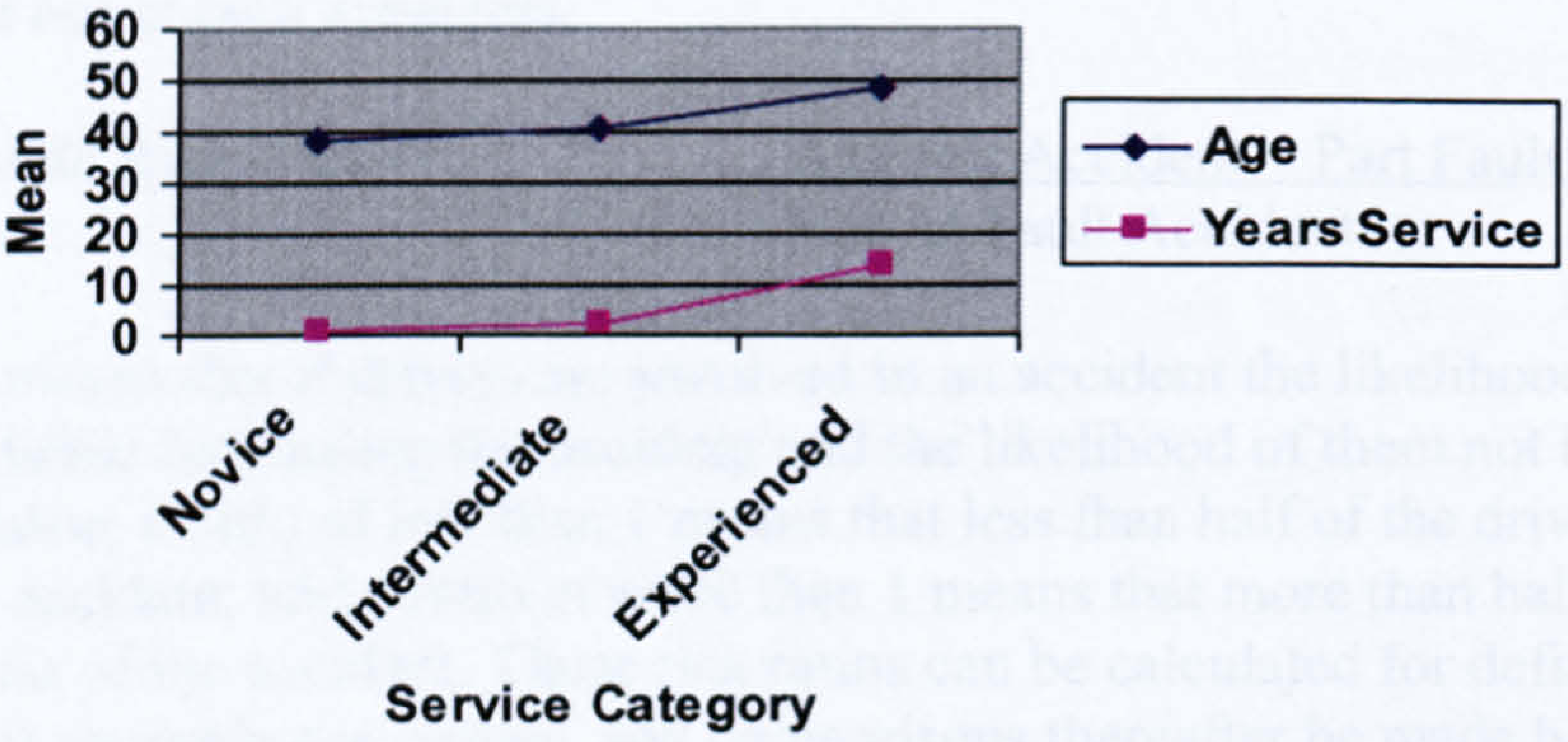


Figure 7 Bus Drivers' Mean age and LOS

The results of a one-way ANOVA show a significant difference in the mean age of bus drivers in each length of service category (F (2, 15097) = 1453.62, p<.0001). Post hoc tests show that all three categories are significantly different (P<.0001). Novice bus drivers were the youngest bus drivers and experienced bus drivers were the oldest bus drivers. The mean service length of bus drivers in each category was also significantly different (F(2, 15097) = 12885.56, p<.0001), again post hoc tests showed significant differences between novice bus drivers (LOS1), intermediately experienced bus drivers (LOS2), and experienced bus drivers (LOS3), (p<.0001).

5.6.2 Age, Experience and Culpability for Crashes

The data was split into 10 groups defined by bus driver's age: up to 20 years (N=44), 21-25 (N=691), 26-30 (N=1334), 31-35 (N=2065), 36-40 (N=2278), 41-45 (N=2217), 46-50 (N=410), 51-55 (N=3599), 56-60 (N=1674), and 61-65 (N=788).

Figure 8 shows the culpability risk ratios for drivers of different ages. The results show that risk ratios are highest for the youngest bus drivers. Culpability risk is highest for drivers under 20 years old. Culpability risk ratios exceed 1.0 for drivers who are under 25 and those who are 46-50 years old for solely responsible crashes. For All responsible crashes the culpability risk exceeds 1.0 for drivers under 30 years old, 46-50 and 56-65. The risk ratios indicate that drivers aged 31-45 and drivers aged 51-55 are the safest as solely and All responsible risk ratios are below 1.0.

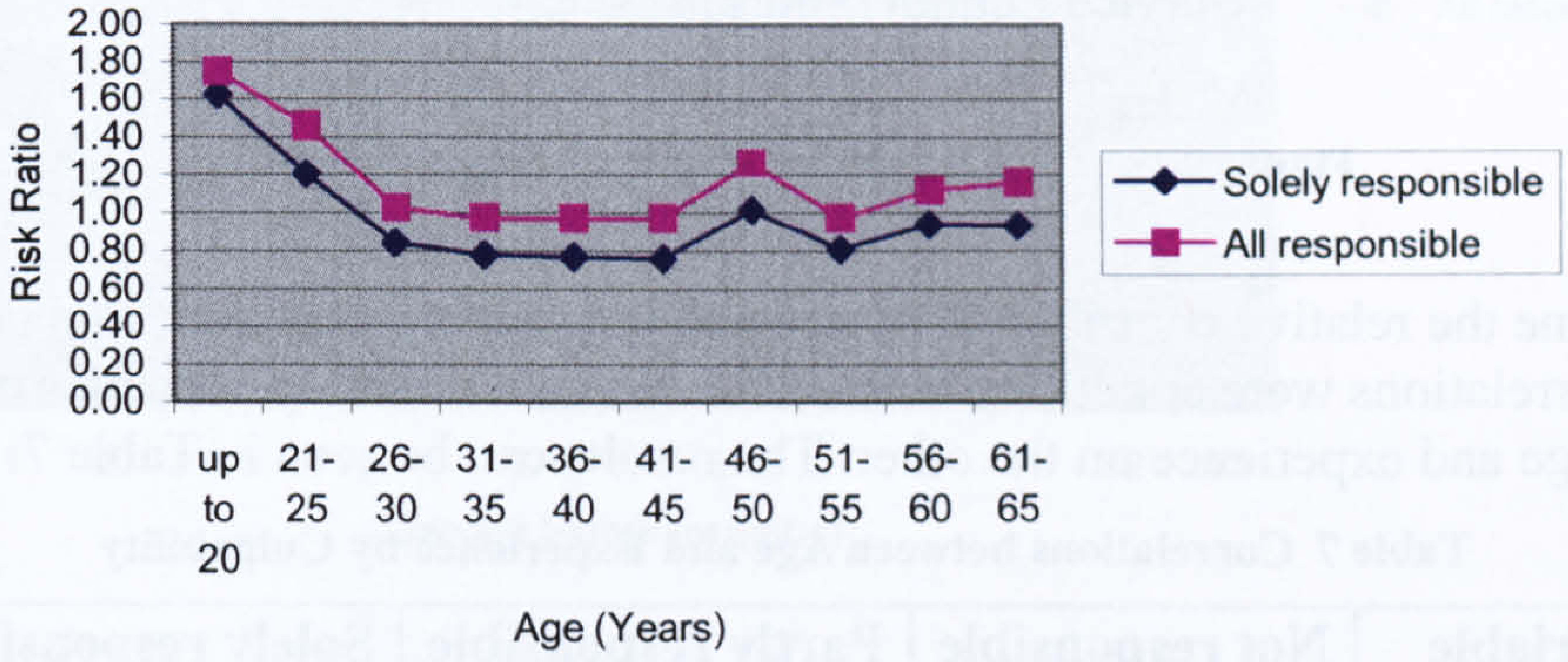


Figure 8 **Culpability Risk by Bus Driver Age**

Figure 9 provides information relating to the culpability ratios for every year of service. The results show that risk ratios decline after the first two years of driving but exceed 1.0 three times after years of service for All responsible crashes (20, 22, 27 and 30 years), whereas for Sole responsibility crashes only exceeds 1.0 for the first year only.

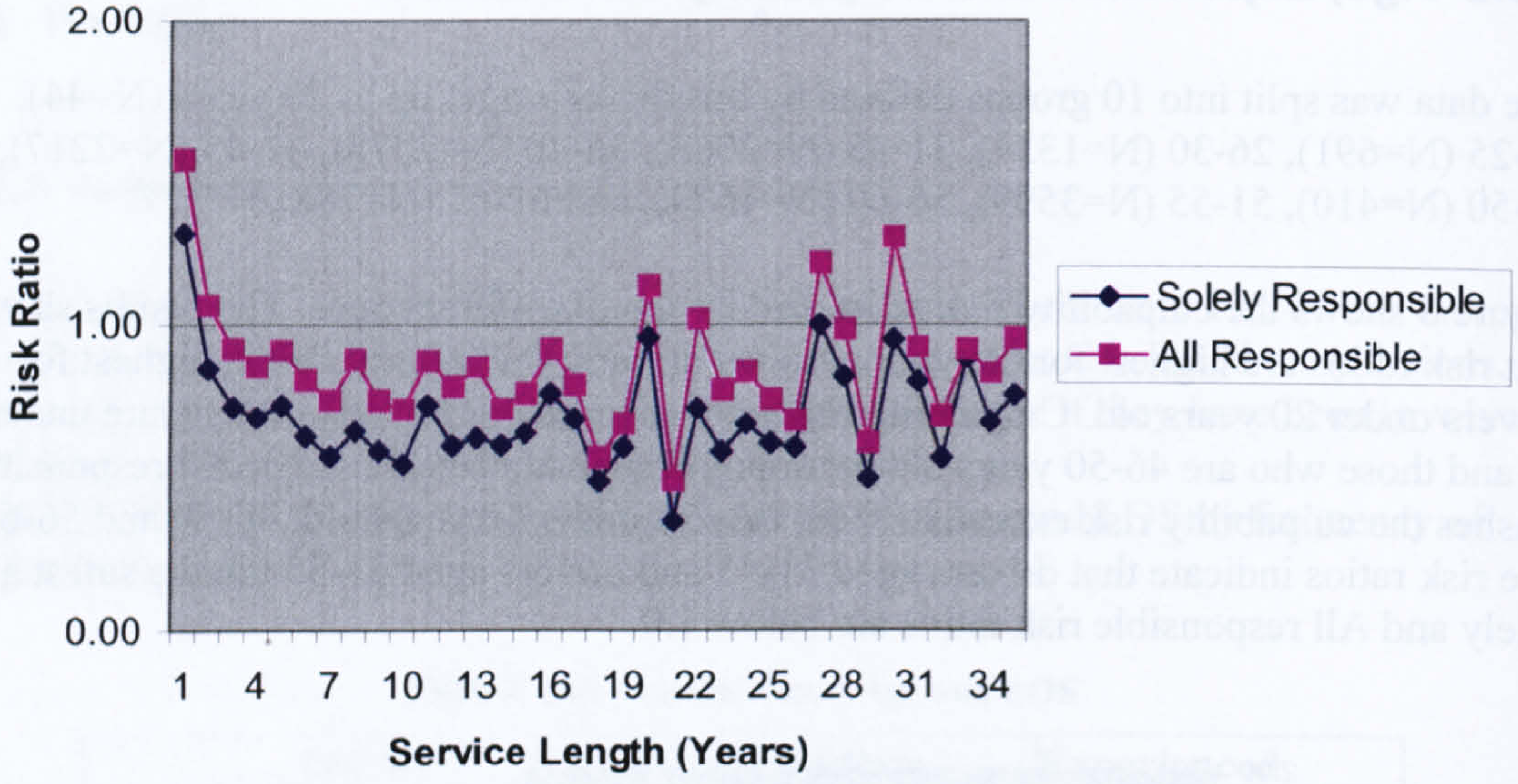


Figure 9 **Culpability Risk by Length of Service**

To determine the relative contribution of age and bus driving experience on culpability, Pearson correlations were conducted between the three culpability variables on one hand and age and experience on the other. The results can be seen in Table 7.

Table 7 Correlations between Age and Experience by Culpability

Variable	Not responsible	Partly responsible	Solely responsible
Age	.003	-.011	.003
Experience	.078**	-.018*	-.069**

(*=p<.05, **=p<.001)

These results imply that, in terms of linear trends, only experience has an effect on crash culpability.

A chi2 test revealed that only the solely responsible and all responsible ratios for the first two years of service were significantly different from later years (Table 8).

Table 8 Chi2 Values for First Three Years of Service versus Later Years

Variable	N	1st Year	N	2nd Year	N	3rd Year
All responsible	15100	229.4*****	10934	22.6****	8828	3.41
Solely responsible	13678	251.7*****	9910	20.6***	8015	2.84

(*** p<.001, **** p <.0001, ***** p<.00001)

The results seem to pinpoint the effect of experience within the first years or so. Given that the first year of service carries the greatest risk of being both Solely and All responsible for a crash, a more detailed analysis of the first year of service was conducted.

5.6.3 Month by Month Culpability Risk

The analysis was conducted on drivers in their first year of service only (N=4166). Length of service was categorised into 12 groups of monthly increments and risk ratios were calculated. Figure 10 shows the risk ratios for every month of a driver's first year of service.

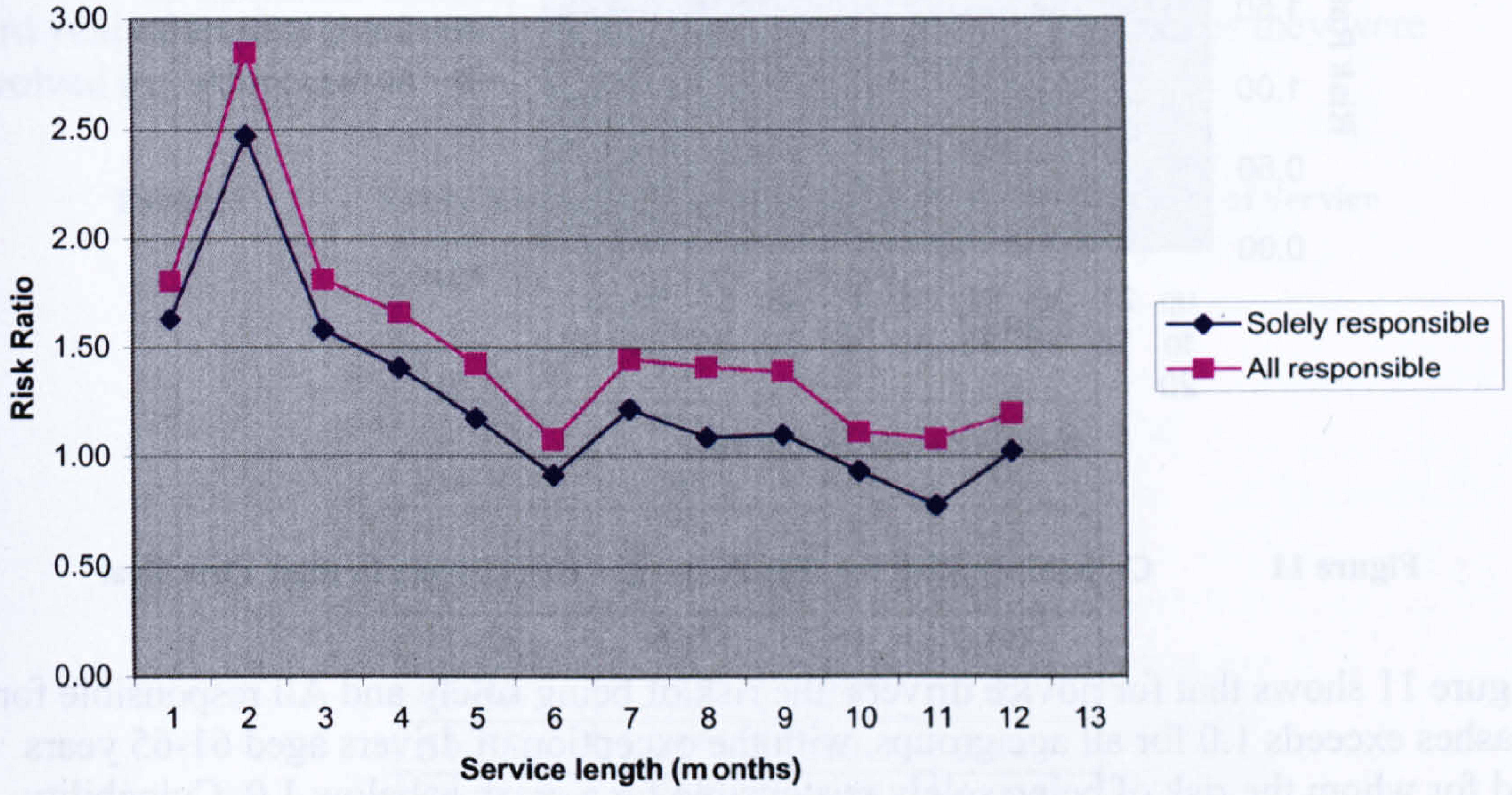


Figure 10 Culpability Risk by Month of Service for Novice Bus Drivers

Figure 10 shows a sharp decline in crash risk for both Sole and All responsible crashes during the first year of service. Novice bus drivers are most at risk of being solely responsible for a collision during their first six months. Culpability risk exceeds 1.0 for All responsible crashes in every month throughout the first year of service. Culpability risk peaks around 2 months for solely responsible and All responsible crashes, with culpability risk at this time being approximately twice that of any other time in a bus driver's first year. At six months novice bus drivers are less likely to be the sole cause of a collision; however beyond six months the risk increases again. After ten months novice drivers are less likely to be the sole cause of a collision.
A chi2 test revealed that culpability risk in the first month is not significantly different from later months, but this is probably due to the peak in the second month. The risks for the first three months combined were significantly different from the last nine months.

Table 9 Chi2 Values for the First Three Months of Experience versus Later Months

Variable	N	1	N	2	N	3	N	1-3
All responsible	4166	1.6	3908	48.5*****	3360	10.8*	4166	48.7*****
Solely responsible	3768	3.2	3526	53.0*****	3030	14.3**	3768	59.1*****

(* p<.05, ** p<.01, ***** p<.00001)

To determine the relative contribution of age and bus driving experience in novice bus drivers, risk ratios for novices who were similar in experience but different in age were calculated.

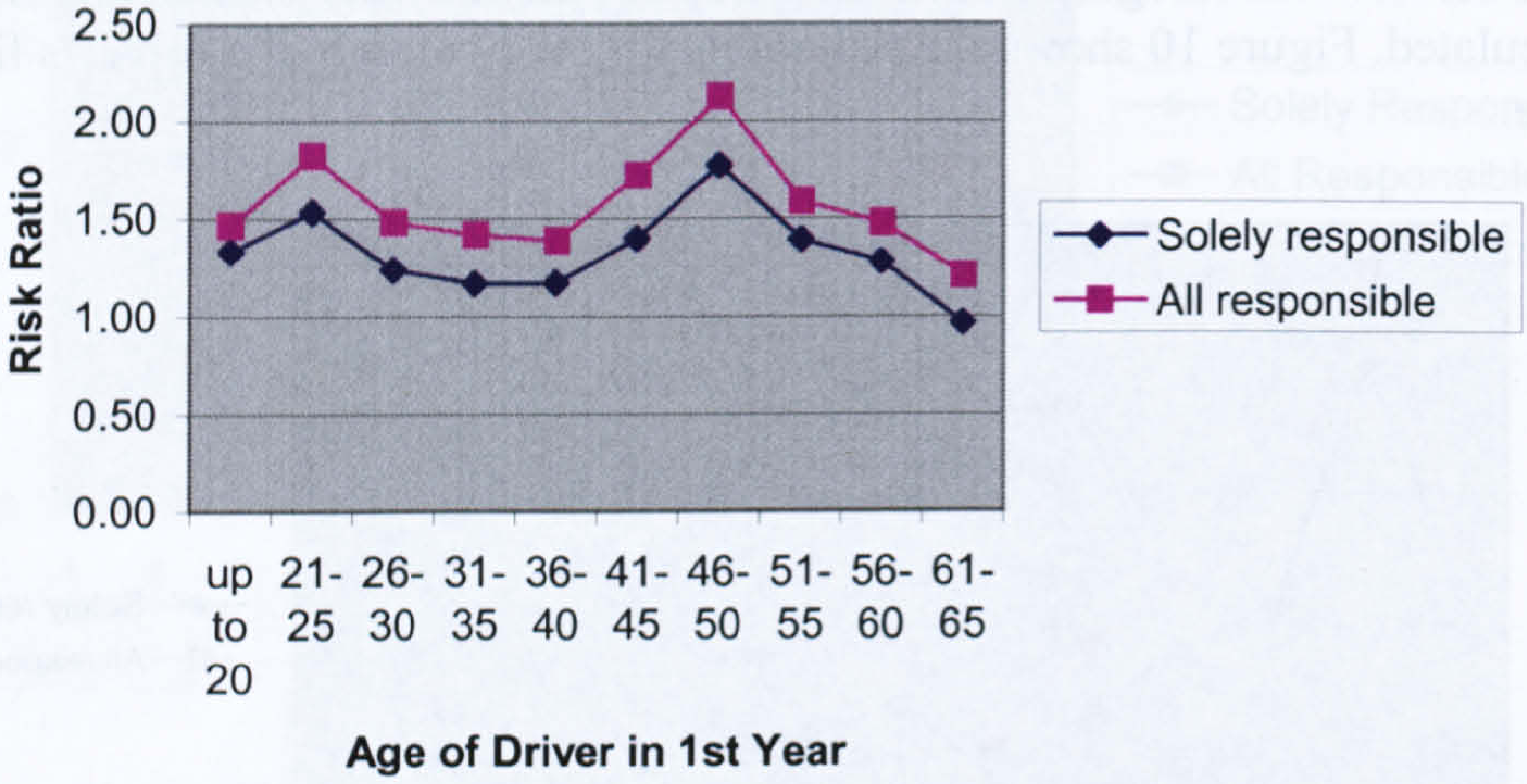


Figure 11 Culpability Risk for Different Aged Bus Drivers in their First Year

Figure 11 shows that for novice drivers, the risk of being solely and All responsible for crashes exceeds 1.0 for all age groups, with the exception of drivers aged 61-65 years old for whom the risk of being solely responsible for a crash is below 1.0. Culpability risks peak for drivers aged 21-25 and those aged 46-50, but are highest for drivers aged 46-50 years old. However a chi2 test revealed that these differences were not significant.

Pearsons' correlations were conducted to determine the relative contribution of age and bus driving experience on culpability in bus drivers in their first year of service. The results can be seen in Table 10.

Table 10 Correlations between Age and Experience for First Year of Service Only

Variable	**Not responsible**	**Partly responsible**	**Solely responsible**
Age	.004	-.013	.003
Experience	.110**	.029	-.124**

(*=p<.05, **=p<.001).

For these data, age again had no association with culpability, although the correlations between experience and culpability increased for not responsible and solely responsible crashes, although there was no association between experience and partly responsible risk in novice bus drivers.

5.6.4 Experience, Maturity and Culpability Risk

To further investigate whether age influences bus drivers' culpability risk, the risk ratios for bus drivers of different ages were compared during their first three years of service. Table 11 and Table 12 show solely responsible and All responsible risk ratios. The asterisk indicates whether drivers are more likely to be involved in the cause of the collision. Risk ratios could not be calculated for bus drivers under 20 years old in their third year of service because they were responsible for all of the crashes they were involved in.

Table 11 **Solely Responsible Crash Risk for First Three Years of Service**

Age	Service Length		
	Year 1	Year 2	Year 3
Up to 20	1.33*	5.00*	-
21-25	1.53*	0.95	0.80
26-30	1.24*	0.85	0.56
31-35	1.17*	0.72	0.58
36-40	1.17*	0.81	0.83
41-45	1.40*	0.79	0.64
46-50	1.78*	1.29*	0.48
51-55	1.39*	0.86	0.84
56-60	1.28*	1.08*	1.06*
61-65	0.97	1.30*	1.52*

Table 12 **All Responsible Crash Risk for First Three Years of Service**

Age	Service Length		
	Year 1	Year 2	Year 3
Up to 20	1.47*	5.00*	-
21-25	1.82*	1.16*	0.97
26-30	1.48*	1.09*	0.70
31-35	1.42*	0.93	0.78
36-40	1.39*	0.99	1.01*
41-45	1.72*	1.02*	0.81
46-50	2.13*	1.54*	0.64
51-55	1.58*	1.01*	1.04*
56-60	1.48*	1.30*	1.25*
61-65	1.21*	1.70*	1.90*

A closer examination of driver age and responsibility for crashes over the first three years of service shows that the risk actually increases for the youngest bus drivers (up to 20) and the oldest bus drivers (61-65) as they gain experience. Middle-aged bus drivers aged 36-40 show a decline in risk, which levels out after two years, but bus drivers aged 46-50 continue to demonstrate a decline in risk in the third year. In the third year, the risk is highest for the youngest drivers, followed by the oldest bus drivers who are both more likely to be solely responsible crashes. Middle-aged bus drivers are not likely to be solely responsible for crashes; risk is lowest for middle-aged drivers aged 46-50.

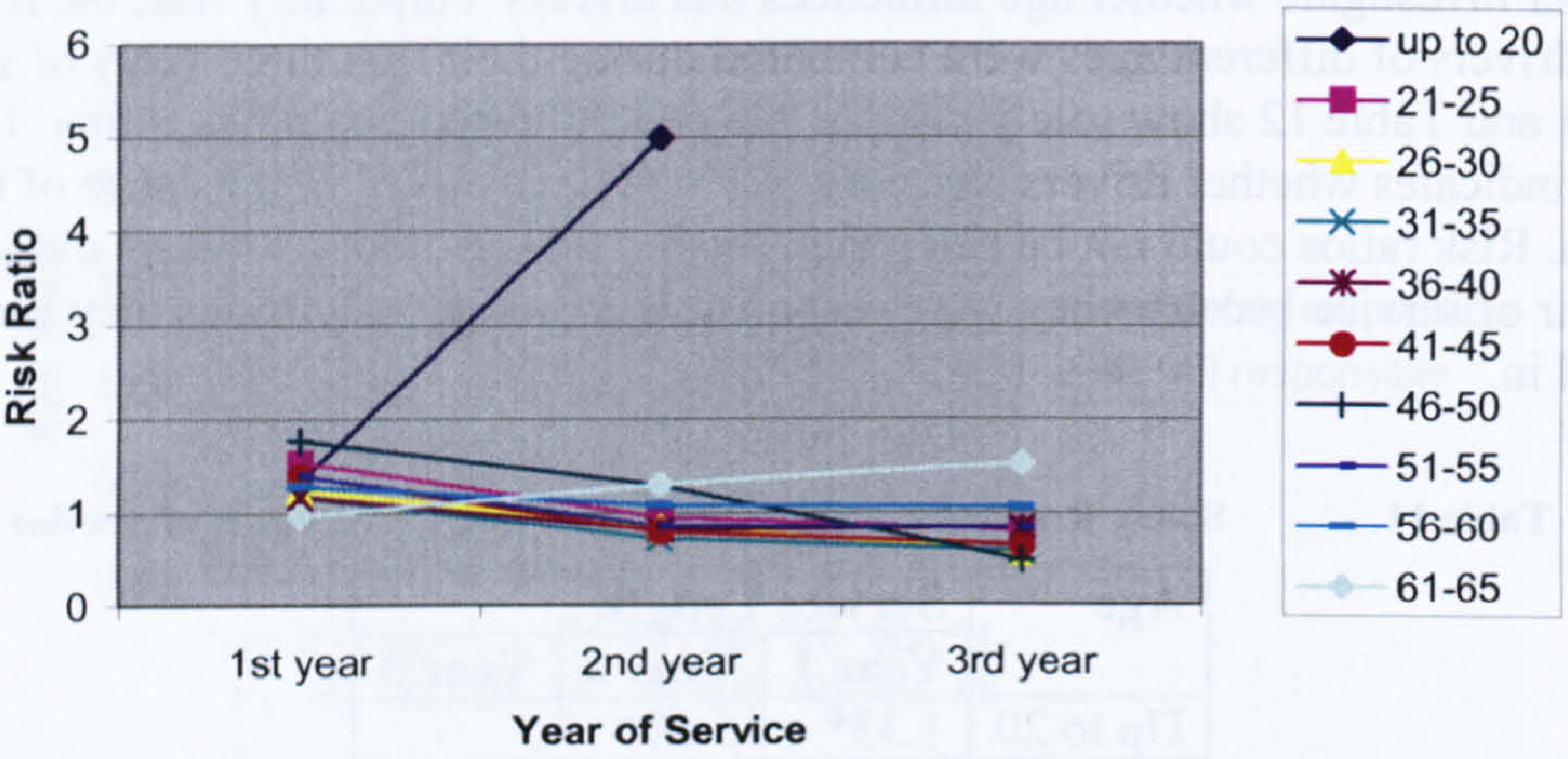


Figure 12 **Solely Responsible Risk Ratios for First Three Years by Driver Age**

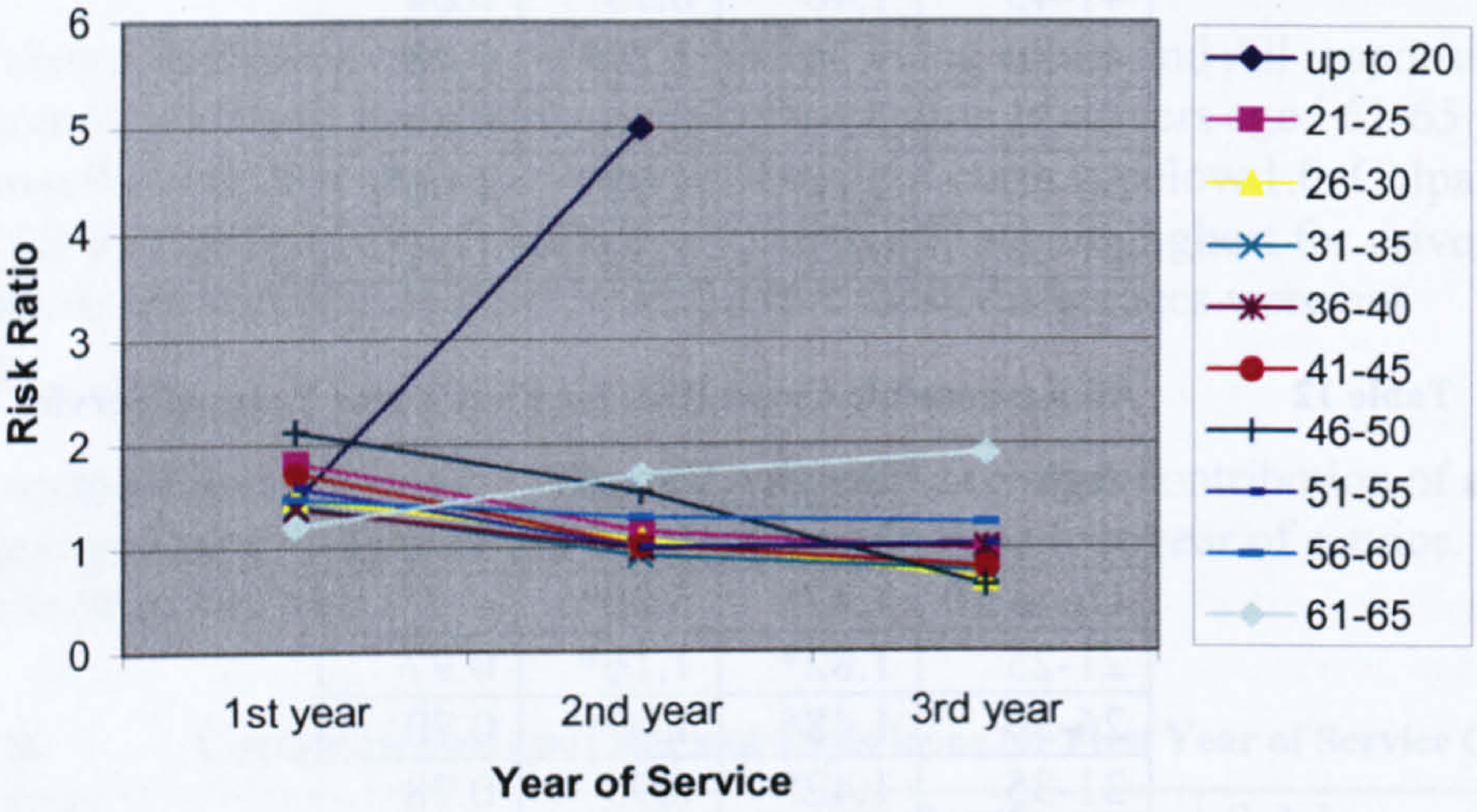


Figure 13 **All responsible Risk Ratios for First Three Years by Driver Age**

A chi2 analysis revealed that the differences in risk ratios for bus drivers in different age categories were not significant.

5.6.5 Length of Service and Bus Crash Characteristics

To simplify the following analysis, length of service was split into three categories: Novice (0-1 years service), intermediate (1-5 years service) and experienced bus drivers (over 5 years service). Risk ratios were calculated accordingly.

5.6.5.1 Risk Associated with Weather and Road Conditions

Table 13 and figure 14 show the percentage of crashes that occur during different weather conditions.

Table 13 **Percentage of Crashes Occurring in Different Weather Conditions**

Service Length	Fine	Raining	Icy/Freezing	Mist	Fog	Strong Wind	Snowing	Sleet
Novice	80.6	14.8	1.5	1.2	0.8	0.5	0.4	0.3
Intermediate	81.3	14.6	1.4	1.1	0.3	0.4	0.7	0.1
Experienced	81.8	13.4	1.6	1.3	0.3	0.6	0.7	0.3

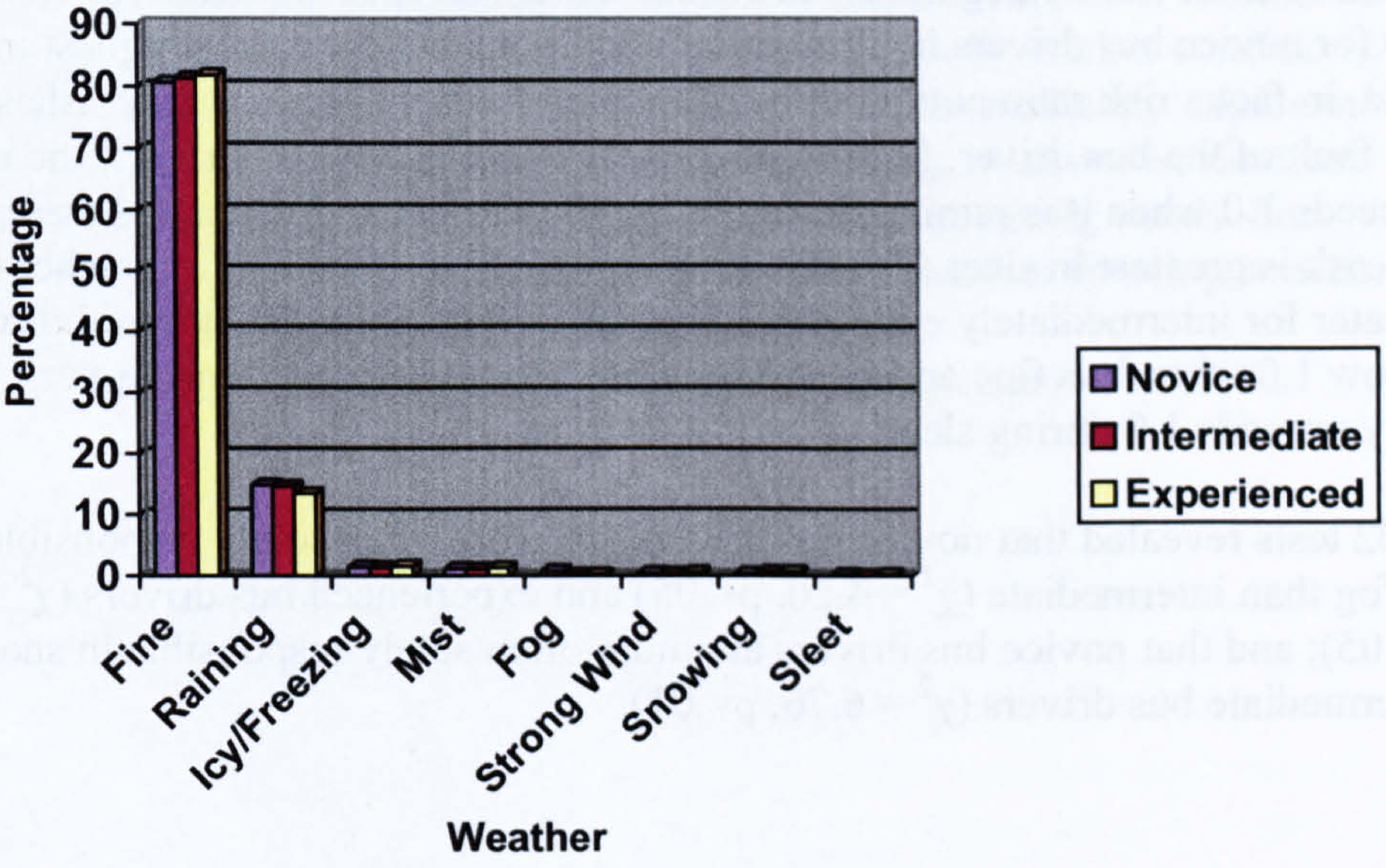


Figure 14 **Percentages of Crashes Occurring in Different Weather Conditions**

The largest proportion of crashes occurs when the weather is fine followed by when it is raining for novice, intermediate and experienced bus drivers. Crashes when it is icy or freezing, mist, fog, strong winds, snow and sleet occur to a lesser extent. The graph also appears to show similar proportions of crashes according to experience level.

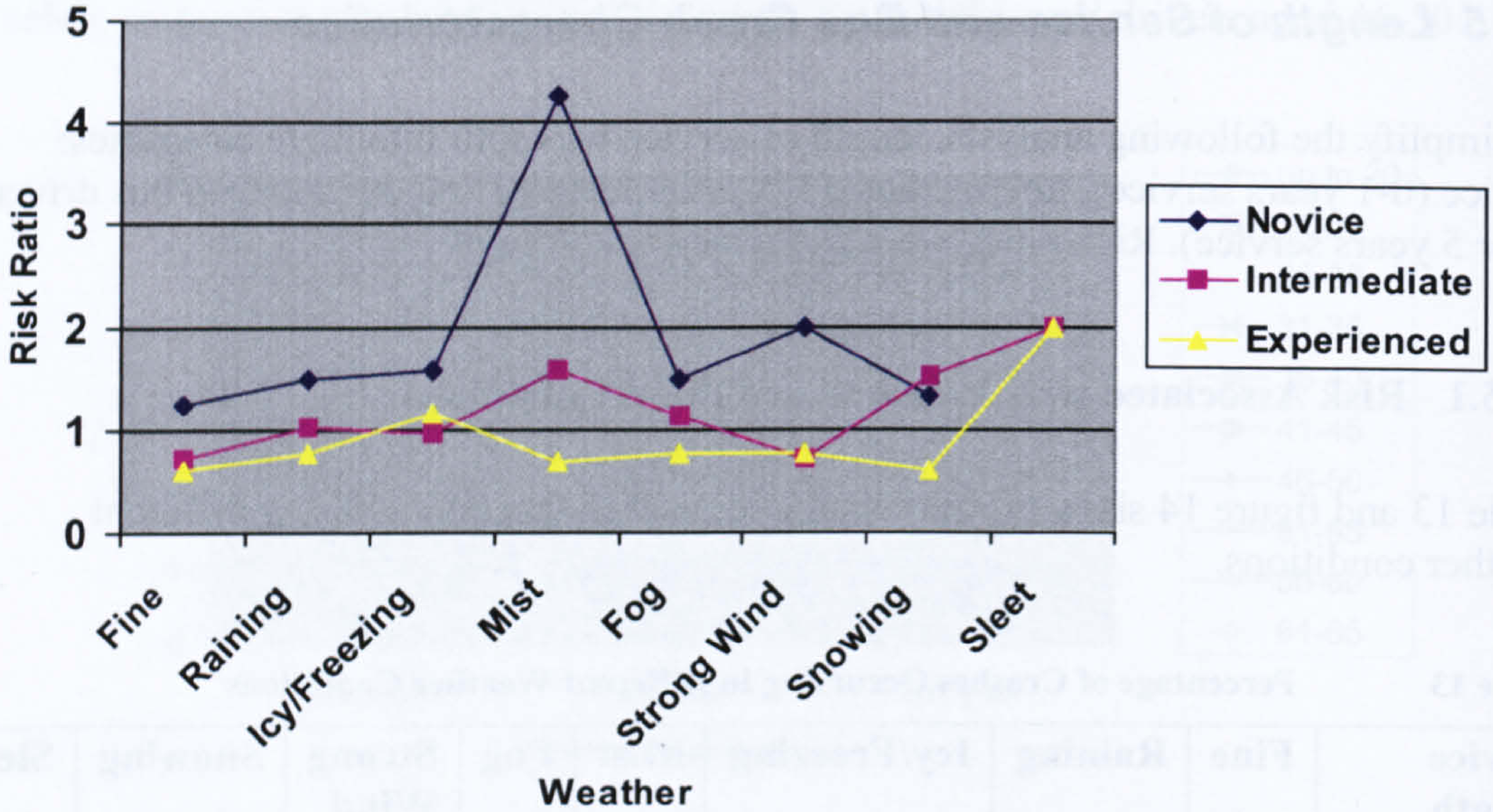


Figure 15 **Sole Responsibility Risk Ratios for Different Weather Conditions**

Figure 15 shows the risk ratios for solely responsible crashes in different weather conditions for LOS categories. The risk of being solely responsible for crashes exceeds 1.0 for novice bus drivers in all weather conditions but the risk is highest in sleet and mist, in fact a risk ratio could not be calculated for sleet because all crashes in sleet were the fault of the bus driver. For intermediately experienced bus drivers, the risk ratio exceeds 1.0 when it is raining, in fog, mist, snow, sleet and when it is freezing or icy; the risk is greatest in sleet. The risk of being solely responsible for crashes in snow is greater for intermediately experienced bus drivers than it is for novice bus drivers. It is below 1.0 when it is fine and in strong winds. For experienced bus drivers, the risk ratio only exceeds 1.0 during sleet.

Chi2 tests revealed that novice bus drivers are more often solely responsible for crashes in fog than intermediate ($\chi^2 = 4.26$, $\rho<.05$) and experienced bus drivers ($\chi^2 = 3.9$, $\rho<.05$); and that novice bus drivers are more often solely responsible in snow than intermediate bus drivers ($\chi^2 = 6.76$, $\rho<.01$).

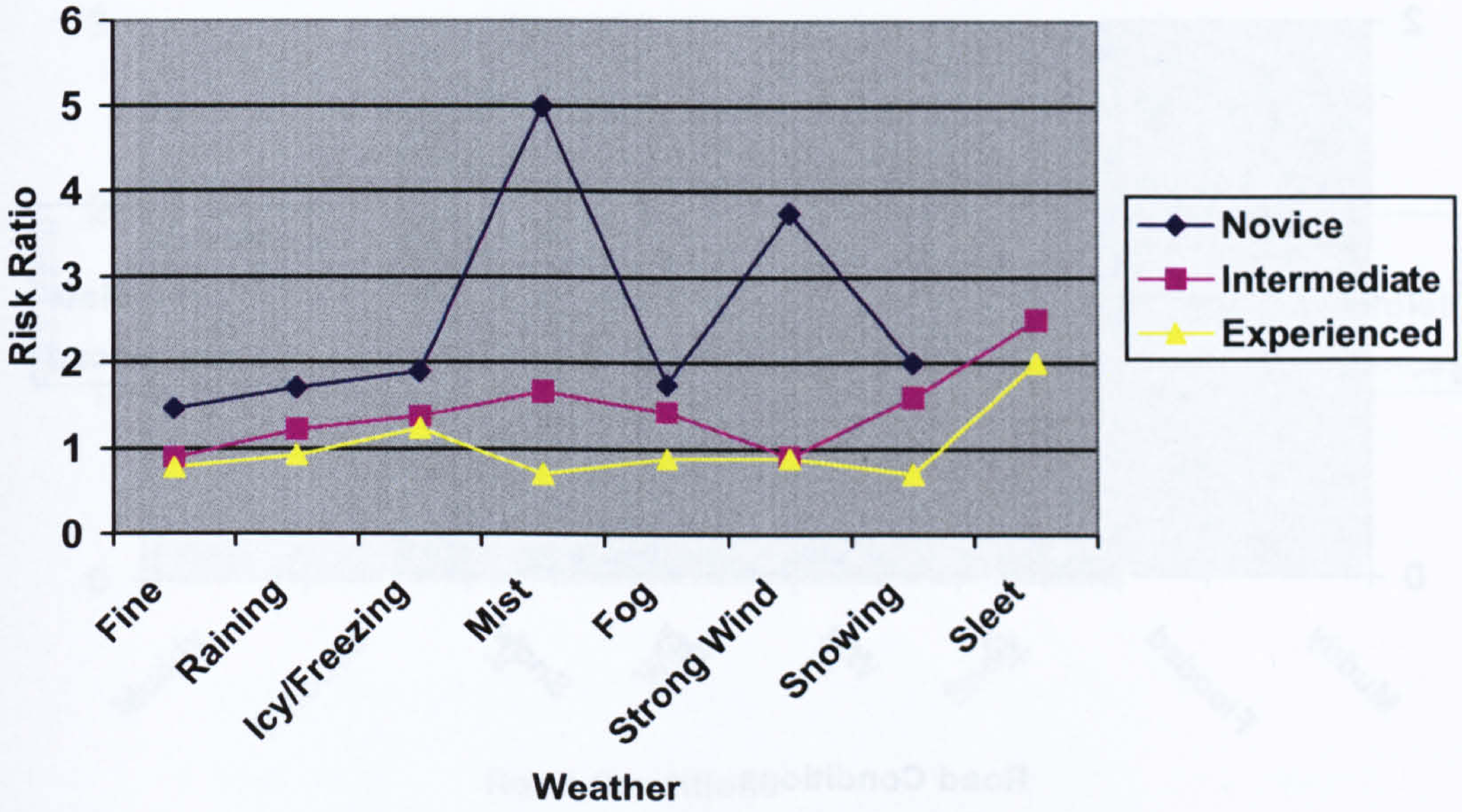


Figure 16 **All Responsible Risk Ratios in Different Weather Conditions**

Figure 16 shows all responsible risk ratios for crashes in different types of weather. The All responsible risk ratios exceed 1.0 for novice bus drivers in all weather conditions. In sleet, novice bus drivers are responsible for all crashes. For intermediately experienced bus drivers, the risk ratio exceeds 1.0 when it is raining, in fog, mist, snow, sleet and when it is freezing or icy and is below 1.0 when it is fine and in strong winds. For experienced bus drivers, the risk ratio exceeds 1.0 in sleet and icy or freezing weather conditions and is below 1.0 for all other weather conditions.
Chi2 tests did not reveal any significant differences between groups.

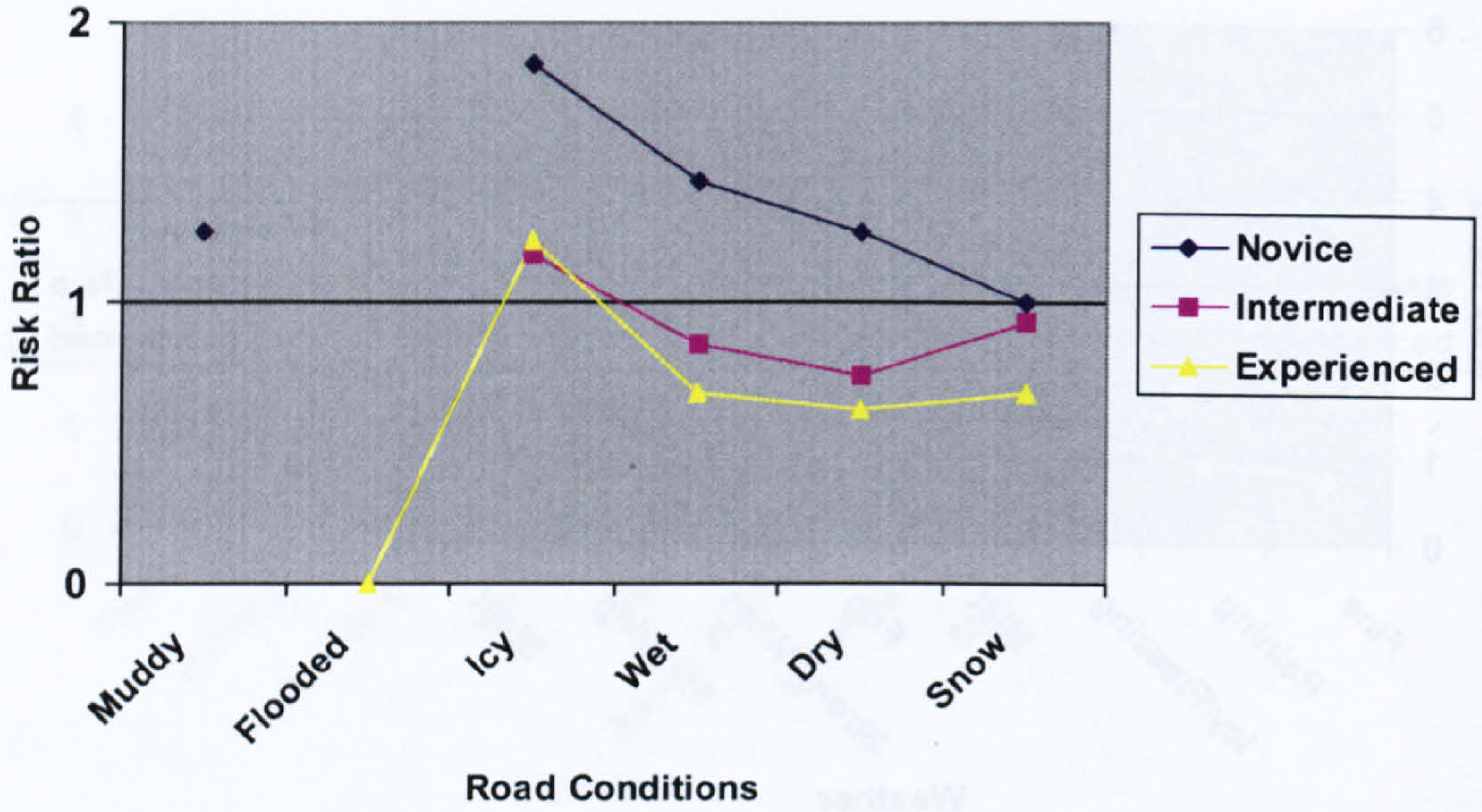


Figure 17 **Solely Responsible Risk Ratios for Different Road Conditions**

Figure 17 shows that the risk ratios for solely responsible crashes exceed 1.0 in most road conditions for novice bus drivers, but the risk is highest when roads are flooded and muddy. Risk ratios could not be calculated for these conditions because novice bus drivers are responsible for all crashes. The exception is when there is snow on the road in which case the risk ratio is equal to 1.0 indicating that there is an equal chance of another road user being solely responsible for crashes. Risk ratios exceed 1.0 for intermediately experienced bus drivers when the road is flooded, muddy and icy. The risk is highest on flooded and muddy roads. Risk ratios could not be calculated for these conditions because intermediately experienced bus drivers are responsible for all crashes. For experienced bus drivers, risk ratios exceed 1.0 only when it is muddy and icy. They are responsible for all crashes when it is muddy.

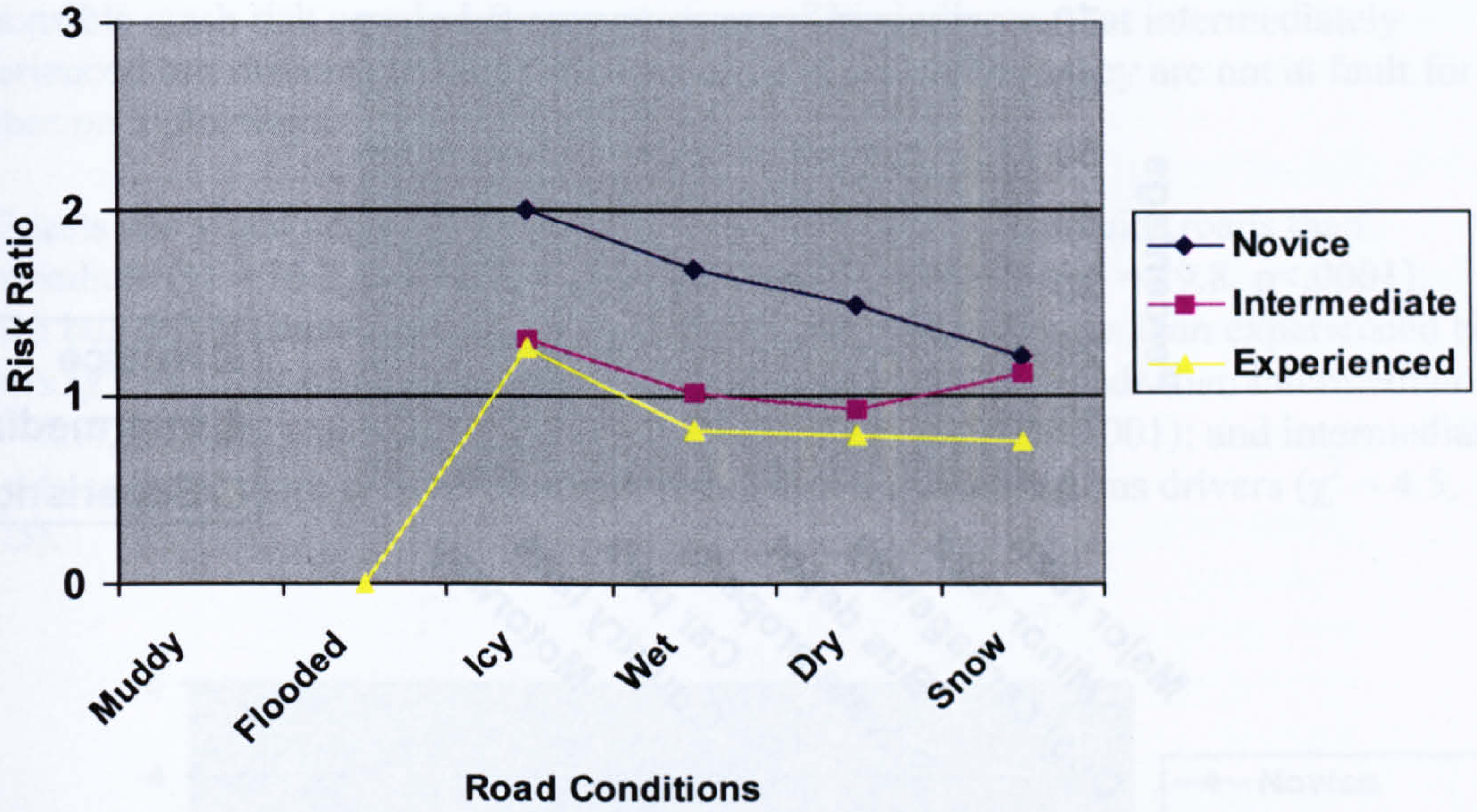


Figure 18 All responsible Risk Ratios for Crashes for Different Road Conditions

Figure 18 shows All responsibility risk ratios for crashes in different road conditions. The All responsible risk ratios for crashes exceeds 1.0 in all road conditions for novice bus drivers and cannot be calculated for muddy and flooded conditions because they are responsible for all crashes. For intermediately experienced bus drivers the risk exceeds 1.0 for most road conditions, except for when the roads are dry. For experienced bus drivers, risk ratios exceed 1.0 when the roads are icy and cannot be calculated when the road is muddy because they are responsible for all crashes. Risk ratios are below 1.0 in all other road conditions.
Chi2 tests did not reveal any significant differences between groups.

5.6.5.2 Collision Risk on Different Types of Road

Table 14 and figure 19 both show that the majority of crashes occur on major roads, minor roads, dual carriageways and in bus depots for all bus drivers. Thereafter there are differences for drivers in different LOS categories. For novice bus drivers this is followed by crashes on private property, in car parks and along country lanes and on motorways. For intermediately experienced bus drivers, crashes in bus depots are followed by private property, country lanes and car parks but no crashes occurred on motorways. For experienced bus drivers, after bus depots most crashes occurred on car parks, private property, country lanes and the fewest on motorways.

Table 14 Percentage of Crashes by Road Type and Length of Service

Service Length	Major road	Minor road	Dual carriageway	Bus depot	Private property	Car park	Country lane	Motorway
Novice	51.4	31.0	6.2	8.4	1.1	0.7	1.1	0.1
Intermediate	61.4	22.0	7.2	7.3	0.7	0.5	0.7	0.2
Experienced	62.9	19.7	7.7	7.7	0.7	0.2	0.9	0.1

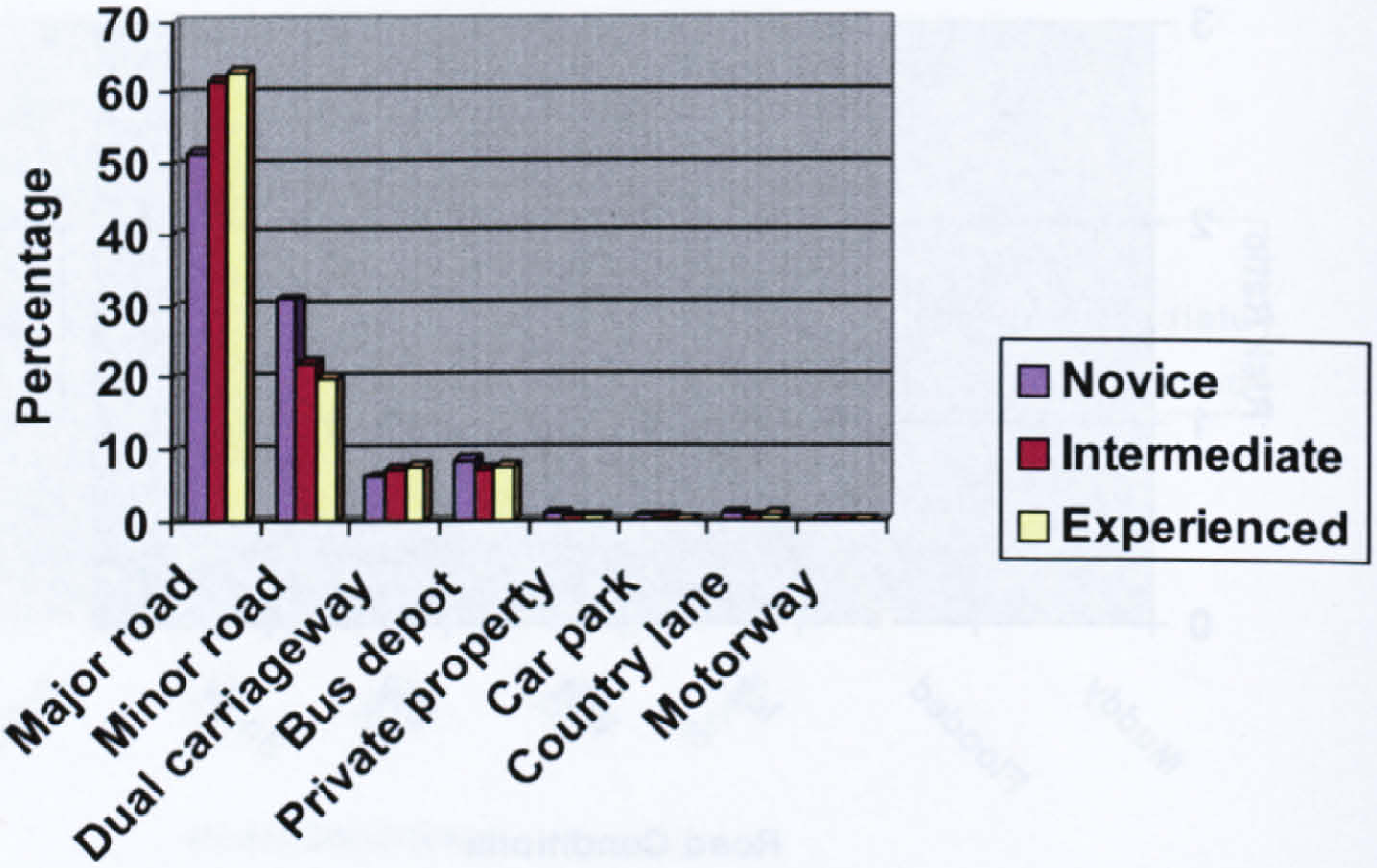


Figure 19 **Percentage of Crashes by Road Type**

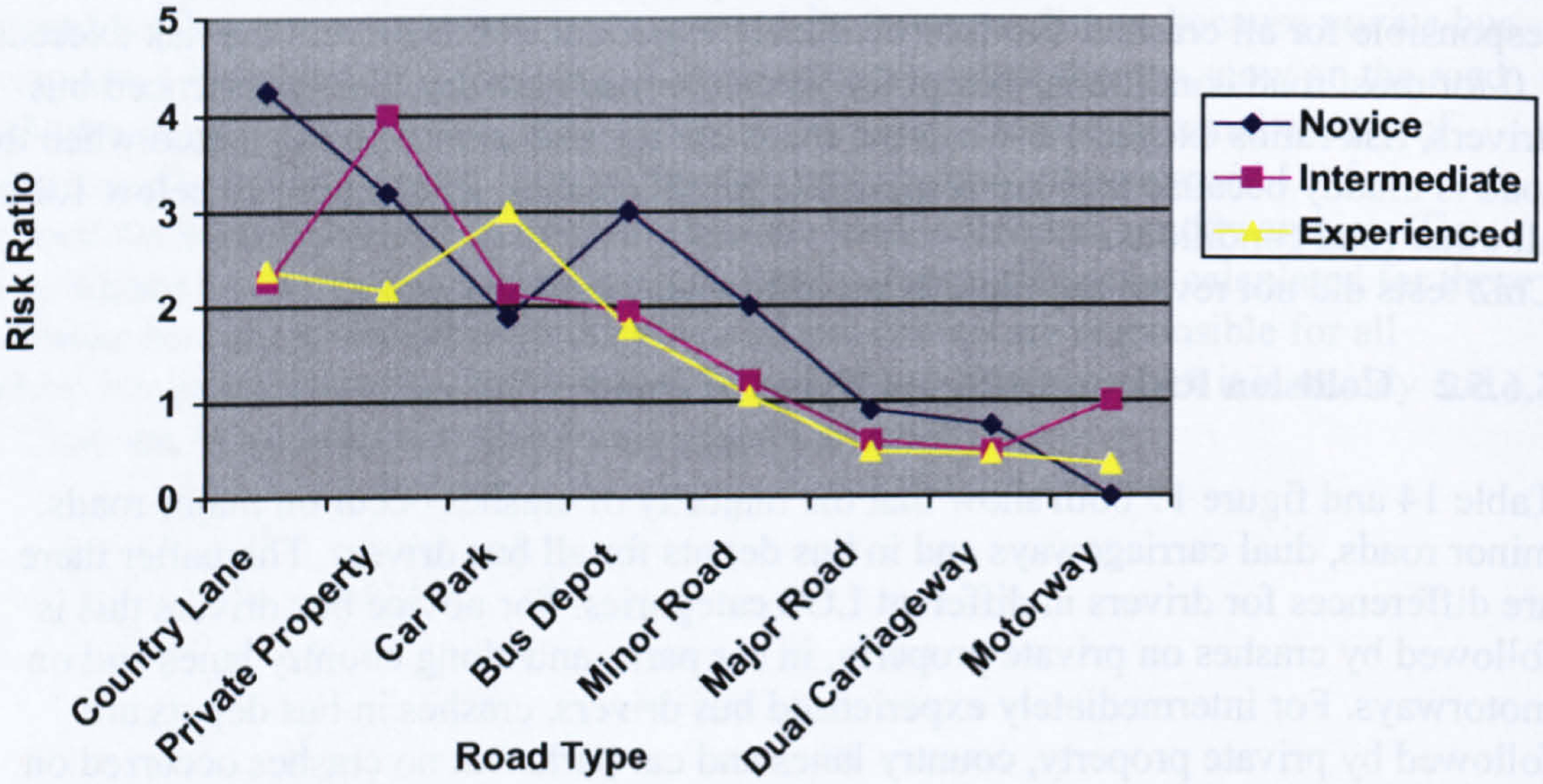


Figure 20 **Solely Responsible Crash Risk on Different Types of Road**

Figure 20 shows that the risk ratio for solely responsible crashes does not exceed 1.0 for any LOS category on major roads and dual carriageways indicating that drivers are most likely to be not at fault. Solely responsible crash risk exceeds 1.0 for crashes on minor roads, in bus depots, on private property, car parks, and along country lanes for all LOS categories, indicating that on these roads bus drivers are likely to be to blame for the crashes they are involved in. For intermediately experienced bus drivers, solely responsible crash risk equals 1.0 on motorways. This indicates that intermediately experienced bus drivers are likely to be just as often at fault as they are not at fault for crashes on motorways.

Chi2 tests show that novices bus drivers have more crashes on major roads than intermediate ($\chi^2 = 16.2, \rho<.0001$) and experienced bus drivers ($\chi^2 = 29.8, p<.0001$); novice bus drivers have more sole responsible crashes in car parks than experienced bus drivers ($\chi^2 = 8.2, \rho<.01$); novices have more crashes on minor roads than intermediate ($\chi^2 = 22.4, \rho<.0001$) and experienced bus drivers ($\chi^2 = 44.4, p<.0001$); and intermediate bus drivers have more crashes on minor roads than experienced bus drivers ($\chi^2 = 4.5, \rho<.05$).

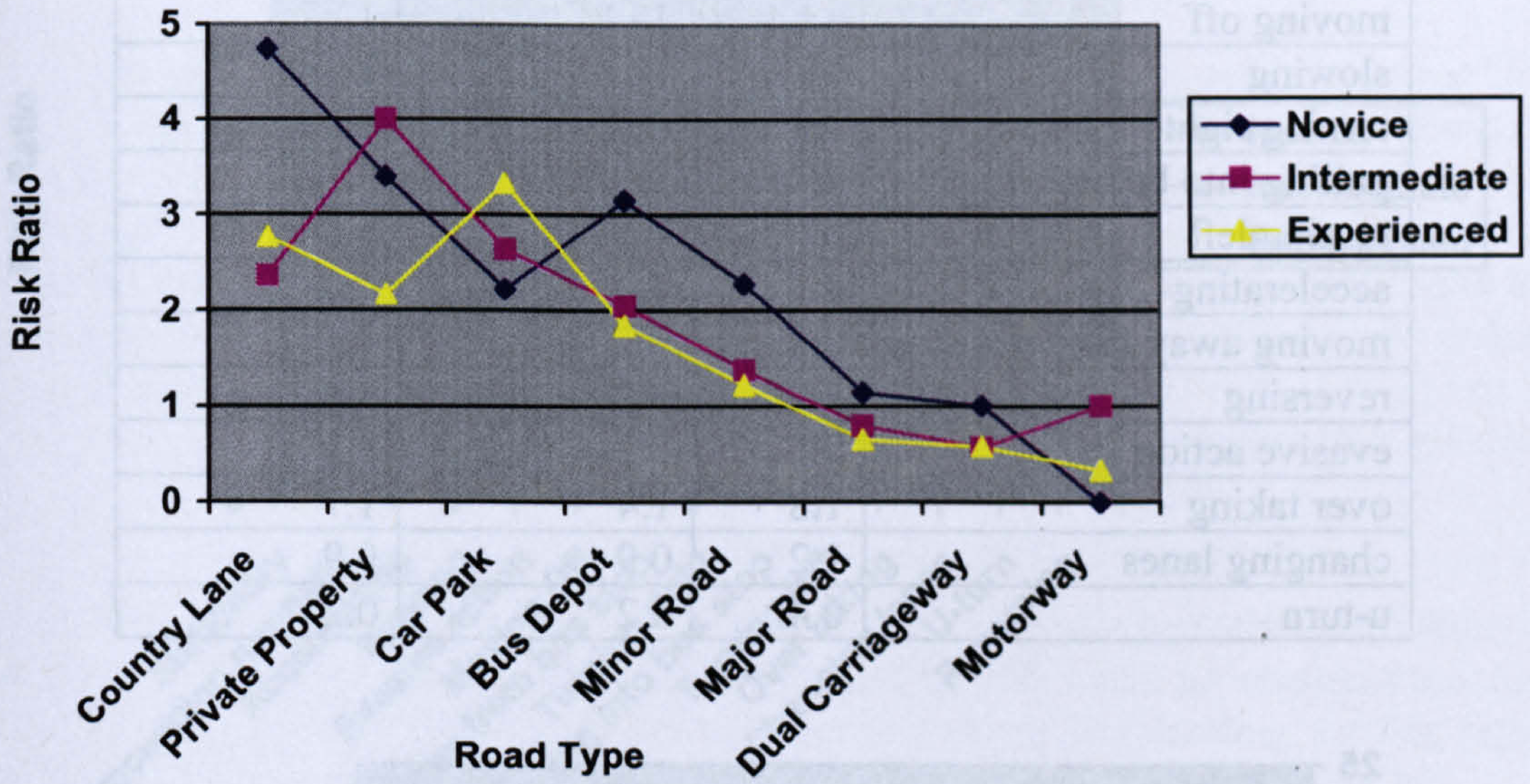


Figure 21 All Responsible Crash Risk on Different Road Types

Figure 21 shows that all responsible risk ratios exceed 1.0 on minor roads, in bus depots, on private property, car parks, and along country lanes for all LOS categories. This means that drivers are likely to contribute to the cause of crashes on these roads. For novice bus drivers, all responsible risk ratios exceed 1.0 on major roads and dual carriageways also indicating that their actions are likely to contribute to crashes on these roads. All responsible crash risk equals 1.0 for crashes on motorways for intermediately experienced bus drivers meaning that there is an equal chance that they may contribute to crashes on motorways.

Chi2 tests show that novices bus drivers have more crashes on major roads than intermediate ($\chi^2 = 28.12, \rho<.0001$) and experienced bus drivers ($\chi^2 = 24.8, p<.0001$); intermediate bus drivers have more all responsible crashes on motorways than novice bus drivers ($\chi^2 = 4.8, \rho<.05$); novices have more crashes on minor roads than intermediate ($\chi^2 = 38.0, \rho<.0001$) and experienced bus drivers ($\chi^2 = 33.4, p<.0001$); and novice bus drivers have more crashes on dual carriageways than experienced bus drivers ($\chi^2 = 6.4, \rho < .05$).

5.6.5.3 Manoeuvre at Time of Crash

Table 15 shows the kinds of manoeuvres performed at the time of the crash in order of their proportion relative to all other kinds of manoeuvres performed.

Table 15 **Percentage of All Crashes by Manoeuvre and Length of Service**

Manoeuvre	Novice	Intermediate	Experienced
stationary	17.2	20.1	22.1
proceeding normally	14.6	19.7	19.3
moving off	14.4	13.7	13.7
slowing	13.2	12.6	11.6
turning right	10.3	7.2	6.6
pulling into bus stop	7.3	5.9	5.1
turning left	6	4.6	5.0
accelerating	3.5	4.4	5.0
moving away from bus stop	3.8	3.7	3.1
reversing	3.9	3.2	3.4
evasive action	2.4	2.2	2.2
over taking	1.8	1.4	1.7
changing lanes	1.2	0.9	0.9
u-turn	0.4	0.2	0.2

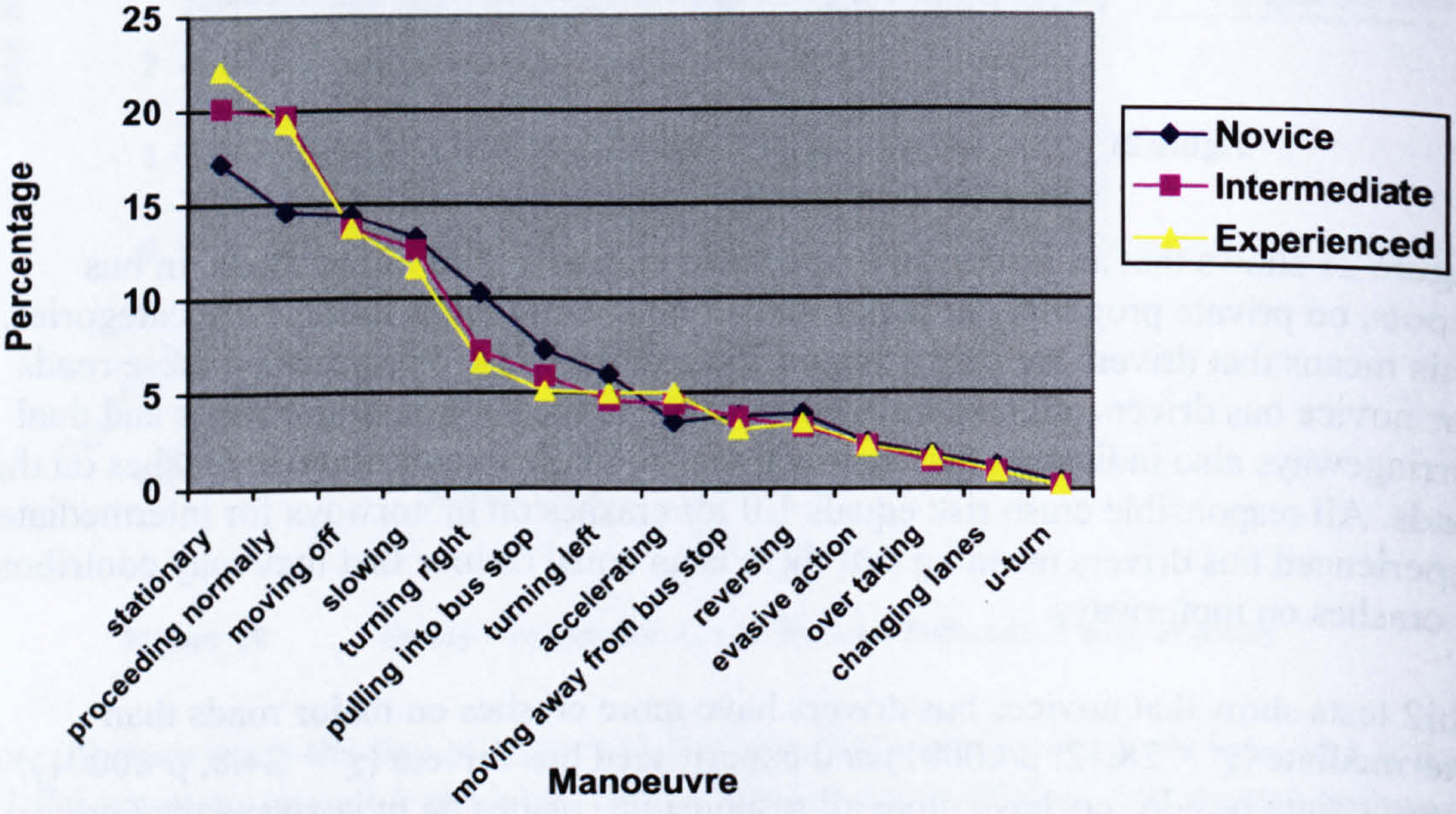


Figure 22 **Percentage of Manoeuvres Preceding the Crash**

Figure 22 illustrates that the pattern of manoeuvres at the time of a crash is similar across all LOS categories with the possible exception of being stationary at the time of the crash and proceeding normally for which novice bus drivers appear to be under represented compared with more experienced drivers.

Bus drivers were most often stationary, proceeding normally, moving off from a stationary position or slowing down at the time of the incident. To a lesser extent turning right and pulling into bus stops posed a problem, as did turning left for novices. Accelerating and pulling away from bus stops, reversing, taking evasive action, overtaking, changing lanes and making U-turns were reported less often.

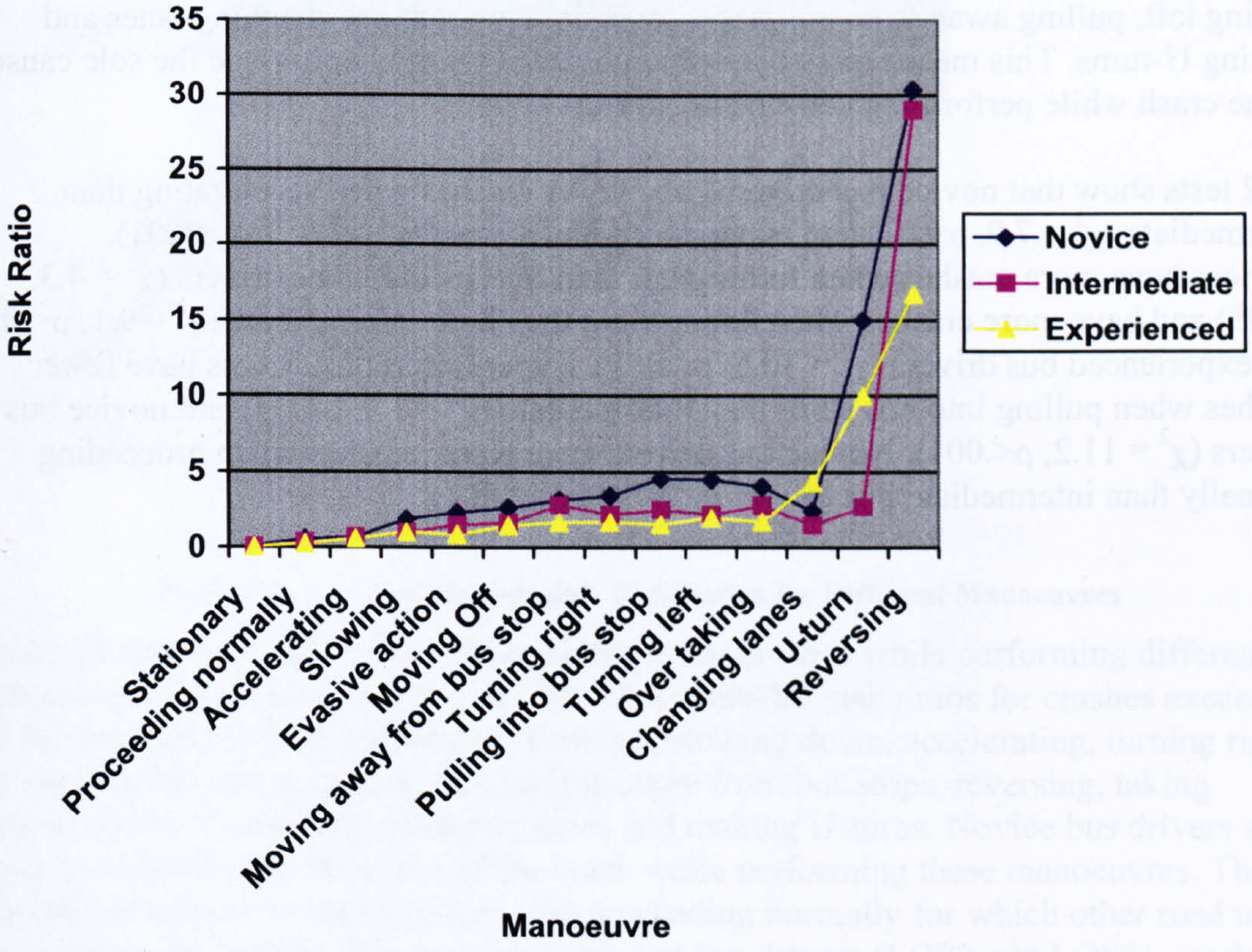


Figure 23 **Solely Responsible Crash Risk for Different Manoeuvres**

Figure 23 shows the risk of being solely responsible for crashes while performing different manoeuvres. For novice bus drivers the risk of being solely responsible and All responsible for crashes exceeds 1.0 for moving off from a stationary position, slowing down, turning right, pulling into bus stops, turning left, pulling away from bus stops, reversing, taking evasive action, overtaking, changing lanes and making U-turns. This indicates that while performing these manoeuvres, novice bus drivers are likely to be solely to blame for the cause of crashes. Risks are highest when reversing, performing a U-turn, pulling into bus stops and turning left.

The risk ratio is below 1.0 for stationary, proceeding normally and accelerating, which indicates that crashes that occur while performing these manoeuvres are likely to be the fault of another road user.

For intermediately experienced bus drivers, crash risk exceeds 1.0 for moving off from a stationary position, turning right, pulling into bus stops, turning left, pulling away from bus stops, reversing, taking evasive action, overtaking, changing lanes and making U-turns. This means that they are likely to be the sole cause of the crash. Crash risk ratios are below 1.0 for stationary, proceeding normally, accelerating and slowing down which indicates that another road user is more likely to be the sole cause of the crash. For experienced drivers, crash risk is below 1.0 for stationary, proceeding normally, accelerating, and taking evasive action, which indicates that another road user is likely to cause the crash. Risk ratios equal 1.0 for crashes when slowing down which shows for this manoeuvre, bus drivers have the same chance as other road users for being to blame. Crash risk exceeds 1.0 for moving off, turning right, pulling into bus stops, turning left, pulling away from bus stops, reversing, overtaking, changing lanes and making U-turns. This means that experienced bus drivers are likely to be the sole cause of the crash while performing these manoeuvres.

Chi2 tests show that novice bus drivers have fewer crashes when accelerating than intermediate ($\chi^2 = 7.9$, $\rho=.01$) and experienced bus drivers ($\chi^2 = 13.3$, $\rho=.0001$). Novices have more crashes when turning left than intermediate bus drivers ($\chi^2 = 4.3$, $\rho<.05$) and have more crashes when tuning right than both intermediate ($\chi^2 = 9.1$, $\rho<.05$) and experienced bus drivers ($\chi^2 = 10.5$, $\rho<.001$). Experienced bus drivers have fewer crashes when pulling into bus stops than intermediate ($\chi^2 = 3.9$, $\rho<.05$) and novice bus drivers ($\chi^2 = 11.2$, $\rho<.001$). Novice bus drivers have fewer crashes when proceeding normally than intermediate bus drivers ($\chi^2 = 10.5$, $\rho<.001$)

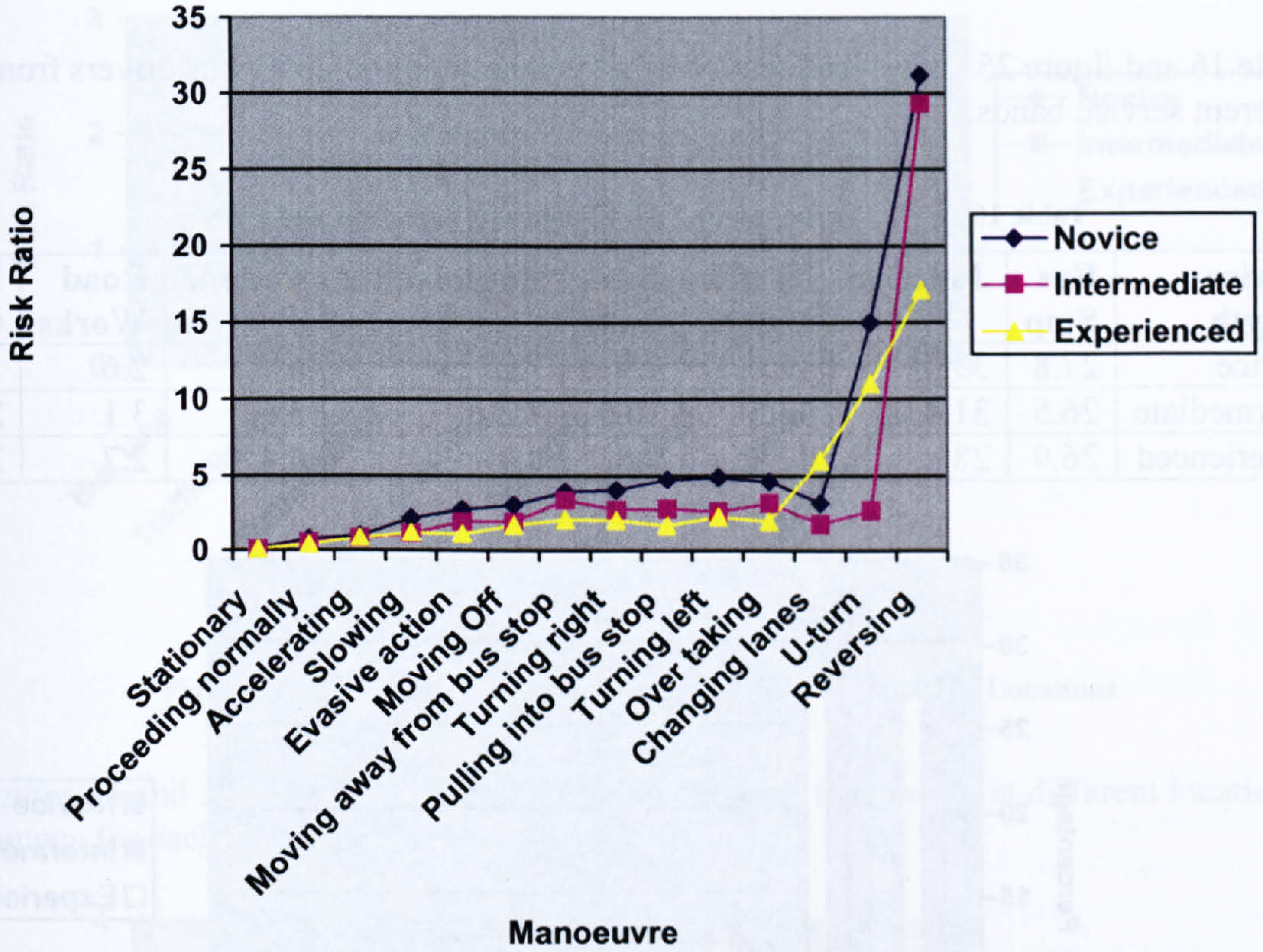


Figure 24 All Responsible Risk Ratios for Different Manoeuvres

Figure 24 shows the All responsible risk ratios for crashes while performing different manoeuvres. For novice bus drivers, the All responsible risk ratios for crashes exceeds 1.0 for moving off from a stationary position, slowing down, accelerating, turning right, pulling into bus stops, turning left, pulling away from bus stops, reversing, taking evasive action, overtaking, changing lanes and making U-turns. Novice bus drivers are likely to contribute to the cause of the crash while performing these manoeuvres. The risk ratio is below 1.0 for stationary and proceeding normally for which other road users are to blame for crashes. For more experienced bus drivers (LOS2 and LOS3), crash risk exceeds 1.0 for moving off from a stationary position, slowing, turning right, pulling into bus stops, turning left, pulling away from bus stops, reversing, taking evasive action, overtaking, changing lanes and making U-turns. This shows they are likely to contribute to the cause of the crash. Risk ratios are below 1.0 for stationary, proceeding normally and accelerating, which indicates that other road users are likely to be at fault.

Chi2 tests revealed that experienced bus drivers had fewer all responsible crashes than intermediate ($\chi^2 = 16.2$, $\rho < .01$) and novice bus drivers ($\chi^2 = 42.4$, $\rho < .001$) while stationary. Novice bus drivers had more all responsible crashes than intermediate bus drivers while stationary ($\chi^2 = 9.6$, $\rho < .05$). Experienced bus drivers had more all responsible crashes when slowing than intermediate ($\chi^2 = 7.7$, $\rho < .01$) and novice bus drivers ($\chi^2 = 10.9$, $\rho < .001$), and had more all responsible crashes when moving off than intermediate ($\chi^2 = 3.9$, $\rho < .05$) and novice bus drivers ($\chi^2 = 5.4$, $\rho < .05$).

5.6.5.4 Location at Time of Crash

Table 16 and figure 25 shows the location of all crashes committed by bus drivers from different service bands.

Table 16 **Percentage of All Crashes by Location and LOS**

Service Length	Bus Stop	Junction	Traffic Lights	Bus Lane	Roundabout	Pothole	Road Works	Pedestrian Crossing
Novice	27.8	33.0	12.0	9.9	7.2	6	2.6	1.5
Intermediate	26.5	31.4	13.5	10.6	7.2	5.6	3.1	2.2
Experienced	26.9	28	13.1	9.6	8.4	6.4	2.7	2

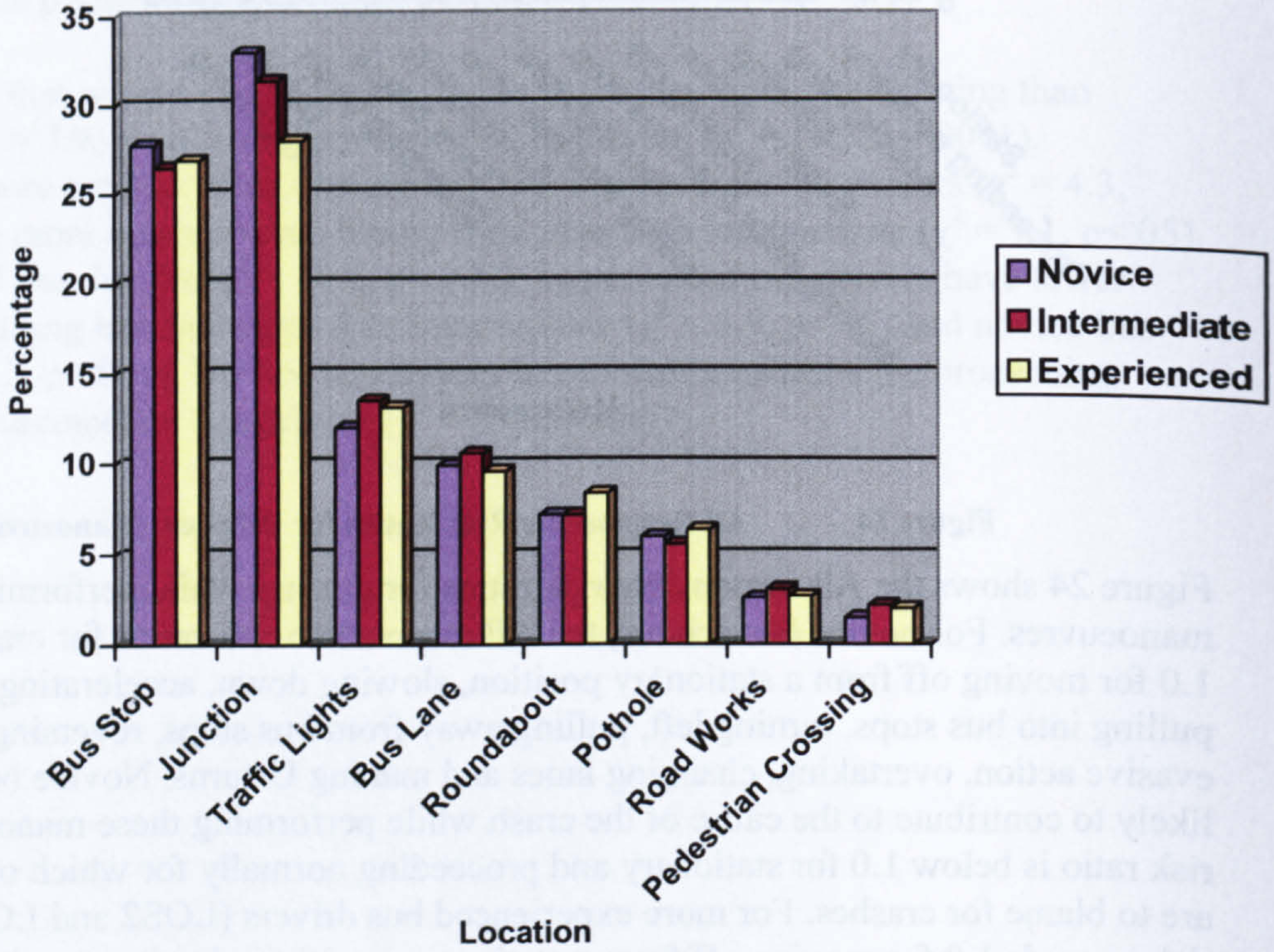


Figure 25 **Percentages of All Crashes by Location**

For all bus drivers, most crashes occur at bus stops, junctions, traffic lights and in bus lanes. This is followed by crashes at roundabouts, potholes, road works then pedestrian crossings. The same pattern is seen in drivers of all LOS categories.

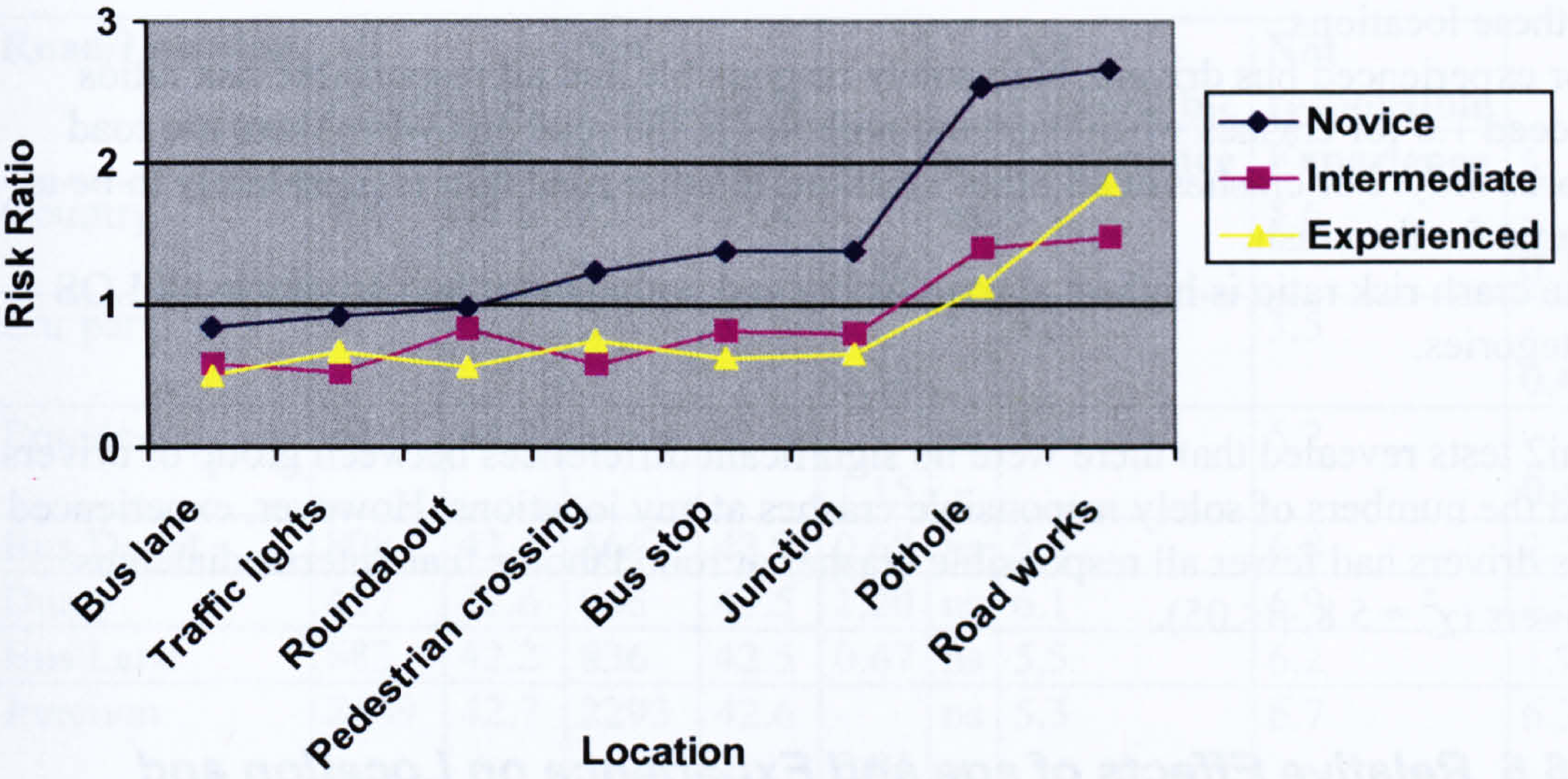


Figure 26 Solely Responsible Risk Ratios at Different Locations

Figures 26 and 27 show how the risk of being culpable for crashes at different locations changes for each LOS category.

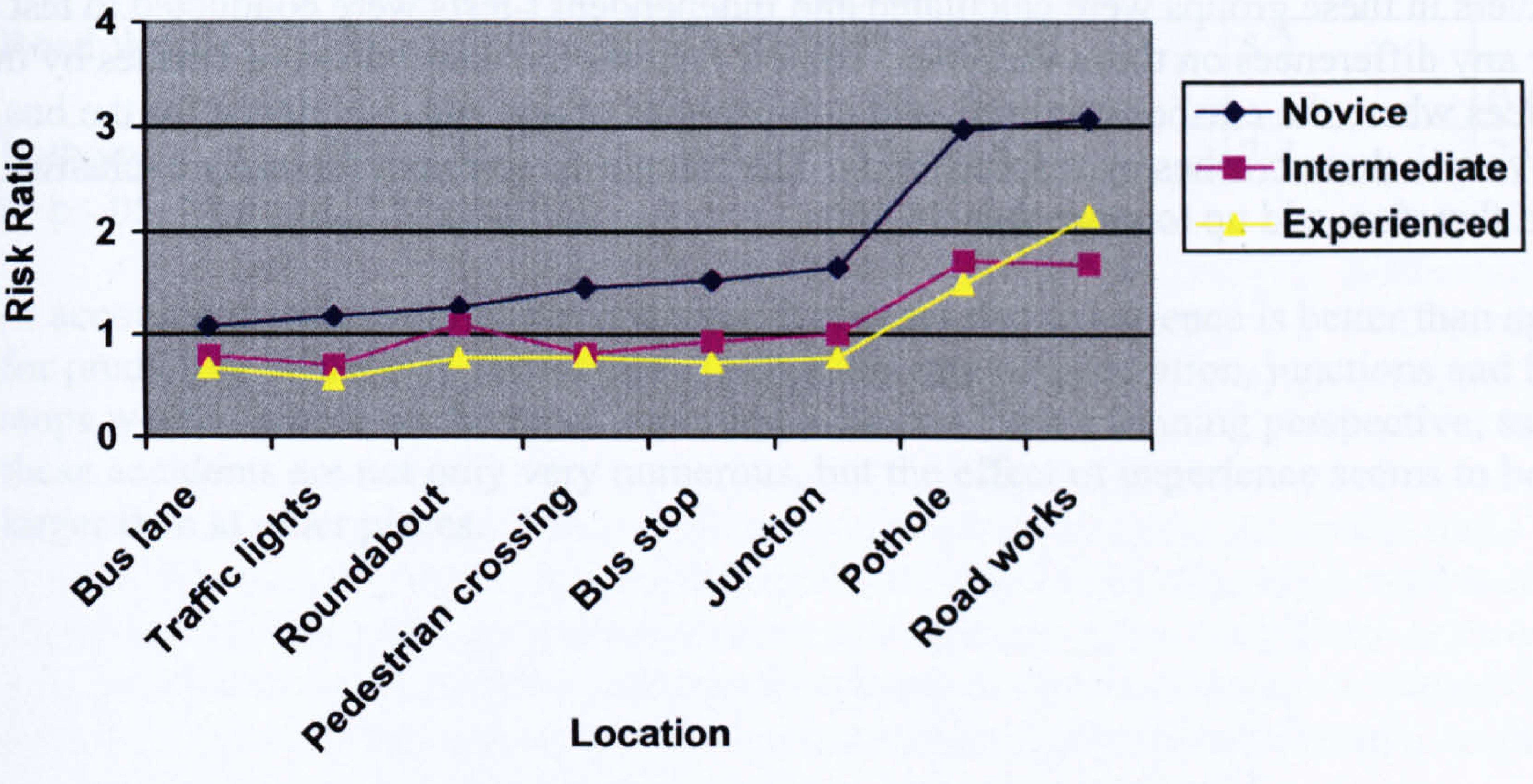


Figure 27 All Responsible Risk Ratios at Different Locations

The all responsible risk ratios exceed 1.0 at every location for novice bus drivers. This means that they are likely to contribute to the cause of crashes at these locations. Furthermore, since the risk ratio for being solely responsible for crashes exceeds 1.0 for bus stops, junctions, pedestrian crossings, road works and potholes, at these locations they are most likely to be solely to blame for the crash.

The risk ratio for solely responsible crashes exceeds 1.0 for intermediately experienced bus drivers when there are potholes in the road and when there are road works only and the risk ratio for All responsible crashes exceeds 1.0 at junctions, roundabouts, potholes

and road works which means that they are likely to contribute to the cause of the crash at these locations.
For experienced bus drivers, both solely responsible and all responsible risk ratios exceed 1.0 for crashes when there are potholes in the road and when there are road works only. For crashes at all other locations another road user is most likely to be to blame for the crash.
The crash risk ratio is highest at road works and potholes for bus drivers in all LOS categories.

Chi2 tests revealed that there were no significant differences between group of drivers and the numbers of solely responsible crashes at any locations. However, experienced bus drivers had fewer all responsible crashes at roundabouts than intermediate bus drivers ($\chi^2 = 5.8$, $p<.05$).

5.6.6 Relative Effects of age and Experience on Location and Manoeuvre at Time of Crash

To examine the effects of age and experience on location and manoeuvre, crashes were divided into groups depending on the road type, location, manoeuvre and responsibility (All responsible and Not responsible). The mean age and mean experience for the drivers in these groups were calculated and independent t-tests were conducted to test for any differences on these variables. Table 17 shows the distribution of crashes by the places where the crashes occurred, and comparisons of age and experience for the bus drivers in these crashes by responsibility. The categories were not mutually exclusive, and therefore add up to more than 15 100.

Table 17 **Differences in Age and Experience by Road Type and Location**

Road/Location	All responsible		Not responsible				All responsible	Not responsible		
	N	Age	N	Age	t	p	Experience	Experience	t	p
Country	100	44.6	32	43.4	-0.50	ns	6.1	5.6	-0.35	ns
Car park	51	42.4	20	35.5	-2.50	*	4.3	3.5	-0.48	ns
Private	92	44.2	30	41.3	-1.15	ns	5.5	5.2	-0.15	ns
Bus Depot	808	43.4	364	43.9	0.69	ns	5.8	6.8	2.16	*
Dual	427	42.6	645	43.5	1.20	ns	6.1	6.9	1.57	ns
Bus Lane	683	42.2	836	42.5	0.67	ns	5.5	6.2	1.98	*
Junction	2489	42.7	2293	42.6	-0.01	ns	5.3	6.7	6.29	***
Roundabout	573	42.9	577	43.3	0.53	ns	6.2	6.7	1.17	ns
Traffic Lights	862	42.1	1089	42.3	0.41	ns	5.7	6.5	2.36	*
Pedestrian Crossing	138	40.9	152	42.7	1.40	ns	5.2	6.5	1.68	ns
Bus Stop	2028	43.3	2048	43.1	-0.56	ns	5.3	6.9	6.76	***
Road Works	291	43.0	138	43.9	0.73	ns	5.8	5.3	-0.69	ns
Pothole	588	43.6	315	44.6	1.37	ns	5.8	7.4	2.98	**

(* p<.05, ** p<.01, *** p<.001)

In accordance with the previous analyses, it appears that experience is better than age for predicting culpability for crashes. Taking this into consideration, junctions and bus stops would seem to be the most important locations from a training perspective, as these accidents are not only very numerous, but the effect of experience seems to be larger than at other places.

Table 18 shows the results for age and experience of the bus drivers who performed different manoeuvres before being involved in a crash. Crashes are categorized according to responsibility.

Table 18 . Differences in Age and Experience for Manoeuvre

Manoeuvre	**All responsible**		**Not responsible**				**All responsible**	**Not responsible**		
	N	Age	N	Age	t	p	Experience	Experience	t	p
Stationary	291	41.7	2737	42.8	1.77	ns	5.7	6.7	2.01	*
Slowing	1095	42.5	779	43.0	0.88	ns	5.3	6.1	2.23	*
Accelerating	312	41.9	344	42.5	0.68	ns	6.2	7.1	1.46	ns
Reversing	503	44.1	21	45.6	0.60	ns	6.1	8.1	1.12	ns
Moving off	1421	42.7	681	42.8	0.27	ns	5.7	6.4	1.98	*
Turning left	579	43.5	196	43.9	0.35	ns	5.9	7.2	1.95	ns
Turning right	876	42.6	310	43.6	1.35	ns	5.0	6.4	2.87	**
Proceeding normally	964	42.3	1773	42.6	0.65	ns	5.5	6.7	3.94	***
Changing lanes	114	43.2	38	41.4	-0.95	ns	5.5	3.6	-1.59	ns
Over taking	181	44.2	63	45.1	0.56	ns	6.2	8.1	1.66	ns
U-turn	34	40.3	5	32.8	-1.30	ns	5.6	8.9	0.79	ns
Evasive action	219	43.1	125	43.8	0.54	ns	5.1	8.3	3.73	***
Pulling into bus stop	666	43.6	243	43.7	0.22	ns	4.9	7.4	4.33	***
Moving away from bus stop	397	42.3	133	42.1	-0.16	ns	5.0	7.0	2.84	**

(* p<.05, ** p<.01, *** p<.001)

When culpability was taken into account, pulling into bus stops seems to be the manoeuvre where experience had the largest effect, followed by taking evasive action and proceeding normally. Again, there were no differences in the ages of bus drivers who were responsible or not responsible for crashes while performing different manoeuvres, indicating that age was not as important as experience.

5.7 Discussion

5.7.1 Effect of Age and Length of Service on Crash Risk

In line with previous research (e.g. Stamatiadis and Deacon, 1995) the results show that culpability risk is attributable to age-related factors, with younger bus drivers having a higher risk than older bus drivers. Middle-aged bus drivers are less likely to be responsible for crashes when compared with the youngest and oldest bus drivers, which is consistent with research by Shephard, Price and Hughes (1988) who also showed that middle-aged bus drivers were safe in comparison to younger and older drivers. Other researchers who used this method to calculate risk also found similar (but not identical) patterns of risk ratios among the youngest and oldest car drivers (Cooper, 1990; Lyles, Stamatiadis and Lighthizer, 1991; McGwin and Brown, 1999; and Stamatiadis and Deacon, 1997). The results are also consistent with researchers who used other statistical methods, such as Kim, Li, Richardson and Nitz, (1998) who used log-linear modelling to determine the probability of at-fault collisions in Hawiian drivers, and found that very old and very young drivers faced up to three times the risk of being at fault compared to middle-aged drivers. In this sample of bus drivers, drivers in their first year of service are most at risk of being involved in the cause of bus crashes. This pattern was also observed by Cooper, Pinili and Chen (1995), who found greater crash rates for at fault accidents and lower crash rates for not at fault accidents in car drivers in their first year after obtaining their licence. Bus drivers in their first year are likely to be responsible for collisions due to their lack of experience in traffic. The risk of being All to blame for a collision, although greatly reduced, still persists during the bus drivers second year of service suggesting that, while they have the benefit of one years' experience, they are still building the skills that enable them to interpret the actions of other road users. As the driver builds up their experience in traffic, they become more aware of the hazards associated with bus driving and learn the techniques that are appropriate to deal with them and so are responsible for fewer accidents. In this study, experienced bus drivers who have developed a procedural understanding of the bus driving task (Anderson, 1983) are less likely to be involved in the cause of a crash. This is consistent with other researchers who also found that bus accident risk decreased with experience (Blom, Pokorny and van Leeuwen, 1987; Wåhlberg, 2005), and with Hamed, Jaradat and Easa (1998), who found that accident risk in Jordan's commercial mini-bus driver's decreases with increased experience and attributed this to better awareness of routes and the acquisition of less risky driving habits.

Consistent with previous research (Sagberg, 1998; Mayhew, Simpson and Pak, 2003), this study shows that some of the decline in crash risk in the first few years of bus driving experience is attributable to age-related factors. The results show that crash risk is lowest for older novice bus drivers than middle aged and younger novice bus drivers, but then the risk for older and younger bus drivers increases with length of service but declines for middle-aged drivers. There is also an effect of age on the rate of decline in middle aged bus drivers (36-50), with drivers in the upper age bracket (46-50) showing greater reduction in risk over the first three years than drivers in the lower age bracket (36-40). This effect may be due to greater risk taking in younger bus drivers. However, some of the decline is also attributable to experience, which is shown in the analysis of the month-to-month crash risk by the steep decline in crash risk over the first six months of driving. Overall crash risk is relatively low in the first month when drivers are supervised by more experienced drivers. Probably because experience gained under supervision reduces the risk of being involved in a crash (Gregersen, Nyberg and Berg, 2004). Those in their second month have the greatest predisposition towards responsibility for accidents. At this time the period of confidence building with a mentor driver is over and novices have sole responsibility for passengers in addition to coping with the demands of traffic and working to a bus schedule. Crash risk is particularly high at this period as they consolidate their new bus driving skills. This effect is also found in novice pilots who take more risks while they are learning to fly because they have poor mental models of the operational environment (Amalberti and Wibaux, 1995). After six months, novices are less likely to be the sole cause of a crash; however beyond six months the risk increases again. Then after ten months novices are less likely to be the sole cause of a crash but are still more likely to be partly to blame. Blom, Pokorny and van Leeuwen (1987) and Wåhlberg (2005) also showed a steeper decline in accident risk in the first few years of service. Like novice car drivers (Forsyth, Maycock and Sexton, 1995; West, 1998), a decrease in accident risk is seen over the first three years of bus driving, perhaps in part because more experienced bus drivers have improved hazard perception skills (McKenna and Crick, 1991) and have better control over their vehicle.

Pearson's correlations were conducted to evaluate the relative contribution of age and experience on risk of culpability. Crash risk was split into three types: Solely responsible, not responsible and partly responsible. The results of the correlation show that for solely and partly responsible crashes, length of service is negatively correlated showing that bus drivers have fewer accidents as their length of service increases. This means that novice bus drivers are involved in more crashes and are likely to be responsible for the crashes they are involved in. On the other hand, not responsible crashes are negatively correlated with length of service showing that drivers with longer service length are involved in more crashes than are the fault of another road user. The results of the correlation analysis triangulate the conclusions drawn from the risk ratio calculations and t-tests between bus drivers' experience and age at the time of the crash, i.e. that experience is the greatest predictor of culpability in bus crashes. In this population of bus drivers then, it is experience rather than age that contributes most to the accident problem. These results are also consistent with Wahlberg (2005) who also found that experience was relatively more important in predicting the frequency of bus accidents in a Swedish bus company, although the effect was weak. The same holds true for novice car drivers. In drivers aged 16-55, experience is more important than age as a factor in accident rates (Cooper, Pinili and Chen, 1995). Other researchers have shown that in younger novice car drivers, the benefit of one years extra experience contributes more strongly to reducing risk than one extra year of age (Forsyth, Maycock and Sexton, 1995; Maycock, Lockwood and Lester, 1991). In this sample of bus drivers, the effect sizes in terms of real world effects are extremely small indicating that other factors are involved in the frequency of bus crashes. However, this effect is still very real given the high volume of accidents that bus drivers are involved in.

It should be noted that novice car drivers and novice bus drivers cannot be directly compared because bus drivers differ markedly from the general population of car drivers. Firstly, novice car drivers are typically young (16-19 years) however there is a considerable variation in the age of novice bus drivers so it cannot be assumed that novice bus drivers have the same issues as novice car drivers. In addition to this, even the most experienced bus drivers retire before they are 65 so it is not clear whether experienced bus drivers will also have the same elevated crash frequencies due to age-related physical and cognitive declines. Secondly novice car drivers have had little or no experience in demanding traffic situations, but novice bus drivers have held car licences for a minimum of 3 years and so are already experienced road users. They then receive additional professional training. Thirdly, bus drivers have responsibility for passenger's lives, fourthly they drive a PCV which has different handling characteristics to a car, and finally their collisions are work related and therefore organisational constraints such as bus schedules are likely to have a strong influence on their crash risk.

5.7.2 Bus Accident Characteristics by Length of Service

Table 19 summarises the risk of being culpable for collisions when novice, intermediately experienced and experienced bus drivers (LOS1, LOS2 and LOS3) encounter various factors that may lead to collisions.

Table 19 Collision Factors with Risk Ratios that Exceed 1.0

Factor		LOS1	LOS2	LOS3
Weather Conditions	Fine	**		
	Rain	**	**	
	Icy	**	*	*
	Mist	**	**	
	Fog	**	**	
	Wind	**		
	Snow	**	**	
	Sleet	**	**	**
Road Conditions	Dry	**		
	Wet	**	*	
	Flooded	**	**	
	Muddy	**	**	**
	Icy	**	**	**
	Snow	**	*	
Road Type	Major	*		
	Minor	**	**	**
	Dual Carriageway	*		
	Bus Depot	**	**	**
	Private Property	**	**	**
	Car Park	**	**	**
	Country lane	**	**	**
	Motorway		**	

Location	Bus Stop	**		
	Junction	**	*	
	Traffic Lights	*		
	Bus Lane	*		
	Roundabout	*	*	
	Potholes	**	**	**
	Road Works	**	**	**
	Pedestrian Crossing	**		
Manoeuvre	Stationary			
	Proceeding Normally			
	Moving Off	**	**	**
	Slowing	**	*	**
	Turning Right	**	**	**
	Pulling into Bus Stop	**	**	**
	Turning Left	**	**	**
	Accelerating	*		
	Pulling Away from Bus Stop	**	**	**
	Reversing	**	**	**
	Evasive Action	**	**	*
	Overtaking	**	**	**
	Changing Lanes	**	**	**
	U-turn	**	**	**

** = Solely responsible and All responsible risk ratios exceed 1.0
* = All responsible risk ratio exceed 1.0

5.7.2.1 Road and Weather Conditions

The analysis shows that while the risk of crashes in good weather declines rapidly with experience, the risk of crashes in adverse weather takes longer to decline and in some severe conditions, the risk remains high even for bus drivers with many years of experience. To elaborate, novice bus drivers are likely to contribute to the cause of crashes in all weather and road conditions, but risk ratios are highest for collisions in conditions of low visibility such as sleet and mist and on flooded and muddy roads. Reduced visibility in these conditions makes it difficult to see unfolding hazards, such as pedestrians stepping off the pavement and other obstacles in the road ahead, especially since there is also evidence to suggest that scanning is reduced in non optimal conditions (Crundall, Chapman, Phelps and Underwood, 2003). The problem may then be further compounded by the fact that novice drivers do not scan the road as effectively as more experienced drivers (Brown, 1982; Crundall, Chapman, Phelps and Underwood, 2003). In addition to this, driving at inappropriately high speeds and tailgating the lights of the vehicle in front are common mistakes made while driving in fog. These behaviours may put bus drivers at increased risk of having an accident (Evans, 1991) because they have little time to react to any changes occurring in their immediate environment (Bailley, Bellet and Goupil, 2003). Crash risk is reduced in good weather and road conditions for intermediately experienced bus drivers, perhaps because of improved scanning and ability to detect and respond to hazards (Crundall, Chapman, Phelps and Underwood, 2003; McKenna and Crick, 1994), but crash risk is still high in adverse weather conditions, especially when visibility is reduced such as in mist, fog, snow, sleet and rain and when roads are flooded, muddy and icy. However, experienced bus drivers have a comparatively low risk in good and most adverse road and weather conditions, but still have a high risk in sleet and when the roads are icy or muddy, which may increase the difficulty of handling a large PCV. These results are concordant with Cooper (1990) and McGwin and Brown (1999), who also found that adverse weather was a less common cause of accidents in older car drivers. However, this was attributed to the fact that older drivers can avoid driving in bad weather, but this cannot be true of bus drivers who have to drive for a living in all weather conditions. The effect then may be due to an inexperienced bus driver's lack of exposure to adverse weather conditions.

5.7.2.2 Road Type

The results show that bus drivers' experience is linked to their involvement in accidents on different roads. The risk of being culpable for crashes on minor roads and country lanes and in car parks, bus depots, and on private property, remains high regardless of experience. This may be because the space for manoeuvring a large PCV is restricted on these roads, which may increase the risk of crashes.

Novice bus drivers are also at risk of being culpable for crashes on major roads and dual carriageways, which have higher maximum speed restrictions and multiple lanes. The risk then declines for more experienced bus drivers who are less likely to be responsible for crashes on major roads and dual carriageways. Since novice bus drivers are prohibited from driving on motorways, lack of experience may still explain why intermediately experienced bus drivers are at risk of being responsible for crashes on motorways. The risk on motorways is then reduced in experienced bus drivers. The results may be All explained by the influence of experience on the allocation of visual attention on different road types. For example, novice drivers display a limited search of the immediate environment when manoeuvring on dual carriageways (Underwood, Crundall and Chapman, 2002) and experienced drivers, in comparison with novice drivers, allocate their visual attention more effectively on freeways and highways (Wikman, Nieminen and Summala, 1998). In Wikman et al's study, all drivers accommodated their glance duration to the time margins on the different road types, but novice drivers were more likely to take risky glances that were associated with larger lateral displacements of the car. Such large lateral displacements could lead to a crash. Perhaps then a similar influence of experience on visual attention explains why novice bus drivers have a greater risk than more experienced bus drivers on dual carriageways and why experienced bus drivers have a lower risk on motorways.

5.7.2.3 Location

For all bus drivers, most accidents occur at junctions, bus stops, traffic lights, bus lanes and at roundabouts. However, the risk of being culpable for accidents at these locations is linked to bus driving experience. Novice bus drivers are most likely to be responsible for crashes at bus stops and junctions but only All to blame for crashes at bus lanes, roundabouts and traffic lights. Intermediately experienced and experienced bus drivers are not likely to contribute to the cause of crashes at bus stops, traffic lights and in bus lanes. The risk of being culpable for crashes declines with length of service. Although the risk declines, the results suggest that intermediately experienced bus drivers may still be partly to blame for crashes at junctions and roundabouts, but experienced bus drivers are not likely to be responsible for crashes at junctions or roundabouts. When scanning for hazards at these locations, drivers must make more head movements in order to access the visual field. This higher workload may then increase the potential for errors in detecting hazards at these locations (Hancock, Wulf, Thom and Fassnacht, 1990). While experienced drivers may compensate for the increased workload by knowing the optimal focal points on different roads (Crundall and Underwood, 1998), the effect may be further exacerbated in novice bus drivers who have a more limited ability to predict situational developments at junctions than experienced drivers (Vogel et al, 2003) and have a more limited search strategy (Crundall and Underwood, 1998). These results highlight the difficulty of driving a bus safely at junctions and roundabouts and suggest that it may take over five years to learn to recognise the risks and anticipate the actions of other road users that may lead to crashes at these locations and to deal with them effectively. These results clearly indicate a training opportunity to reduce bus crash risk.

Novice bus drivers also have a high risk of being culpable for crashes at pedestrian crossings, but after one year of service the risk declines. Hence, intermediately experienced and experienced bus drivers are not likely to be to blame for crashes at pedestrian crossings.

Potholes and road works pose the greatest risk for all bus drivers in terms of them being culpable for the crash, although the risk is still highest for novice bus drivers. Problems at these locations may be due to the nature of the hazard. Peripheral static hazards, like traffic cones, are less likely to attract attention than dynamic and central hazards (Underwood, Chapman, Berger and Crundall, 2003). It may not be easy to drive a bus through narrow lanes, especially if the drivers cannot accurately judge the space they require and so may collide with obstructions.

The results show that while some bus accidents occur at locations that are also problematic for other road users, for example those at junctions and traffic lights (Clarke et al, 1998), others are due to problems inherent in the bus driving environment, for example crashes occurring at bus stops. The evidence suggests that driving a bus is more difficult at junctions, roundabouts, potholes and road works. Novice bus drivers in particular may not be aware of the hazards specific to these locations. Even drivers with more experience may still lack the skills to successfully negotiate through traffic in these areas (Aphaloe et al, 1987).

5.7.2.4 Manoeuvre

For all bus drivers, most crashes occur when they are stationary and proceeding normally, however in these circumstances bus drivers are not likely to be to blame for the crash. On the other hand all bus drivers are at risk of being to blame for crashes when moving off, turning right, turning left, pulling into a bus stop, pulling away from a bus stop, reversing, overtaking, changing lanes and making a U-turn, and the risk is still high for experienced bus drivers. This research is in contrast to other researchers who studied car drivers and found age related differences in the likelihood of crashes when performing different manoeuvres, such as turning right, turning left, changing lanes and over taking (Clarke, Ward and Jones, 1998; Cooper, 1990; McGwin and Brown, 1999). It appears that bus driving is difficult and dangerous, but bus drivers may not be aware of the high risk of being culpable for an accident when they are actively controlling the bus (Groeger and Chapman, 1990).

Experience-related differences in crash risk are only found when bus drivers are accelerating, taking evasive action, and slowing down. For instance, novice bus drivers are at risk of being partly to blame for crashes when accelerating. However, more experienced bus drivers are not likely to be to blame for crashes when accelerating. Forward motion may have a reinforcing effect (Olsen and Austin, 2001), but the fact that buses are slower to accelerate than cars may make novice bus drivers more vulnerable to accidents while accelerating if they have problems adjusting their speed appropriately to coincide with the traffic flow. As bus drivers become accustomed to the handling characteristics of the bus then crash risk while accelerating decreases. Novice bus drivers are likely to be to blame for crashes when taking evasive action, the risk is still high for intermediately experienced, however experienced bus drivers are not likely to be the sole cause of the crash but may still be All to blame. Experienced drivers are able to detect hazards unfolding in the traffic environment earlier than inexperienced drivers (Crick and McKenna, 1991), which gives them more time to react. Bus drivers may then be forced to take evasive action in response to hazards. This involves the ability to effectively re-orientate attention in complex situations. For example, when another vehicle is approaching on a collision course - an easily perceptible hazard but what do you do? Slow down or swerve? This involves judging what the other driver will do and what other hazardous effects swerving might have. Inexperience in the form of lack of knowledge about hazards and the appropriate vehicle handling skills to allow the driver to manoeuvre safely may result in the driver taking unnecessary risks (Bailley, Bellet and Goupil, 2003; Horswill and McKenna, 1999; McKnight and McKnight, 2003; Underwood et al, 2002). But as a bus driver's knowledge and awareness of their surroundings develops they will eventually learn to anticipate the actions of other road users (Johnson-Laird, 1983; McKenna and Crick, 1991; Renge, 2000) and therefore may be able to avoid incidents. Even so, while experienced bus drivers have a reduced risk they may still be in some way responsible for crashes when taking evasive action.

The risk of being culpable for crashes while slowing down is highest for novice and experienced bus drivers who are likely to be solely responsible for causing a crash while slowing. To avoid rear-end collisions it is necessary to be able to detect decelerations of the lead vehicle. Failure to detect decelerations may be due to perceptual factors or because decelerations are unexpected (Rumar, 1990). Novice bus drivers may then not recognise the warning signals that indicate that the lead vehicle is braking, but older more experienced drivers may have difficulty judging speed and distances, which results in errors when braking. Risky driving, such as driving too fast for the road conditions and following too closely may increase the likelihood that the driver will be involved in an accident (Al-Ghamdi, 2002; Cooper, Pinili and Chen, 1995; Evans and Courtney, 1985). Intermediately experienced bus drivers have a reduced risk of being solely responsible for crashes but are still likely to be responsible for crashes while slowing down. This suggests that they may have some of the benefits of experience without the functional declines that may be associated with older bus drivers.

5.8 Implications for Bus Driver Training

To follow on from this analysis, the next step is to implement training strategies to increase bus driver's awareness of risk in the different situations highlighted and to allow them the opportunity to discuss and practice mechanisms for coping with problems specific to these areas. The results suggest that novice bus drivers would benefit most from additional training since the risk of contributing to the cause of crashes is generally highest for this group of drivers.

The results indicate that novice bus drivers should practice safely performing different manoeuvres, as their risk of causing a crash is high. Furthermore, bus drivers with more experience may also benefit from the opportunity to reinforce their vehicle control skills in safe conditions as their crash risk is also high while performing particular manoeuvres. However, in order to be a safe driver it is not enough to be able to control the vehicle in accordance with traffic rules. Novice bus drivers must also gain the knowledge of where risks occur and how to avoid them. In this analysis, most crashes occur at bus stops, junctions, traffic lights, bus lanes and roundabouts - although novice bus drivers have problems in comparison to more experienced bus drivers in just about every situation they find themselves in. Even so the analysis shows that particular attention should be paid to risks at junctions and roundabouts. Also, if novice bus drivers were given the opportunity to practice keeping low speeds and maintaining longer headways between themselves and other road users in sleet, snow, rain, mist and fog, then crashes might be reduced. The benefit of early experience in adverse road and weather conditions may then have a knock on effect of reducing accidents later on in a bus drivers' career. The accelerated acquisition of experience is therefore a crucial element in driver training. For novice car drivers, research has shown that if experience is gained under the supervision and in safe conditions then the accident involvement after licensing is reduced when compared with gaining the experience alone or with peers after obtaining a full licence (Gregersen, Nyberg and Berg, 2004). However, the fact that novice bus drivers' accident rates are highest in the second month suggests that they may not have had enough opportunity to practice the skills they learned in the driving school before going on the road. Perhaps the mentor period is not long enough or maybe mentor drivers are not sufficiently trained to coach the new drivers to avoid collisions (indeed anecdotally, novice bus drivers may even have acquired bad habits under the influence of their mentor driver!). The period of supervision could be extended, but there are disadvantages because this would increase the pressure on operations due to driver shortages. Instead, novice bus drivers could continue to consolidate their newly trained skills by using automated simulator training designed to increase novice bus driver's knowledge and experiences. A bus simulator would allow them to practice their skills and provide feedback on their progress. The accident analysis presented here suggests that this type of training might usefully continue throughout their first 6-10 months of service.

Accident rates are also comparatively high for older, more experienced bus drivers. A possible explanation is that age-related cognitive declines are adversely affecting their ability to drive. Unfortunately, due to the nature of their work they still have to drive for long periods on a daily basis, so unlike car drivers, aging bus drivers cannot regulate their driving by reducing their exposure to risky situations. Also due to a tendency for drivers to overestimate their own skills and abilities (McCormick et al, 1986), older bus drivers may not be aware of any skills deficits until they have been involved in an accident. Therefore it seems a good idea to regularly examine older bus drivers for any medical or physical impairment that may affect their ability to drive safely. This may be achieved by conducting a simulator-based assessment to isolate any skills deficits due to physical or cognitive problems before they lead to accidents on-road, and then to provide on-going refresher training after 20 years of service.
Specific simulator based training scenarios are described in detail in chapter 11.

5.9 Limitations

It is important to consider that this study is based on crash data and so there is no indication of the age and experience profiles of accident free bus drivers. The findings only reveal the relative likelihood of at fault, part fault or not at fault crashes, given that the bus driver is involved in an accident. This method reveals systematic differences in behaviour and ability of different groups of bus drivers, but not the accident involvement rates or the probability that bus drivers in different groups will be involved in an accident. This is because data concerning non-involvement in accidents is not available for comparison. Therefore the data in this study does not allow a thorough examination of the conditions and actions that lead to accidents or the exact circumstances of the accidents in detail without the use of a control group. Although, the propensity of drivers with various levels of experience to be involved in different types of crashes can be demonstrated, more detailed research is needed to fully explain accident risk. However the analysis was conducted with the aim of identifying the bus drivers who are most at risk of being culpable for a crash and as such the data are useful in the development of effective interventions.

There are other methodological limitations of this study that need to be considered. It is reasonable to assume that many of the higher accident involved employees will tend to either leave the company, or be asked to leave. However the present data set does not reveal how many bus drivers have had multiple accidents over the course of their service. Perhaps then the reduction in crash frequency over time is due to the natural selection of drivers who are still with the company because of higher safety standards. Following the same group of drivers over time in a longitudinal study would control for this (Maycock, Lester and Lockwood, 1996). However, such a study conducted with bus drivers may suffer from a very high turn-over of drivers. It is also important to note that the calculations for longer time periods contain rather few data points. Rather the strength of the investigation lies in the detailed computations for the first few years of service.

The analysis of culpability for this study should also be regarded with some caution. Firstly, depot managers, in collaboration with the insurance company, undertook the assignment of culpability. As there were a large number of depots from which the data was gathered and as no inter-rater reliability tests were undertaken, it is expected that there is a large degree of error variance. Secondly, culpability assumes that the driver has exhibited behaviour that is inappropriate for the prevailing traffic demands and/or the capabilities of the vehicle being driven. However, bus driving is governed by factors outside the traffic system, such as maintaining schedules, which may increase exposure to risk if a bus driver is running late and feels that they must take risks to keep to schedule. Therefore, culpability is a questionable assumption, even if assigned correctly on the basis of an insurance claim settlement. This is especially true when there are multi-vehicle accidents to investigate.

Finally, the induced exposure technique supposes that non-culpable accidents are directly related to exposure and can be used as a proxy for it. However, the assumption that non-culpable accidents are a good replacement for exposure data might not be true, especially because changing the assignment of culpability could have strong effects on the ensuing ratios.

5.10 Conclusion

The results show that for bus drivers, experience over age is a relatively more important predictor of bus crashes. Inexperienced bus drivers have a greater risk of being culpable for crashes than more experienced bus drivers and this risk is greatest for novice bus drivers at bus stops, junctions, traffic lights and roundabouts and in adverse weather conditions. The analysis indicates that novice bus drivers are likely to benefit most from additional training and provides the basis for the design of simulator-based training scenarios to enhance hazard perception and decision-making skills for novice bus drivers. A detailed description of the training scenarios resulting from this analysis is given in chapter 11.

6 Construction of the Arriva Bus Simulator

Simulator design, particularly fidelity is thought to have a significant impact on training transfer (Allen et al, 1991; Dennis and Harris, 1998; Hays and Singer, 1989; Stoffregen et al, 1999). The following section describes how the hardware and software components of off-the-shelf driving simulator technology were adapted to produce an interactive bus simulator which is intended to supplement traditional in-vehicle bus driver training by supporting the development of hazard perception and risk perception skills. The face validity of the ABS was tested throughout the construction period using a fidelity assessment method, the results of which are reported in appendix A. The initial results of the face validity analysis revealed discrepancies between the ABS and a real bus, which led to improvements to the configuration of the operating characteristics of the ABS. The final configuration of the hardware and software components of the ABS is detailed here.

6.1 ABS Hardware

6.1.1 PC Hardware

The basic construction of the ABS is fixed-base and uses the STIsim PC-based interactive driving simulator model 400 (Systems Technology Incorporated). The STIsim takes detailed performance measurements, enables scenario design and feedback and de-briefing during training. Plus, scenario presentation can be automated and can be systematically presented to the user once it is developed. These were identified as important features of successful simulator-based training programmes (Salas et. al., 1998). The simulation software includes a simple vehicle dynamics model and a simple power train model and it provides visual and auditory feedback and a performance measurement system. Driving tasks and events are programmable within a unique Scenario Definition Language (SDL), which allows the specification of sequences of tasks, events and performance measurement intervals (Allen, Rosenthal, Aponso, Harmsen and Markham, 1999). The STIsim software runs on a Windows 2000 operating system, which allows networking for increased computational capability (Netgear sport 10/100 Mbps Fast Ethernet switch Model FS105.) Three AMD Athlon ™ XP 1800+ AT/AT COMPATIBLE Pentium computers with 768 MB RAM compute complex vehicle dynamic responses to the human operators control input with an adequate update rate to satisfy visual, proprioceptive and auditory cueing requirements. PC processors are fitted with PCIM-DDAO6/16 analog output and digital I/O board, V266B Motherboard, PCI QUAD04 Four channel quadrature encoder input board, NVidia GeForce 4 MX460 128-bit 3D Processor graphics card provides visual cueing and Soundblaster sound processor cards provides auditory cueing. A Philips multimedia speaker system (20W RMS) provides audio feedback to the driver. Over 50 sound effects were created for the purpose of bus driver training. Four Samsung SyncMaster 753DFX colour monitors with 17 inch display and 1024 x 768 resolution support three driving displays (right, left, centre) to give a 180° field of view plus an operator's display. A fourth 3D Perception processing computer supports the ABS projection theatre. The STIsim model 400 was supplied with a modular steering unit with speed sensitive feel provided by a computer controlled torque motor through a full-size steering wheel (+/- 360 degree steering capability) and a modular accelerator and brake pedal unit. These were adapted so that a bus steering wheel, brake pedal, accelerator pedal and speedometer are available and the driver sits in a bus cab mock up. Figure 28 depicts how the simulator components are connected.

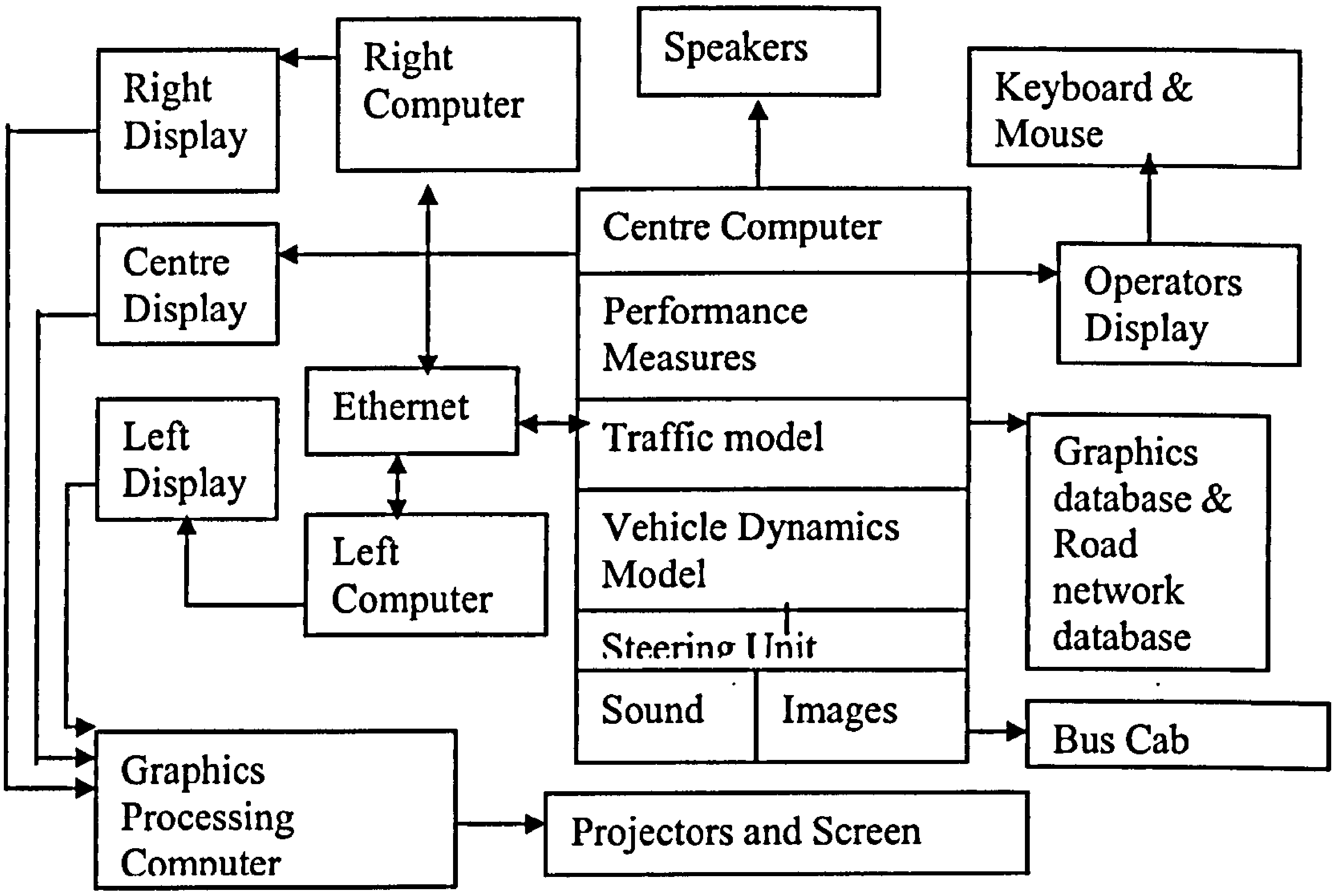


Figure 28 **Functional Diagram of the ABS**

6.1.1.1 Cab

The driver sits in full size mock up of a bus cab situated in the centre of the screen so that the driver's immediate environment is as realistic as possible. The indicators and horn on the dashboard can be operated when the driver is within the simulation. The STIsim either represents a speedometer in abstract form in the on-screen display or allows the addition of a fully operational speedometer. The ABS has a fully operational speedometer that was calibrated to give realistic feedback to the driver. Figure 29 shows the inside of the drivers cab.

Figure 29 **ABS Cab**

6.1.2 Controls

The STIsim model 400 is supplied with a modular steering unit with speed sensitive feel provided by a computer controlled torque motor through a full-size steering wheel (+/- 360 degree steering capability) and a modular accelerator and brake pedal unit. Since the units supplied were intended as a car simulator, some adaptation was required so that a normal bus steering wheel, brake pedal, accelerator pedal and speedometer are available (Figures 29 and 30). The simulator outputs a voltage to the speedometer unit which is proportional to the speed of the bus. This is output from a card in the computer that can have a maximum range of 0 to + 5 volts. Unfortunately the output voltage was not powerful enough to drive the speedometer unit by itself so an amplifier was needed. Even so, the speedometer is restricted to a maximum reading of 50mph although the speeds recorded by the simulator can exceed this value. The main shaft in the steering unit is connected by a stepped belt to a torque motor which acts to create a force on the steering wheel to oppose the movements made by the driver. The computer continuously sends a signal to the torque motor for it to create a force that is a function of an assortment of parameters at any given moment for example rate of turn, road friction, road camber, side winds and forward speed. The size and strength of the torque motor was chosen to give good feel with the car-size steering wheel that was originally supplied. However the steering wheel came directly from a real bus and was approximately twice the size of the original car steering wheel, which effectively halved the force needed from the driver to oppose the torque motor. A further problem was that there was a large amount of friction in the bus steering column, which prevented the steering centering mechanism from working. The original computer controlled torque motor that was supplied with the STIsim was not capable of supplying the force required to provide force feedback on the wheel of a bus, given that it is far larger than that of a car. Therefore a larger torque motor was fitted and the parameters of the computer that controlled the motor were adjusted so that the maximum force was available. However, even with a larger torque motor fitted, the force feedback on the steering wheel was not as great as the original. The cab steering wheel was connected to the STI steering box by clamping an extension shaft with two large alan-key headed screws to the STI supplied components. Unfortunately these screws were susceptible to becoming loose which prevented the wheel from turning the STI mechanism and so the steering did not work. This meant that the screws had to be continually tightened to ensure that the steering mechanism worked. The steering on a real bus has an automatic self-centering mechanism so it will effectively spin back to the centre position once the driver has completed a turning manoeuvre. The equivalent mechanism inside the STI box are two shafts. The first main shaft is connected to the steering wheel. Beside it, and connected by gears, is a lay shaft which has two coil springs on it that wind up as the wheel is turned and will return the wheel to the centre position when no force is applied. Unfortunately the Arriva wheel and/or connection mechanism seems to have some friction that prevented this from happening. Plus, there was also a lot more inertia than before this adjustment was made. The problem is that one driver may leave the wheel turned mostly to one side, for example the right, so that the next driver starts the trial with only half a turn to the right and three turns to the left available. In order to have the steering wheel centre itself, stronger springs could have been added outside or inside the STI box. However this solution required that drivers applied more force to the steering wheel that was not a function of their speed and turning rate etc. Therefore it was necessary to engineer a self-centering mechanism from bungee cord so the steering wheel would return to position after it had been displaced. The drawback with using bungy cord is that over time the elastic slackens and the steering becomes mis-aligned. This means that the elastic must be regularly checked for wear and replaced. Figure 31 shows the new steering centering mechanism. In addition to this, drivers were instructed to turn the wheel all the way to the right and then back two turns before starting a run to ensure that it was centred.

Figure 30 ABS Brake and Accelerator

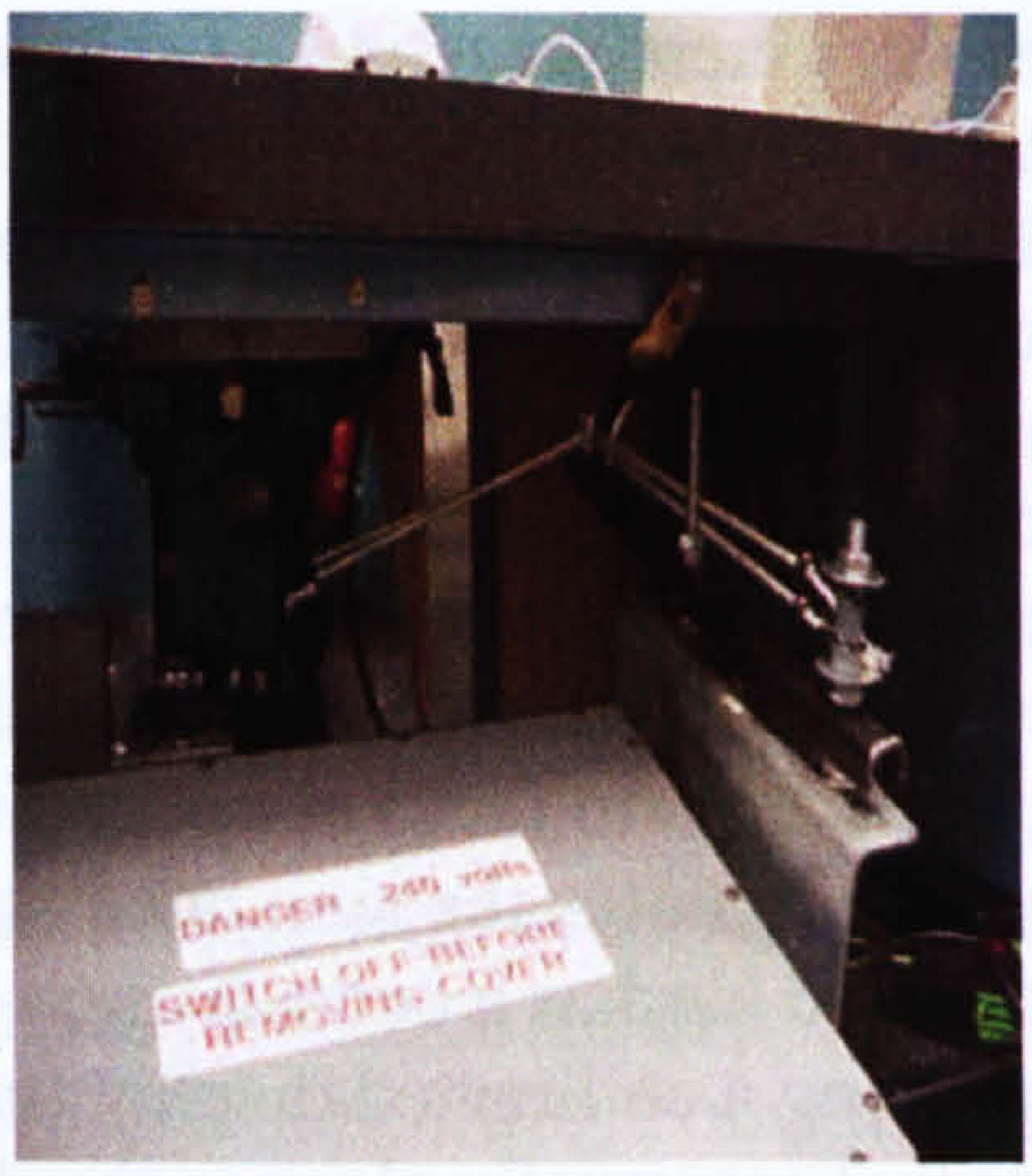


Figure 31 **ABS Steering Self-centring Mechanism**

6.1.3 Display

The guiding principle in the selection of the visual display was to get the largest field-of-view possible, with as high a resolution as possible for the lowest possible cost. There was a choice of five basic types of display system on the market: direct-view monitors, rear-projected images, mirror collimators, front-projected images and Head-Mounted Displays (HMD's). Each display type offers the potential of enhancing the realism of the simulation.

The potential of HMD's rests in their capability to provide drivers with an unrestricted field of regard, which would enhance the realism of the simulator. However, there is often a conflict between eye accommodation and vergence in HMD's (Farmer et al, 1999), which can be uncomfortable for the trainee. To date, the visual performance of HMDs is not adequate in terms of delay compensation for head movement and field of view (Blackham, 1999). This could compromise the validity of the ABS and cause negative transfer. HMDs have been used successfully in full combat mission simulations (Chung et al, 1989) however Burns and Dennis (1999) thought that one of the reasons why their driving simulator lacked validity was because they used a HMD. Although all-round vision may be an advantage in a driving simulator, it may be sufficient to have 180º field of view to support behaviour at junctions and bus stops (Korteling and Sluimer, 1999) and it may not be worth compromising validity for higher fidelity. Plus, HMDs are too costly and cumbersome to use.

Another option that was considered was collimated projection, which is widely used in flight simulators, but has not been used previously in ground vehicle simulation because of large costs. The flight simulator at Cranfield University utilises a collimated display. Collimated displays consist of a projection system cross firing above the cab, which form an image on the outer surface of a rear-projection screen, usually spherical placed above and in front of the cab. A collimated mirrored surface is then wrapped around in front of the cab for a large horizontal field of view. The most cost-effective method is to stretch a polyester film coated in an aluminium reflective surface over the edge of an evacuated mirror cell. The rear-projected image is viewed via this curved mirror. The relationship between the curvature of the mirror and the rear projection screen is such that the image distance can be set to enhance the subjective realism of the scene. The image distance is usually set to 20 or 30 metres, which is significantly greater than the physical mirror radius, which is typically 3 metres. Collimation is important in flight simulation so that pilot and co-pilot can perceive the correct image geometry for the same distant objects. However, these components drive the cost of the display system up and may be difficult to justify for ground vehicle simulation. Roscoe (1991) argued that collimated images do not cause eyes to focus at optical infinity. Instead focus lapses inward to the pilot's dark focus. This causes the simulated scene to appear shrunken and causes pilots to touch down long and hard as a consequence of mis-accommodation of the eyes. If this is the case then using a collimated display for bus driver training would be problematic because objects that are usually close to the driver such as other vehicles would be presented at an image distance of 20 metres so relative cue sizes would be distorted. Instead, Roscoe suggests that a projection screen a few feet away from the trainee but with the same magnifications as the scene would be better for training and based on this view the bus simulator uses projectors with a similar magnification as found in the real world.

An all-round display can be obtained using a flat or curved screen placed around the simulator cab with front or rear projectors projecting onto it. Cathode Ray Tube (CRT) projectors form their images by a continuous scanning process. This confers the advantage that the projected image can be distorted in a continuous manner, which is particularly useful when projecting onto a curved screen. CRT projection is dominant in simulation displays because of this capability. Liquid Crystal Display (LCD) projection is also promising because of reduced system maintenance, versatile lens options and the small physical size and weight for a given light output. LCD projectors offer advantages because the increased light output can be traded for higher image contrast performance, system-level enabling technologies of distortion correction and optical blending and low maintenance overheads. The drawback with using front projected displays is that large cabs can occlude the projected light path to the screen. Rear projection solves the problem of image occlusion from large simulator cabs. Projectors are arranged outside the simulator enclosure so that the simulator cab does not share the same space as the projection devices. However, there are performance limitations associated with rear projection. Large fields of view are usually realised by placing multiple flat screens together so screen-joins present a discontinuity in the image and eye accommodation distances also vary. This could affect depth perception in simulated driving. Another problem is that rear projectors do not distribute light as evenly as front-projection screens but exhibit a preferential distribution along the axis of the incident light. This means that luminance at the edges of the image are not as bright as luminance in the centre. There is also a limit to how far off-axis the projectors can be placed before field of view is compromised by wasted displayable pixels. The advantages of front projection over rear projection then are that images are presented continuously and the quality of dynamic image presentation is good. Images can be electronically blended and the projection technology is mature and therefore less risky. Plus, the projectors can be bought off the shelf, which keeps costs low. Hence, for the purpose of bus driver training, the virtual environment is presented to the driver by projecting the three driving displays, each providing a 60° FOV onto a 180° curved screen, which is 6 metres in diameter and 2.75 metres high through 3 Panasonic LCD projectors mounted on the top rear of a 360° chrome framework. The boundaries between the three projector images were blended and geometrically corrected by an additional graphics processing system. However, there was still some wastage of displayable pixels as a result of the blending process as the side images now ‘overshoot’ the edge of the screen.

6.1.4 The ABS Projection Theatre

In order to create a continuous picture with evenly distributed light intensity, it was necessary to manipulate the ABS projection theatre. The image blending equipment includes a Compact UTM zer0 unit supporting Compact Designer and Compact Control software. The Compact UTM zer0 is an external image warping and edge-blending unit that works with any fixed matrix projector, of which LCD is an example. The design of the ABS projection theatre was achieved using Compact Designer software. The room measurements (7m x 7m x 3m) and specifics of projectors and screen geometry (6m x 2.75m) plus the average driver’s eye height (1.6m) were inputted to produce a model of the projection theatre. The Compact Designer software then automatically calculated the parameters for very accurate Non-Linear Image Mapping (NLIM) in order to provide a high quality image as seen from the driver’s eye point. The projectors in the theatre model were then placed at the correct physical locations. Figures 32 and 33 show the ABS projection theatre.

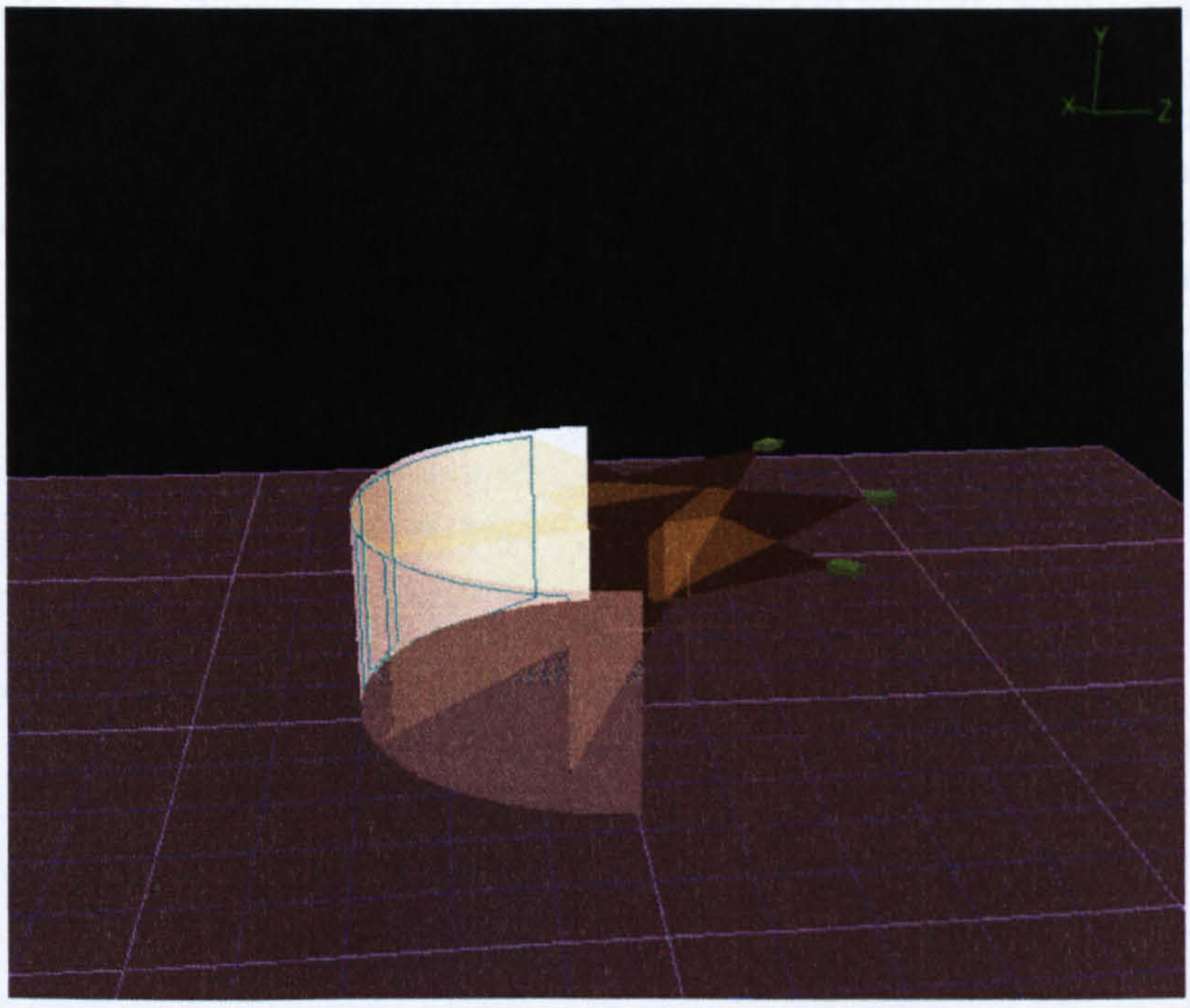


Figure 32 **The ABS Projection Theatre Side View**

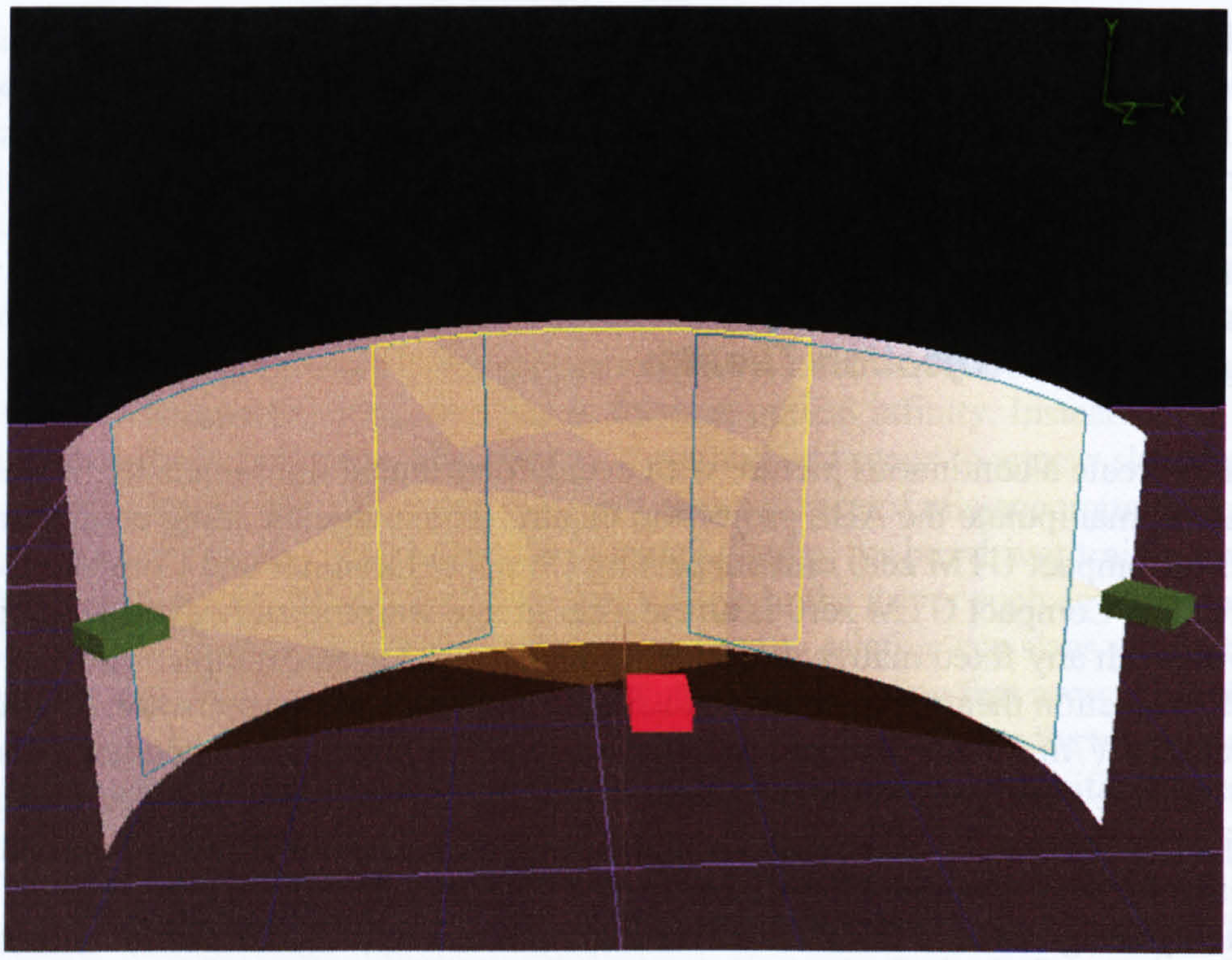


Figure 33 **The ABS Projection Theatre Front View**

Compact Control then allowed the necessary geometry adjustments, edge blending, gamma correction and colour balancing in order to create a continuous picture with evenly distributed light intensity. Figure 34 shows the geometry configuration for the ABS. The projection theatre geometry was then downloaded to the projectors to calibrate the geometry, soft edges and hot spot compensation using a simulated scenario that had been designed specifically for this purpose.

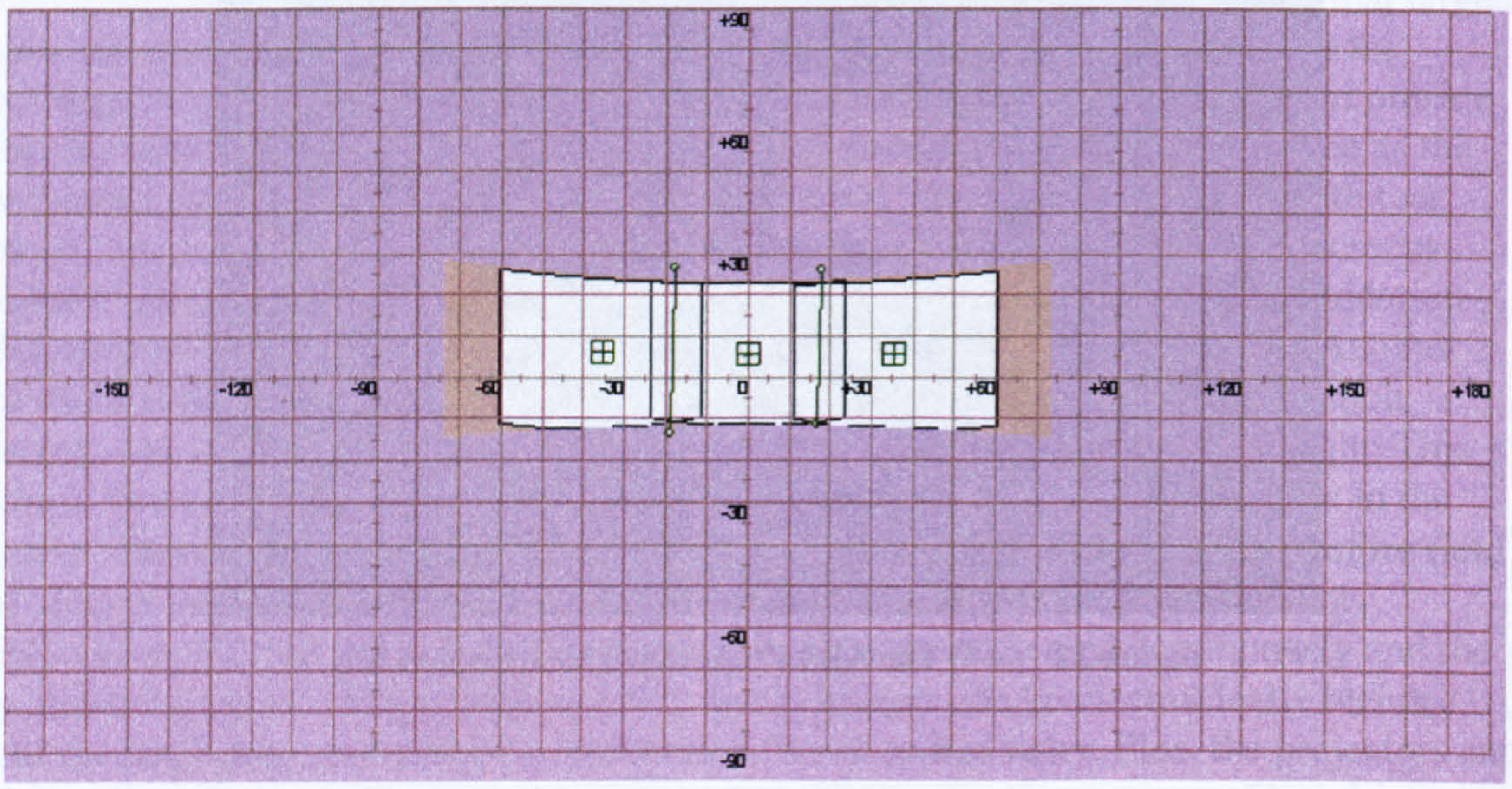


Figure 34 **Geometry for the ABS Projection Theatre**

Figure 35 illustrates the physical fidelity of the ABS.

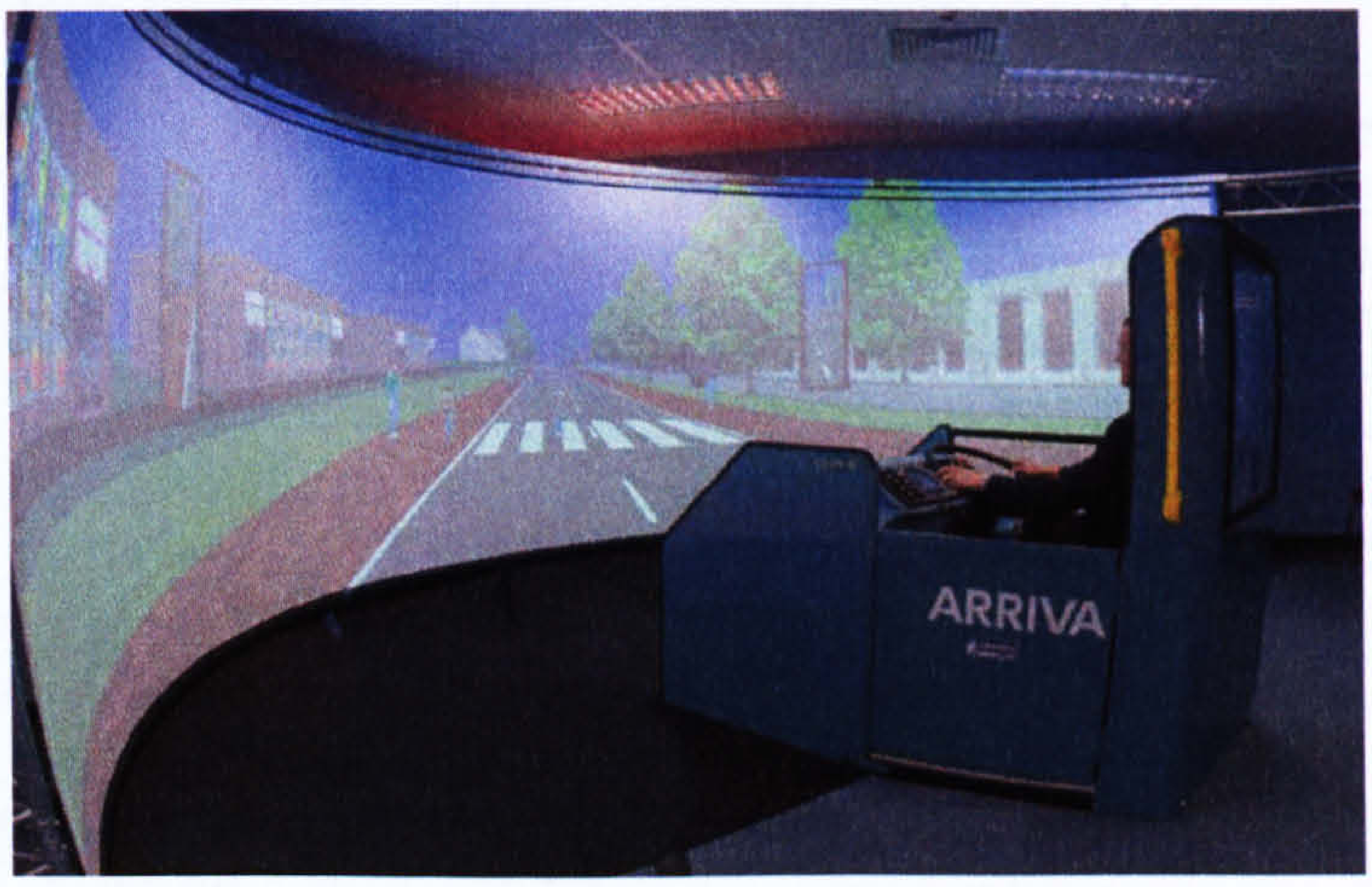


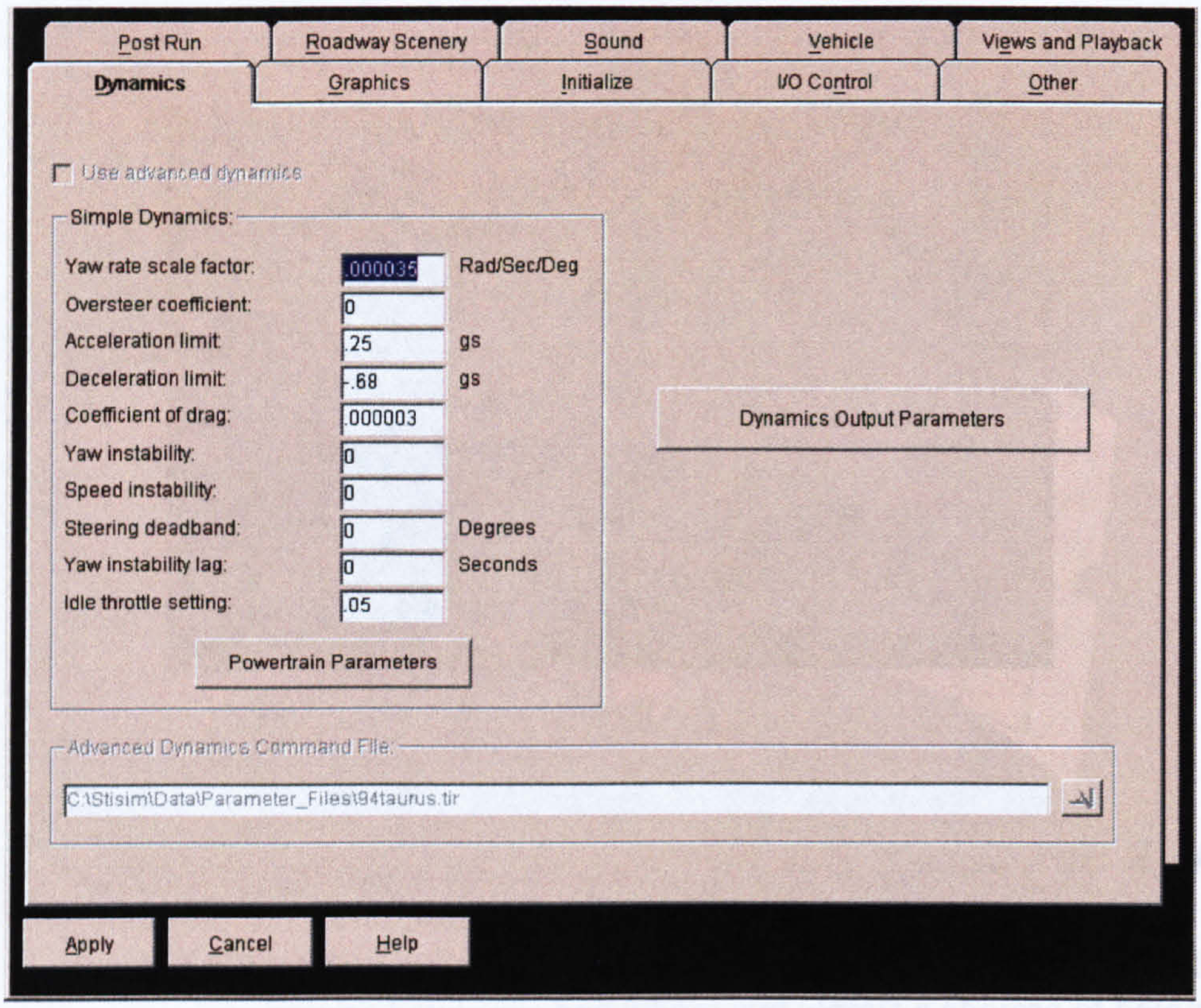
Figure 35 **The Physical Fidelity of the ABS**

6.2 ABS Software

The following section describes how the STIsim software was configured and programmed to provide a simple bus model and simulated scenarios.

6.2.1 Vehicle Dynamics and Simulator Operating Characteristics

Figures 36 to 52 provide a detailed illustration of how the vehicle dynamics, graphics, initialising parameters, Input/output control, vehicle, sound, roadway scenery and post run data collection parameters of the ABS were configured. The STIsim 400 uses a simple linear vehicle dynamics model. The simple vehicle dynamics are comprised of 9 different parameters that control how the vehicle will steer, accelerate and brake. The yaw rate scale factor and oversteer coefficient directly affect how the simulated vehicle responds to steering inputs. The yaw rate scale factor was set relatively low to reflect the fact that a bus is comparatively unresponsive. The over steer coefficient was adjusted by trial-and-error to improve how the bus negotiated curves at different speeds. The acceleration and deceleration limits directed how the bus accelerated and decelerated when the foot pedals were pressed. The coefficient of drag reflected the top end speed and coast down speed of the bus.
The yaw rate and speed instabilities were set zero value because non-zero values made it too difficult to control the speed. To explain, the speed instability causes the speed to fluctuate so that the driver must adjust their throttle input and the yaw rate instability made the car drift from its current path and eventually go off the road and crash. Similarly the steering dead band and yaw instability lag were set to zero because the use of a larger steering wheel meant that non-zero values made the steering completely unresponsive and reduced fidelity. Figure 36 shows how the vehicle dynamics were configured.



☐ Use advanced dynamics

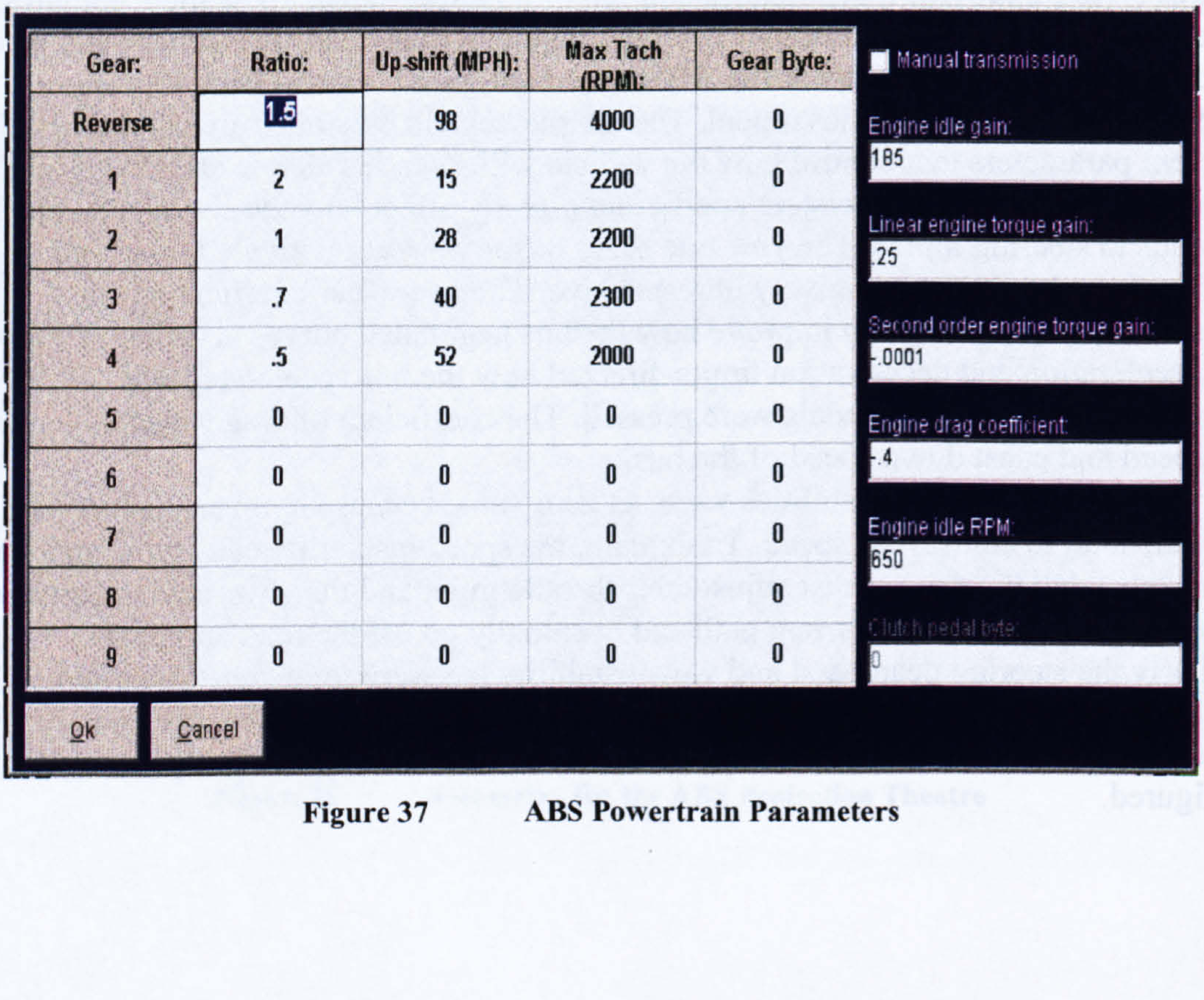
Simple Dynamics:

Yaw rate scale factor: .000035 Rad/Sec/Deg
Oversteer coefficient: 0
Acceleration limit: .25 gs
Deceleration limit: -.68 gs
Coefficient of drag: .000003
Yaw instability: 0
Speed instability: 0
Steering deadband: 0 Degrees
Yaw instability lag: 0 Seconds
Idle throttle setting: .05

Advanced Dynamics Command File:
C:\Stisim\Data\Parameter_Files\94taurus.tir

Figure 36 **ABS Vehicle Dynamics**

Figure 37 shows how the powertrain parameters were configured. The speed of the bus was limited by the interplay between the engine characteristics and the aerodynamic drag.



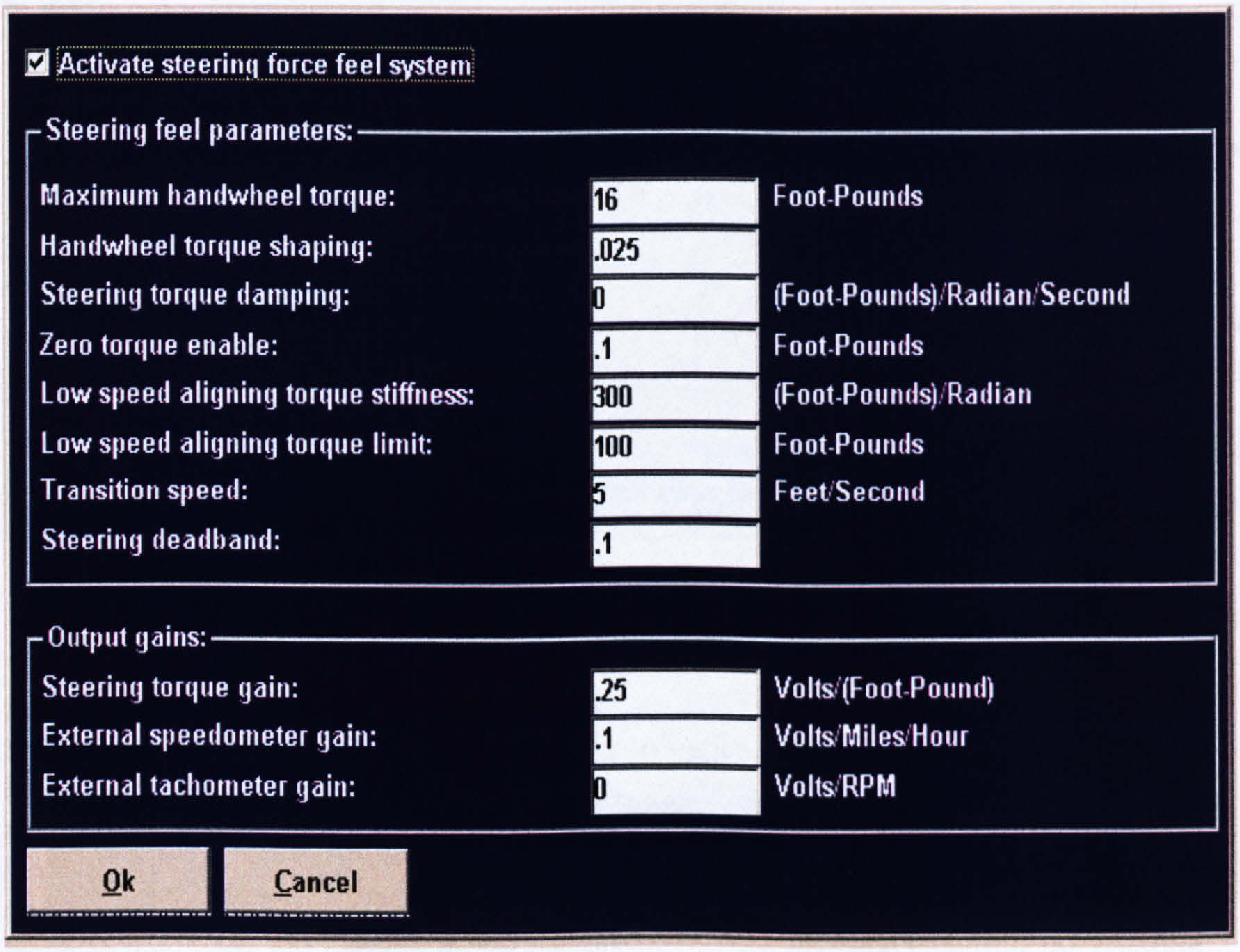
Gear:	Ratio:	Up-shift (MPH):	Max Tach (RPM):	Gear Byte:
Reverse	1.5	98	4000	0
1	2	15	2200	0
2	1	28	2200	0
3	.7	40	2300	0
4	.5	52	2000	0
5	0	0	0	0
6	0	0	0	0
7	0	0	0	0
8	0	0	0	0
9	0	0	0	0

☐ Manual transmission

Engine idle gain: 185
Linear engine torque gain: .25
Second order engine torque gain: -.0001
Engine drag coefficient: -.4
Engine idle RPM: 650
Clutch pedal byte: 0

Figure 37 **ABS Powertrain Parameters**

The steering feel system and speedometer are powered by analogue outputs from the STIsim Drive computer. Figure 38 shows that the steering force feel was activated and illustrates how the parameters were set. The maximum handwheel torque and handwheel torque shaping parameters are used to simulate a power assisted steering system. The maximum handwheel torque limits the amount of torque that the steering model can generate. The steering feel algorithm then computes values of torque up to this amount and then limits the steering feel thereafter. The value for hand wheel torque shaping was set fairly low to simulate the fact that most bus steering wheels are not power assisted. The steering torque damping is the amount of active viscous damping applied to the torque output command based on the rotational velocity of the steering wheel. A non-zero value for steering torque damping was supposed to eliminate small oscillations in the steering wheel feedback, however this parameter was set to zero because non-zero values meant that the steering wheel was difficult to control. The zero torque enable was set to a non-zero value to help to stabilize the steering system. The torque motor is physically turned off below this value, which enables a little bit of 'play' around the centre of the wheel.



☑ Activate steering force feel system

Steering feel parameters:

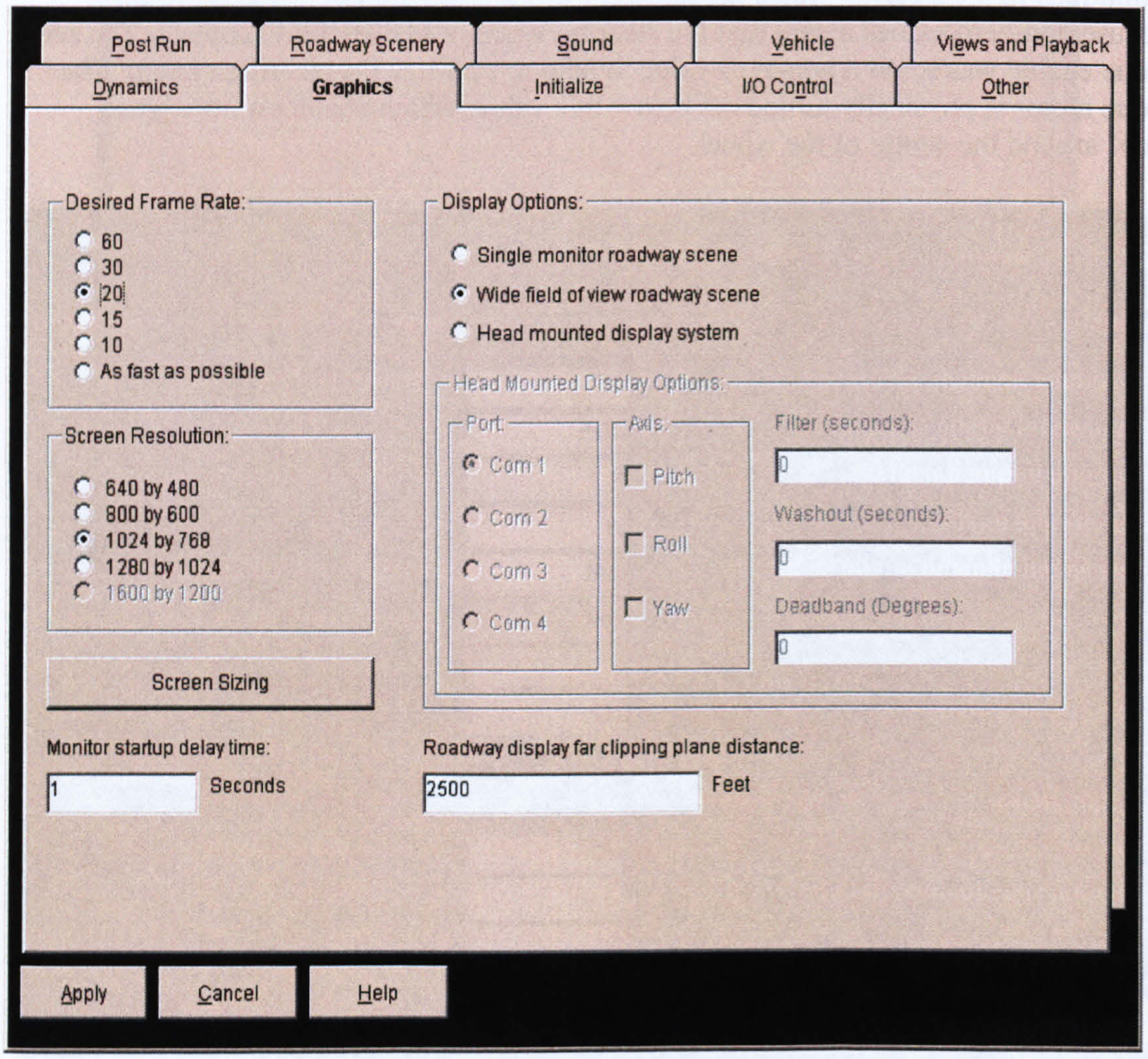
Maximum handwheel torque: 16 Foot-Pounds
Handwheel torque shaping: .025
Steering torque damping: 0 (Foot-Pounds)/Radian/Second
Zero torque enable: .1 Foot-Pounds
Low speed aligning torque stiffness: 300 (Foot-Pounds)/Radian
Low speed aligning torque limit: 100 Foot-Pounds
Transition speed: 5 Feet/Second
Steering deadband: .1

Output gains:

Steering torque gain: .25 Volts/(Foot-Pound)
External speedometer gain: .1 Volts/Miles/Hour
External tachometer gain: 0 Volts/RPM

Figure 38 ABS Dynamics output parameters

Steering feel is a function of the tire aligning moments and so feels different when the bus is travelling at different speeds, for example it is heavy at low speeds but is more sensitive at high speeds. The ABS was configured so that a low speed effect is applied to the steering feel at speeds below 5 feet per second. The low speed effect is based on a torque stiffness provided by the low speed aligning torque stiffness parameter. The torque that is generated acts along this slope until it reaches the low speed aligning torque limit at which point it remains constant even though the steering is increased. The Steering dead-band parameter helps to stabilize the low speed model by specifying a coefficient that is multiplied with the zero speed torque limit so that a minimum value of torque can be computed; below this value the torque is always zero. The steering torque gain defines the actual voltage that will go from the computer to the steering unit, which affects the total amount of torque that the motor will generate. Similarly the speedometer gain defines the voltage that drives the speedometer. The maximum output voltage is +/- 5 volts so the speedometer can only display a maximum speed of 50 mph to the driver, although the actual maximum speed of the ABS is much greater.



Desired Frame Rate:
○ 60
○ 30
● 20
○ 15
○ 10
○ As fast as possible

Screen Resolution:
○ 640 by 480
○ 800 by 600
● 1024 by 768
○ 1280 by 1024
○ 1600 by 1200

Display Options:
○ Single monitor roadway scene
● Wide field of view roadway scene
○ Head mounted display system

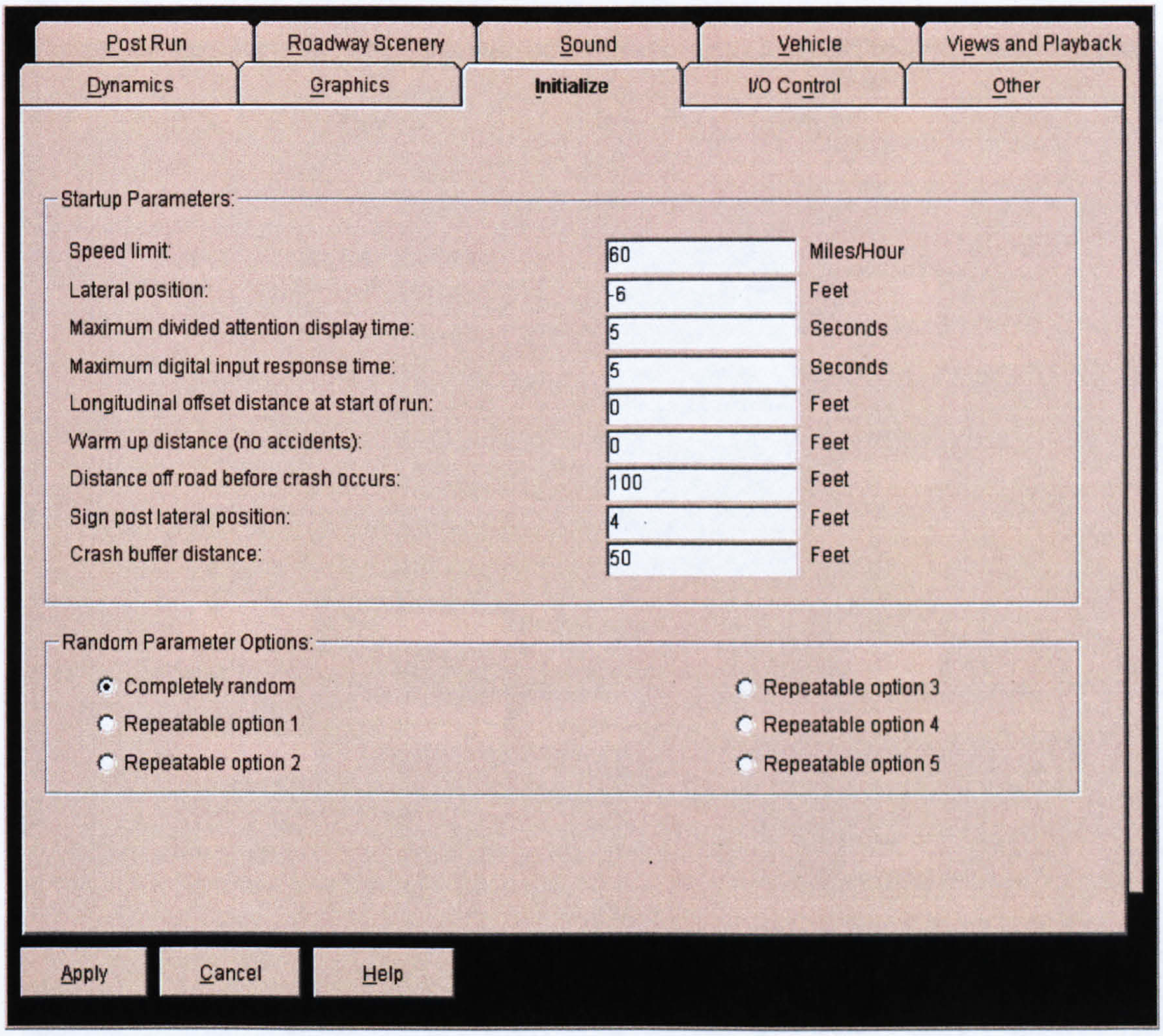
Head Mounted Display Options:
Port:
● Com 1
○ Com 2
○ Com 3
○ Com 4
Axis:
☐ Pitch
☐ Roll
☐ Yaw
Filter (seconds): 0
Washout (seconds): 0
Deadband (Degrees): 0

Monitor startup delay time: 1 Seconds

Roadway display far clipping plane distance: 2500 Feet

Figure 39 **ABS Graphics Configuration**

Figure 39 shows how the Graphics were set to present roadway display information to the driver. The simulation frame rate was set to 20hz and the sizing of each individual screen was 1024 x 768. A wide FOV was selected so that the driver could see more of the roadway scene when turning and crossing intersections. The 'far clipping plane distance' refers to the absolute limit that the driver can see ahead of them in the simulator. It takes a finite amount of time to render all of the images in the roadway display so in order to reduce processing time the far clipping plane was set so that objects past this distance were not rendered. Therefore the objects within the display could be computed faster, resulting in faster frame times and smoother simulations.



Startup Parameters:

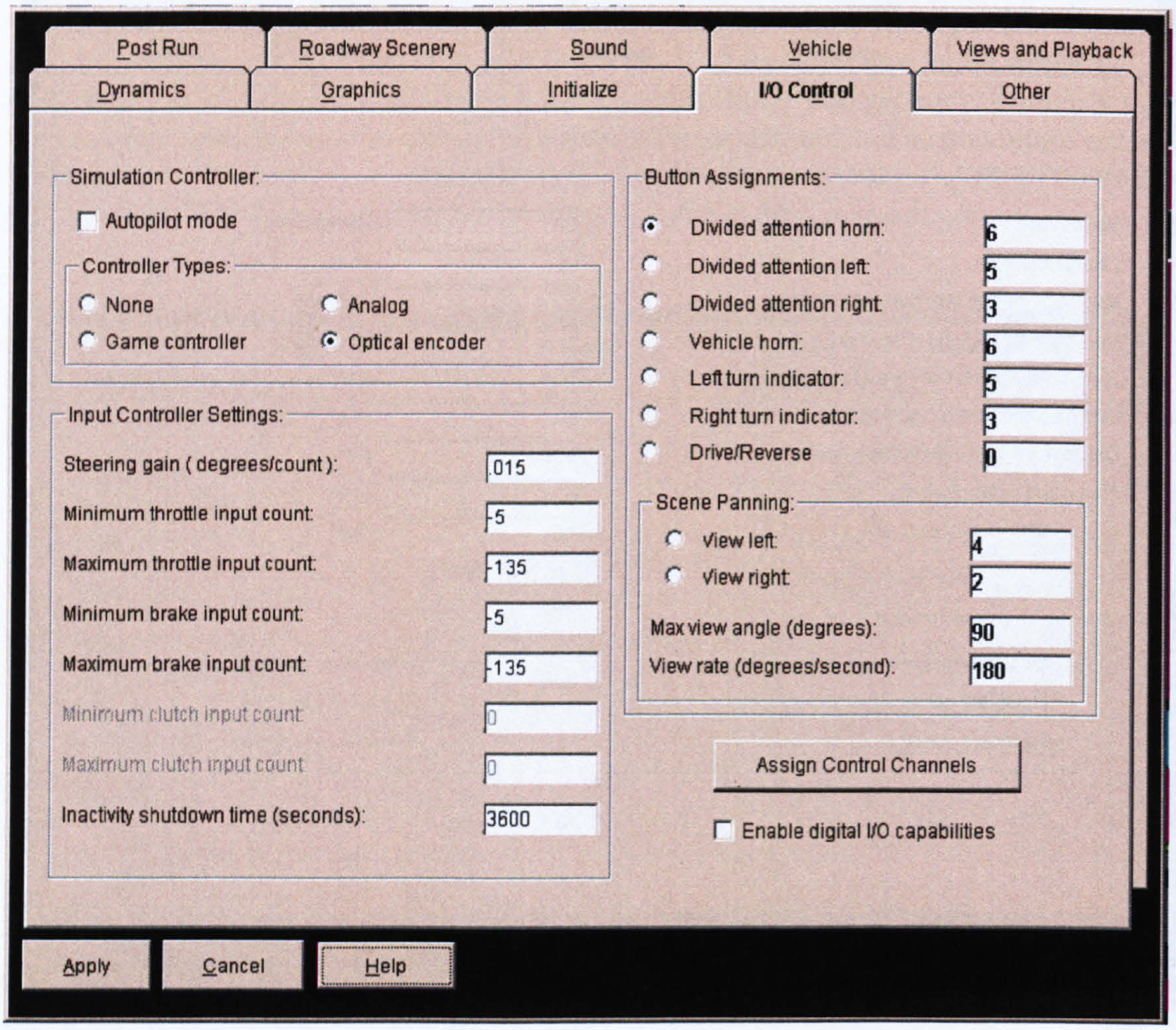
Speed limit: 60 Miles/Hour
Lateral position: -6 Feet
Maximum divided attention display time: 5 Seconds
Maximum digital input response time: 5 Seconds
Longitudinal offset distance at start of run: 0 Feet
Warm up distance (no accidents): 0 Feet
Distance off road before crash occurs: 100 Feet
Sign post lateral position: 4 Feet
Crash buffer distance: 50 Feet

Random Parameter Options:

- ● Completely random
- ○ Repeatable option 1
- ○ Repeatable option 2
- ○ Repeatable option 3
- ○ Repeatable option 4
- ○ Repeatable option 5

Figure 40 ABS Initialising Configuration

The start up parameters define how events are displayed on the screen. The ABS initialising configuration is shown in Figure 40. The speed limit is set to 60 mph. If a bus driver exceeds this limit the simulator automatically records it as a penalty. The lateral position parameter refers to the lateral position of the driver's vehicle with respect to the roadway's dividing line. The negative value indicates that the driver will begin six feet to the left of the centre line. The maximum divided attention display time and maximum digital input response time were set according to the default values because they were not required. The longitudinal offset distance specifies the position within the scenario where the driver starts the simulated run. This was set to zero to indicate that the drivers should begin at the beginning. The warm up distance allows drivers to get used to the steering a pedals with out incurring any penalties. This was set to zero because drivers completed a practice scenario that served this purpose. The distance off road before crash occurs parameter sets the maximum distance, with respect to the edge of the road that the driver can deviate from the roadway without crashing. This was set to 100 feet. Sign posts were automatically set 4 feet from the edge of the road, unless otherwise specified within the scenario programme. The crash buffer distance provides a small distance after a crash where the driver is protected from other crashes occurring.



Simulation Controller:

☐ Autopilot mode

Controller Types:

○ None ○ Analog

○ Game controller ● Optical encoder

Input Controller Settings:

Steering gain (degrees/count): .015

Minimum throttle input count: -5

Maximum throttle input count: -135

Minimum brake input count: -5

Maximum brake input count: -135

Minimum clutch input count: 0

Maximum clutch input count: 0

Inactivity shutdown time (seconds): 3600

Button Assignments:

● Divided attention horn: 6

○ Divided attention left: 5

○ Divided attention right: 3

○ Vehicle horn: 6

○ Left turn indicator: 5

○ Right turn indicator: 3

○ Drive/Reverse: 0

Scene Panning:

○ View left: 4

○ View right: 2

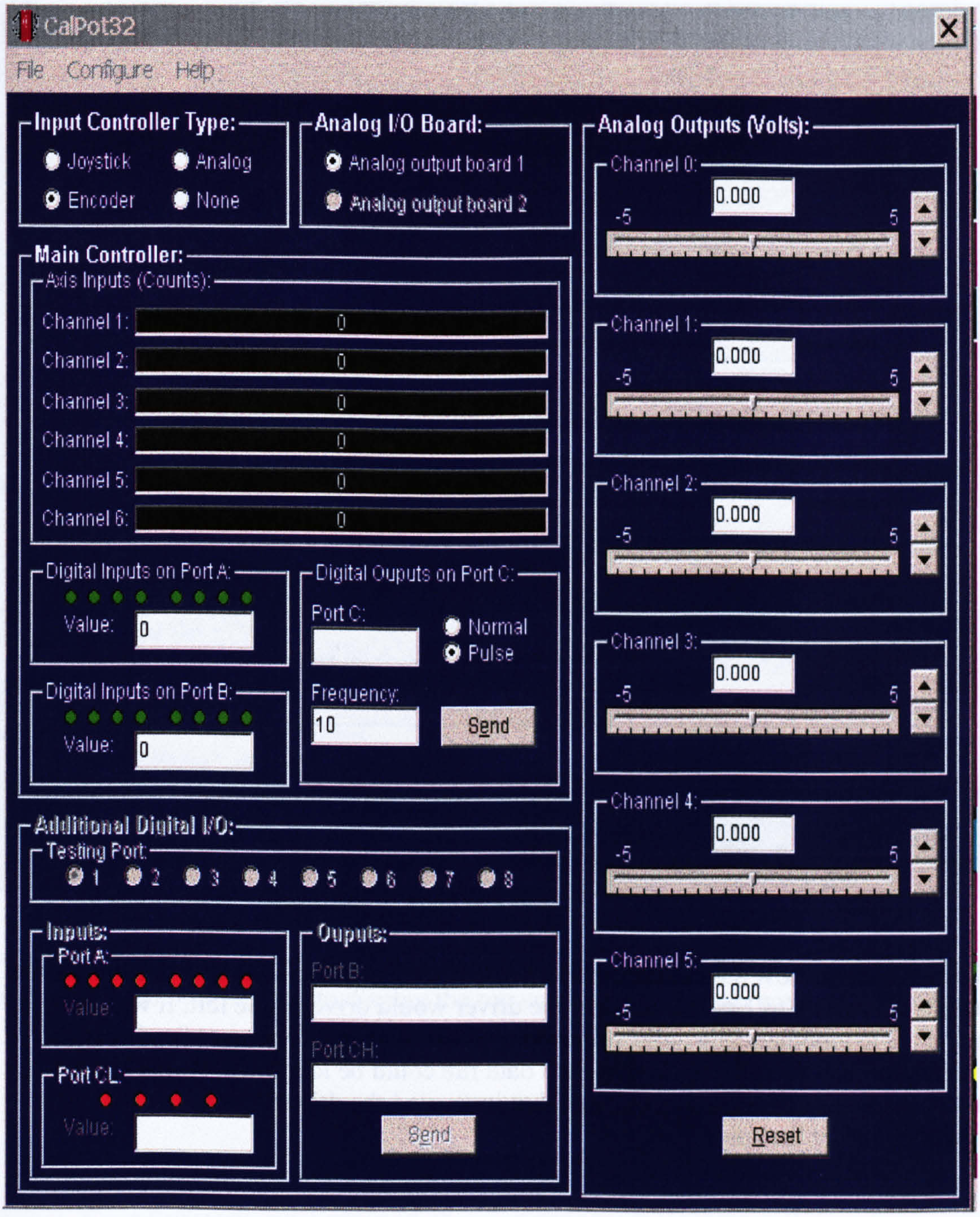
Max view angle (degrees): 90

View rate (degrees/second): 180

☐ Enable digital I/O capabilities

Figure 41 **ABS I/O Control Configuration**

Figure 41 shows how the input and output control parameters were set. Firstly the optical encoder option was selected so that the force feedback steering wheel system could be used. The simulator requires information about the input signals that it will be receiving, which is used to convert the input values into variables that the simulator can understand and use. The values were obtained by looking at the main controller axis inputs in Calpot32 which is a utility programme designed to help obtain these values (figure 42).. The steering gain and brake and throttle counts were then set. Steering gain was calculated by rotating the wheel 90 degrees to the left and then 90 degrees to the right from the centre position then subtracting the first number from the second one and then dividing 180 by this value. The steering gain is positive if the numbers increase when the wheel is turned to the right, and is negative if the numbers decrease when you steer to the right. The minimum brake/throttle input count is the value when the pedal was not pressed and the maximum brake/throttle input count is the value when the pedal was fully depressed.



Input Controller Type:
○ Joystick ○ Analog
● Encoder ○ None

Analog I/O Board:
● Analog output board 1
○ Analog output board 2

Main Controller:

Axis Inputs (Counts):
Channel 1: 0
Channel 2: 0
Channel 3: 0
Channel 4: 0
Channel 5: 0
Channel 6: 0

Digital Inputs on Port A:
Value: 0

Digital Inputs on Port B:
Value: 0

Digital Ouputs on Port C:
Port C:
○ Normal
● Pulse
Frequency: 10

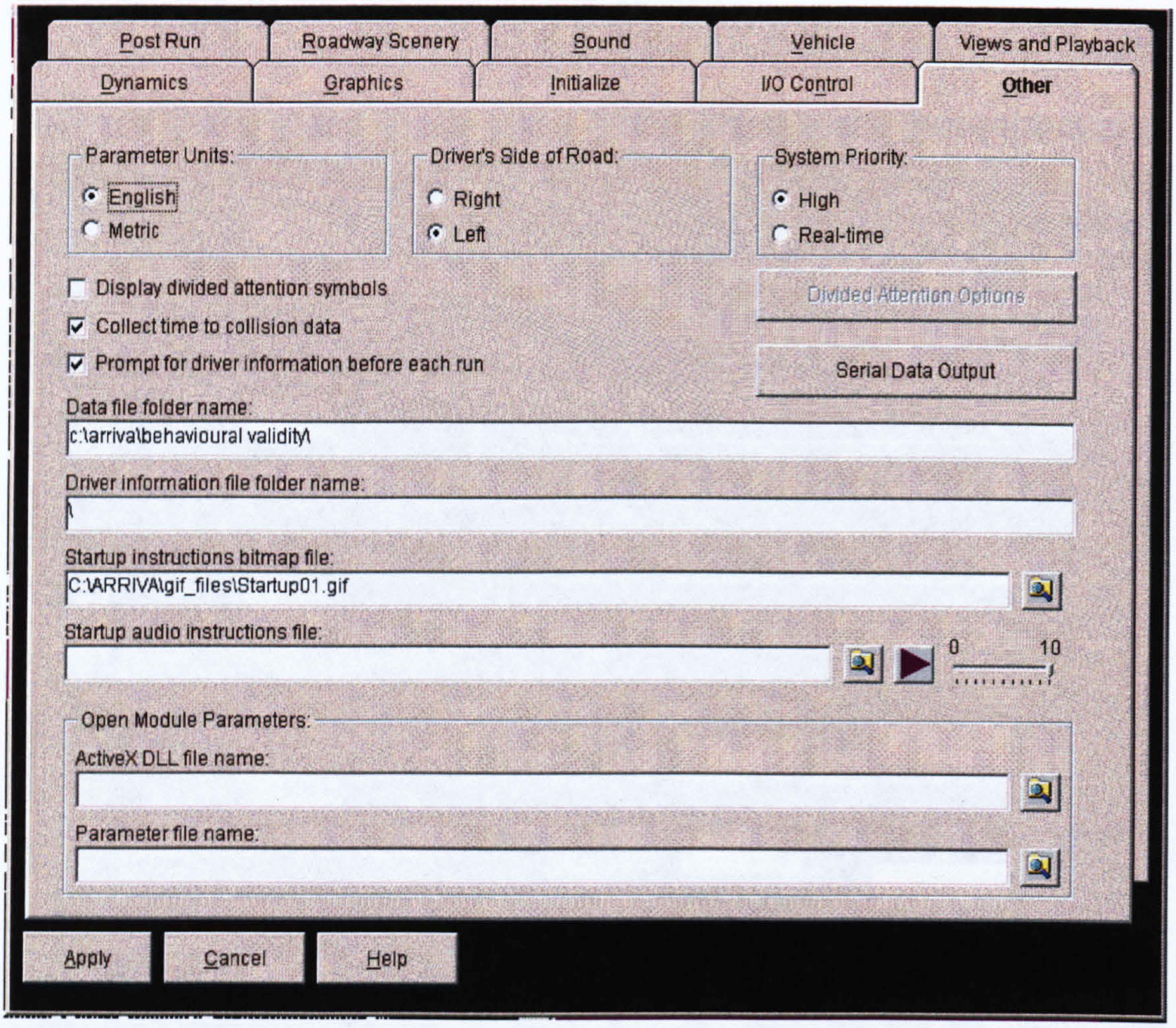
Additional Digital I/O:
Testing Port: ○ 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8

Inputs:
Port A:
Value:
Port CL:
Value:

Ouputs:
Port B:
Port CH:

Analog Outputs (Volts):
Channel 0: 0.000
Channel 1: 0.000
Channel 2: 0.000
Channel 3: 0.000
Channel 4: 0.000
Channel 5: 0.000

Figure 42 **ABS Calpot32**



Parameter Units:
● English
○ Metric

Driver's Side of Road:
○ Right
● Left

System Priority:
● High
○ Real-time

☐ Display divided attention symbols
☑ Collect time to collision data
☑ Prompt for driver information before each run

Data file folder name:
c:\arriva\behavioural validity\

Driver information file folder name:
\

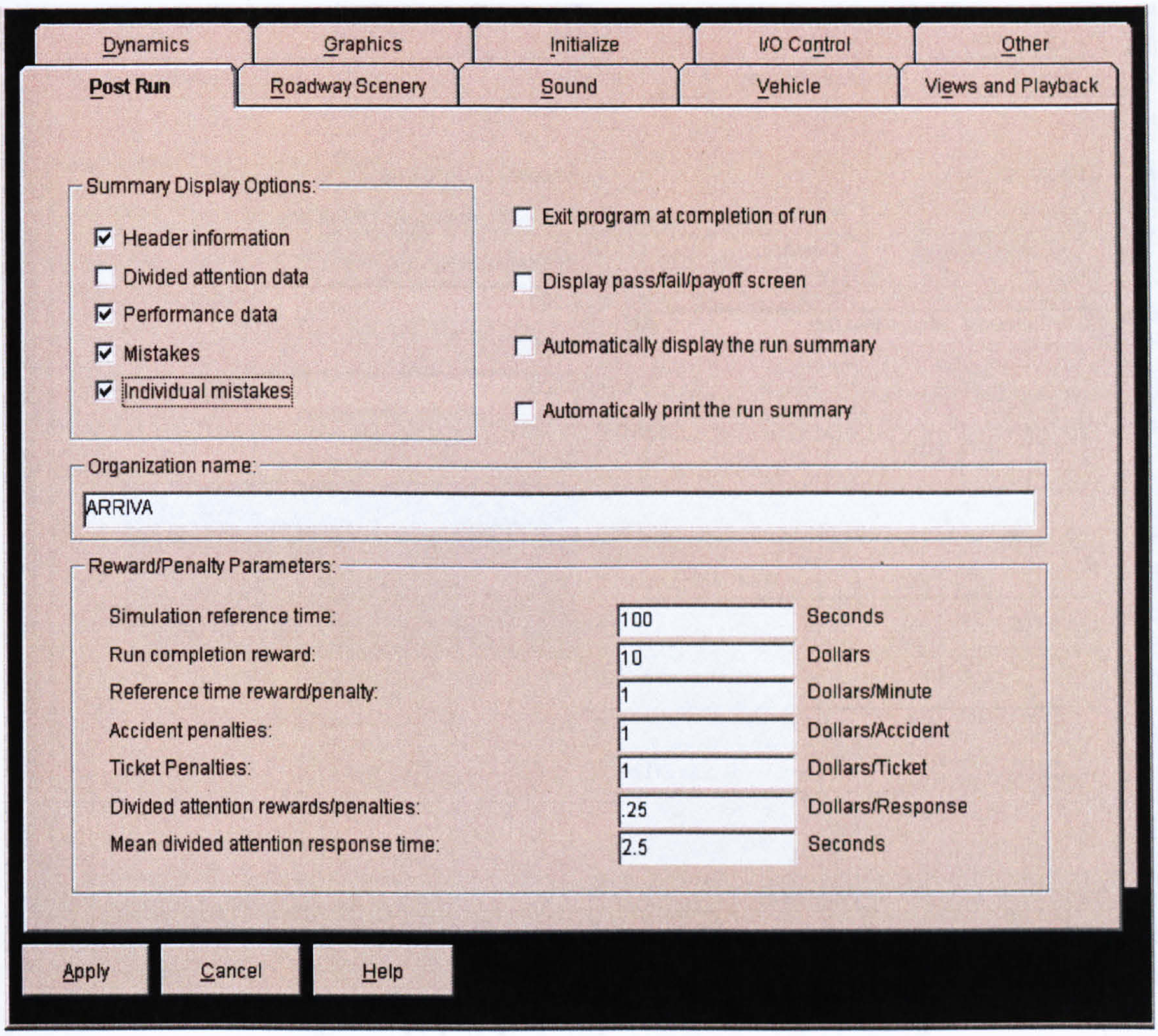
Startup instructions bitmap file:
C:\ARRIVA\gif_files\Startup01.gif

Startup audio instructions file:

Open Module Parameters:
ActiveX DLL file name:
Parameter file name:

Figure 43 **ABS Data Collection and Start up Instruction Configuration**

Figure 43 shows how data collection parameters were set. The simulator was instructed that the scenario was English and that the driver would drive on the left. It was also instructed to automatically collect time-to-collision data and to prompt for driver information before each run so that each data file could be identified. It was also instructed to display a graphical image that instructed the driver how to use the simulator before the run began.



Summary Display Options:

- ☑ Header information
- ☐ Divided attention data
- ☑ Performance data
- ☑ Mistakes
- ☑ Individual mistakes

- ☐ Exit program at completion of run
- ☐ Display pass/fail/payoff screen
- ☐ Automatically display the run summary
- ☐ Automatically print the run summary

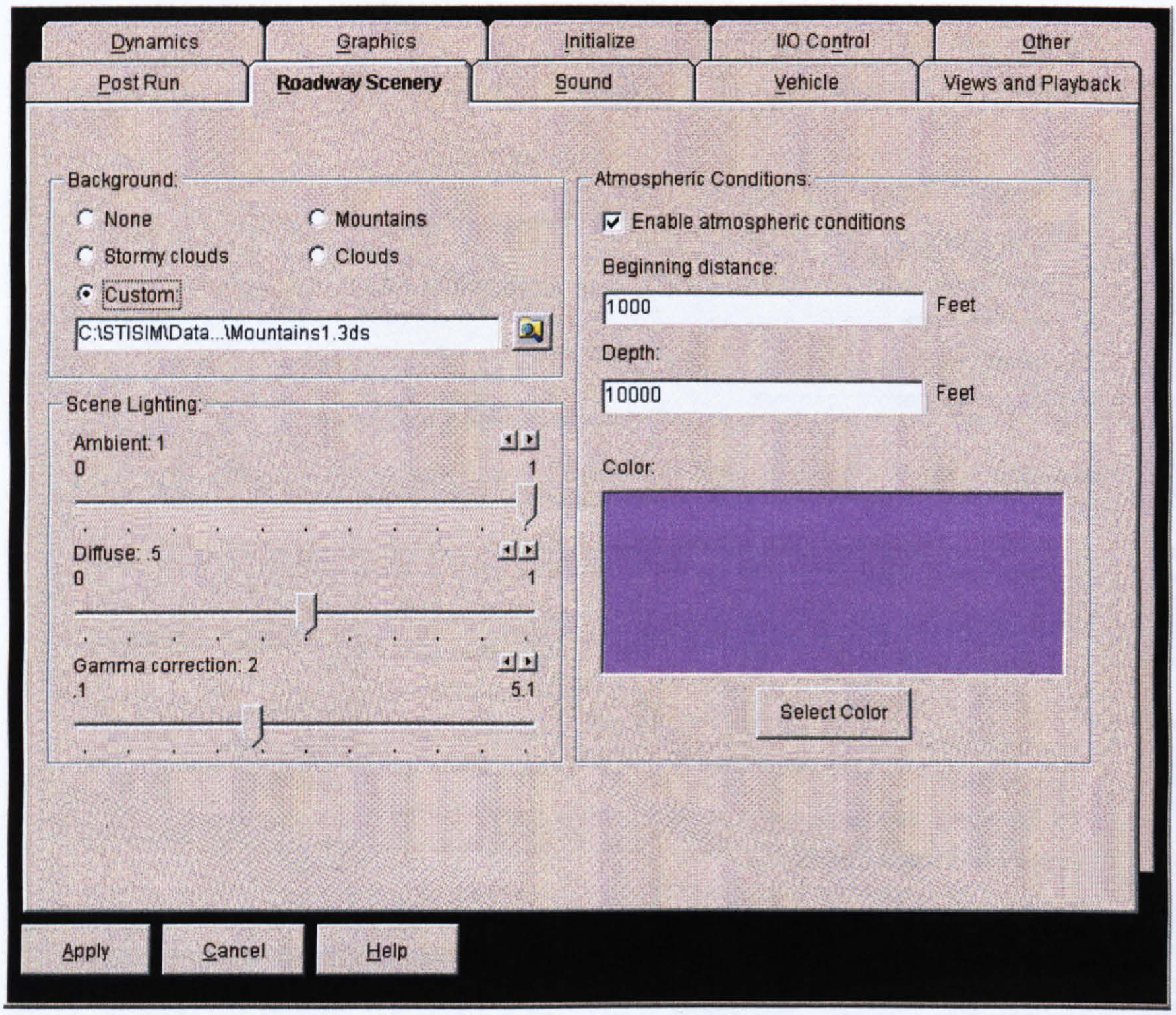
Organization name: ARRIVA

Reward/Penalty Parameters:

Simulation reference time:	100	Seconds
Run completion reward:	10	Dollars
Reference time reward/penalty:	1	Dollars/Minute
Accident penalties:	1	Dollars/Accident
Ticket Penalties:	1	Dollars/Ticket
Divided attention rewards/penalties:	.25	Dollars/Response
Mean divided attention response time:	2.5	Seconds

Figure 44 **ABS Post-run Display Options Configuration**

Figure 44 shows how the post run display option was configured. However the simulator was not instructed to display the run summary so this tab box was obsolete.



Background:

○ None ○ Mountains

○ Stormy clouds ○ Clouds

● Custom

C:\STISIM\Data...\Mountains1.3ds

Scene Lighting:

Ambient: 1 (0 – 1)

Diffuse: .5 (0 – 1)

Gamma correction: 2 (.1 – 5.1)

Atmospheric Conditions:

☑ Enable atmospheric conditions

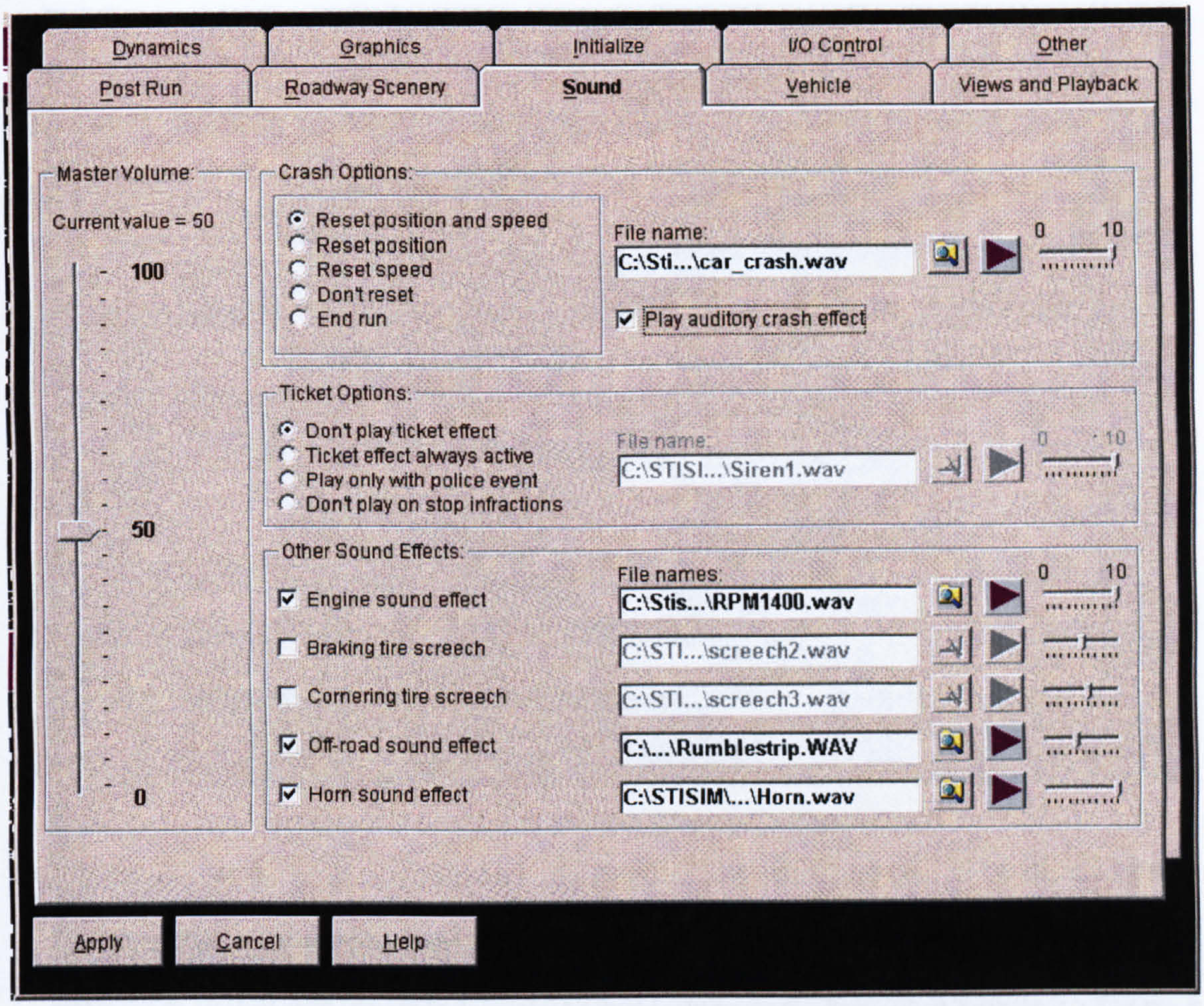
Beginning distance: 1000 Feet

Depth: 10000 Feet

Color:

Figure 45 **ABS Roadway Scenery Display Configuration**

Figure 45 shows how aspects of the driving scene that are specified, which include the background, diffuse and ambient lighting characteristics, gamma correction, and atmospheric conditions. The back ground option is set to show a 360 degree mountain range on the horizon and some clouds overhead. The ambient lighting was set to 1 to simulate daylight lighting conditions so that colours would be strong and the roadway scenery would be bright. Diffuse lighting is set to .5 to provide some shadowing to generate a three-dimensional effect on the roadway objects. Gamma correction was set to 2 because this provided the best way of correcting imperfections in the translation of colours between the graphics card and monitors used in the ABS. Atmospheric conditions simulated the effects of localised fog.



Master Volume:
Current value = 50

Crash Options:
- ● Reset position and speed
- ○ Reset position
- ○ Reset speed
- ○ Don't reset
- ○ End run

File name: C:\Sti...\car_crash.wav
☑ Play auditory crash effect

Ticket Options:
- ● Don't play ticket effect
- ○ Ticket effect always active
- ○ Play only with police event
- ○ Don't play on stop infractions

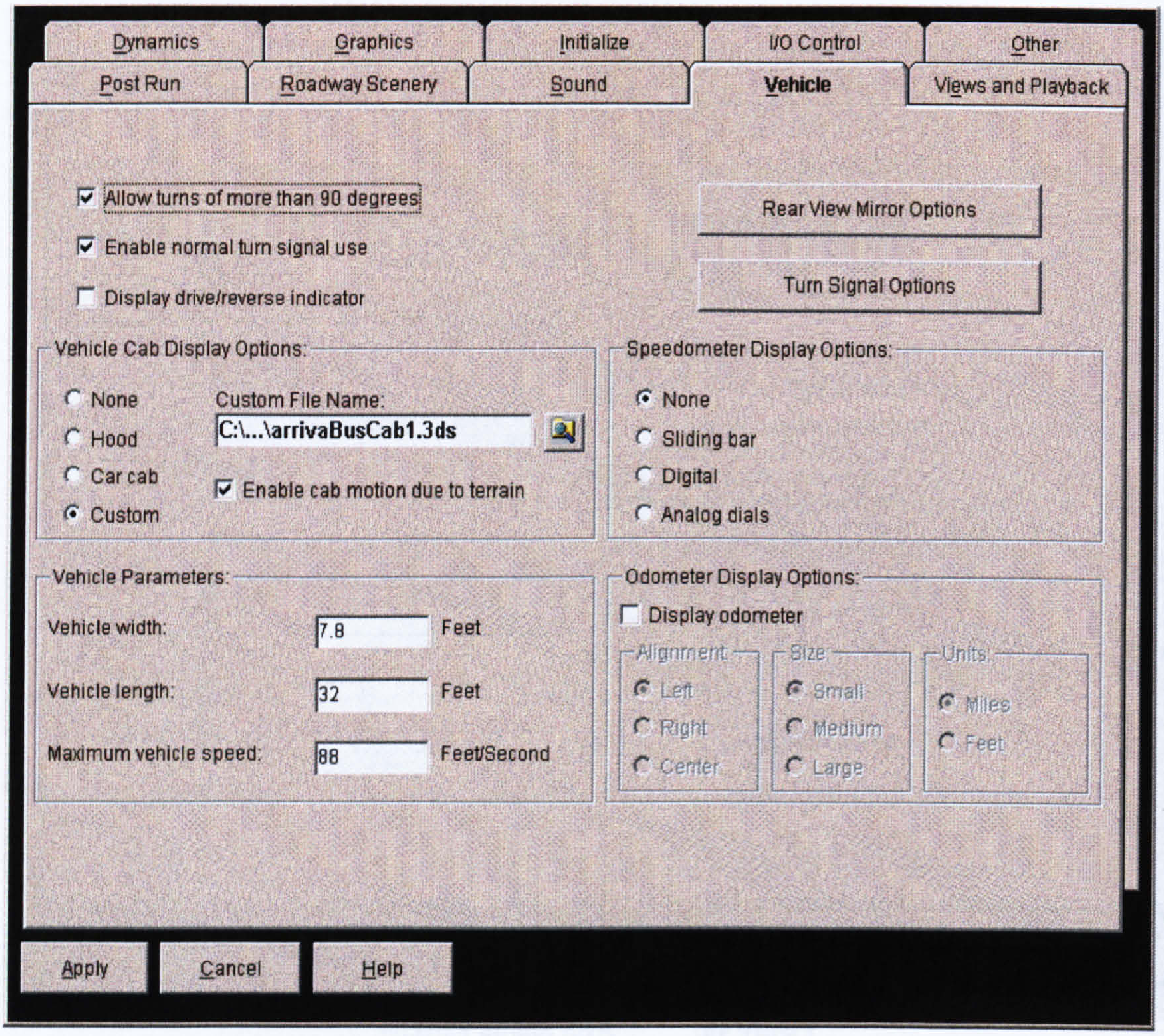
File name: C:\STISI...\Siren1.wav

Other Sound Effects:

	File names:
☑ Engine sound effect	C:\Stis...\RPM1400.wav
☐ Braking tire screech	C:\STI...\screech2.wav
☐ Cornering tire screech	C:\STI...\screech3.wav
☑ Off-road sound effect	C:\...\Rumblestrip.WAV
☑ Horn sound effect	C:\STISIM\...\Horn.wav

Figure 46 **ABS Sound Effects**

Figure 46 shows how auditory cues were set. Various sound files were recorded and were selected to play when various events occurred within the simulated scenario. Specifically these were a car crash effect, engine sounds, horn and an off-road effect which simulated the sound of a vehicle driving over gravel.



☑ Allow turns of more than 90 degrees
☑ Enable normal turn signal use
☐ Display drive/reverse indicator

Vehicle Cab Display Options:
○ None
○ Hood
○ Car cab
● Custom
Custom File Name: C:\...\arrivaBusCab1.3ds
☑ Enable cab motion due to terrain

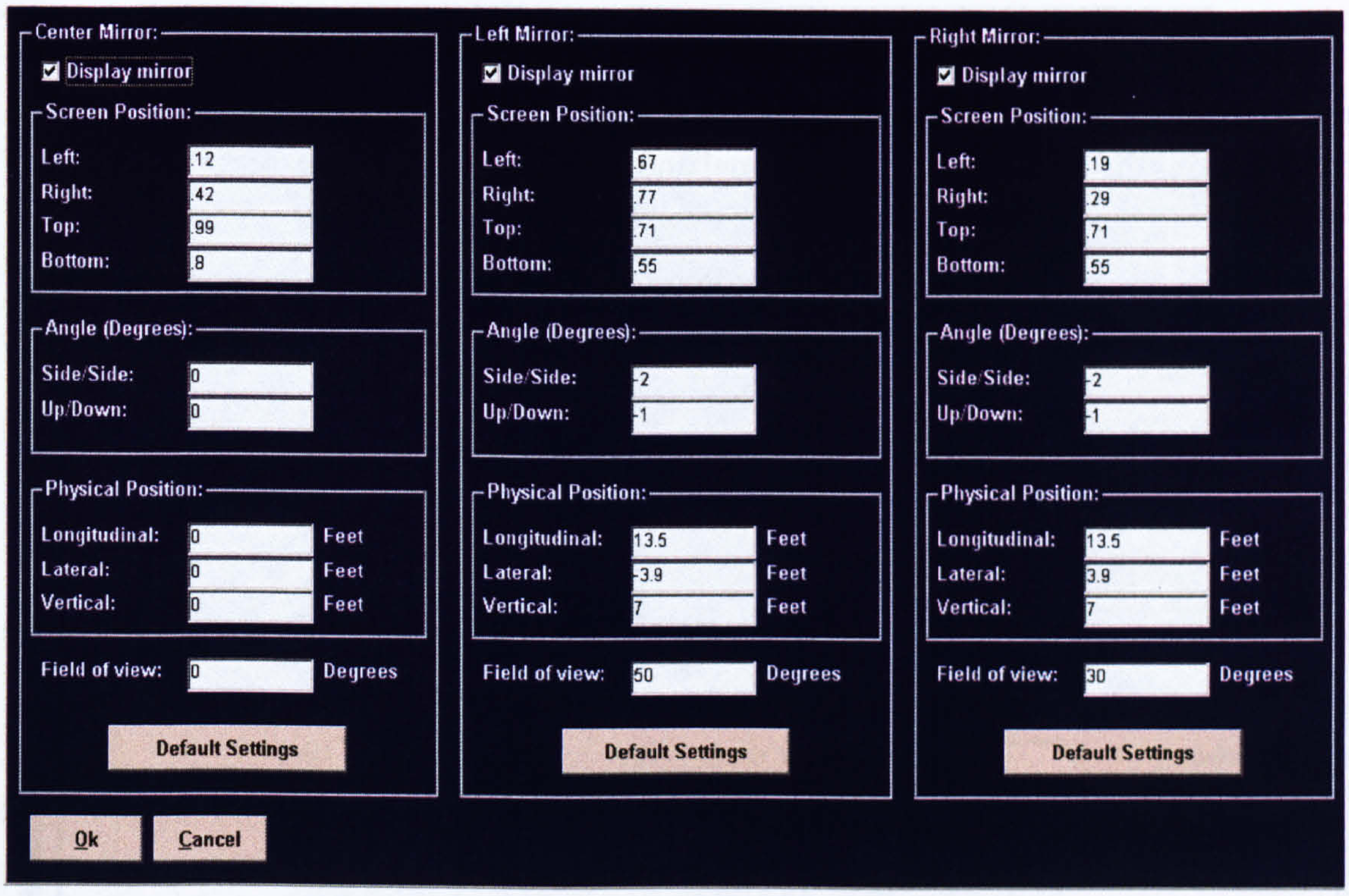
Speedometer Display Options:
● None
○ Sliding bar
○ Digital
○ Analog dials

Vehicle Parameters:
Vehicle width: 7.8 Feet
Vehicle length: 32 Feet
Maximum vehicle speed: 88 Feet/Second

Odometer Display Options:
☐ Display odometer
Alignment: ● Left ○ Right ○ Center
Size: ● Small ○ Medium ○ Large
Units: ● Miles ○ Feet

Figure 47 **ABS Vehicle Display Configuration**

Figure 47 shows how the physical characteristics of the bus were configured and were based on actual measurements of a bus. The vehicle width and length are used by the simulator in its collision detection algorithms to determine whether the driver comes in contact with other objects in the scenario. A maximum vehicle speed of 88 ft/sec was used to limit how fast the bus can go.



Center Mirror:

☑ Display mirror

Screen Position:

Left: .12

Right: .42

Top: .99

Bottom: .8

Angle (Degrees):

Side/Side: 0

Up/Down: 0

Physical Position:

Longitudinal: 0 Feet

Lateral: 0 Feet

Vertical: 0 Feet

Field of view: 0 Degrees

Left Mirror:

☑ Display mirror

Screen Position:

Left: .67

Right: .77

Top: .71

Bottom: .55

Angle (Degrees):

Side/Side: -2

Up/Down: -1

Physical Position:

Longitudinal: 13.5 Feet

Lateral: -3.9 Feet

Vertical: 7 Feet

Field of view: 50 Degrees

Right Mirror:

☑ Display mirror

Screen Position:

Left: .19

Right: .29

Top: .71

Bottom: .55

Angle (Degrees):

Side/Side: -2

Up/Down: -1

Physical Position:

Longitudinal: 13.5 Feet

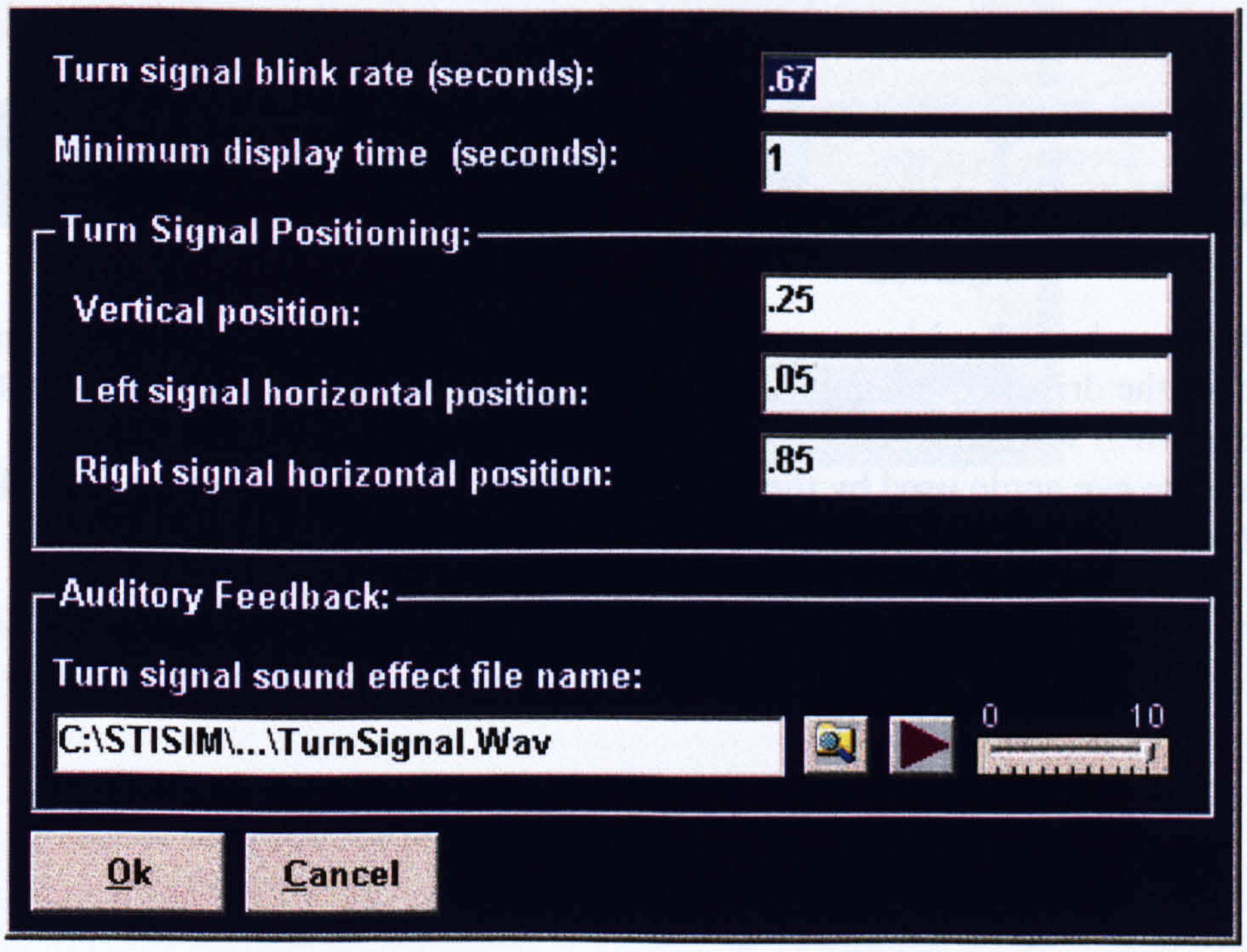
Lateral: 3.9 Feet

Vertical: 7 Feet

Field of view: 30 Degrees

Figure 48 ABS Mirror Display Configuration

Figure 48 shows the size, position and angle of the left, right and rear view mirrors on the screen. There were separate graphics processors for each mirror. Mirrors could also be altered during the simulation run time by using the F9, F10 keys for side to side and F11, F12 for up-down motion.



Turn signal blink rate (seconds): .67

Minimum display time (seconds): 1

Turn Signal Positioning:

Vertical position: .25

Left signal horizontal position: .05

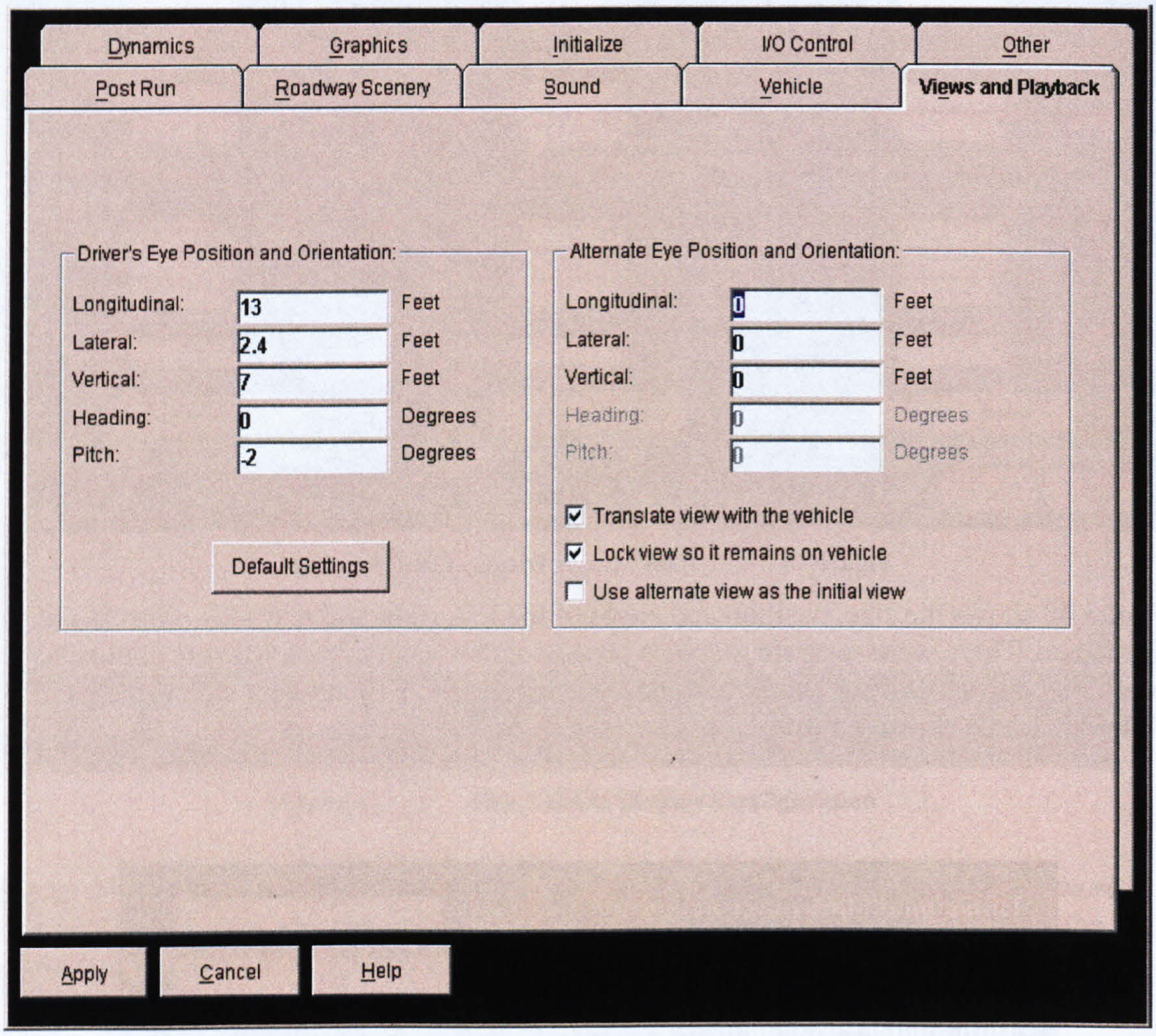
Right signal horizontal position: .85

Auditory Feedback:

Turn signal sound effect file name: C:\STISIM\...\TurnSignal.Wav

Figure 49 **Turn Signal Configuration**

Figure 49 shows how the turn signal was configured. The indicator will remain on for one second if the driver activates the signal and then immediately releases it, otherwise the indication image will disappear when the turn indicator is released.



Driver's Eye Position and Orientation:

Longitudinal: 13 Feet
Lateral: 2.4 Feet
Vertical: 7 Feet
Heading: 0 Degrees
Pitch: -2 Degrees

Alternate Eye Position and Orientation:

Longitudinal: 0 Feet
Lateral: 0 Feet
Vertical: 0 Feet
Heading: 0 Degrees
Pitch: 0 Degrees

☑ Translate view with the vehicle
☑ Lock view so it remains on vehicle
☐ Use alternate view as the initial view

Figure 50 **ABS Views and Playback Option**

Figure 50 shows how the drivers eye position was configured. Eye height is dictated by the height of the driver's seat and was therefore measured from the ground up to the driver's eye when seated in a real bus. The pitch combined with the eye height determines the eye angle used by the simulator to view the roadway scene. The alternate eye position and orientation was not used.

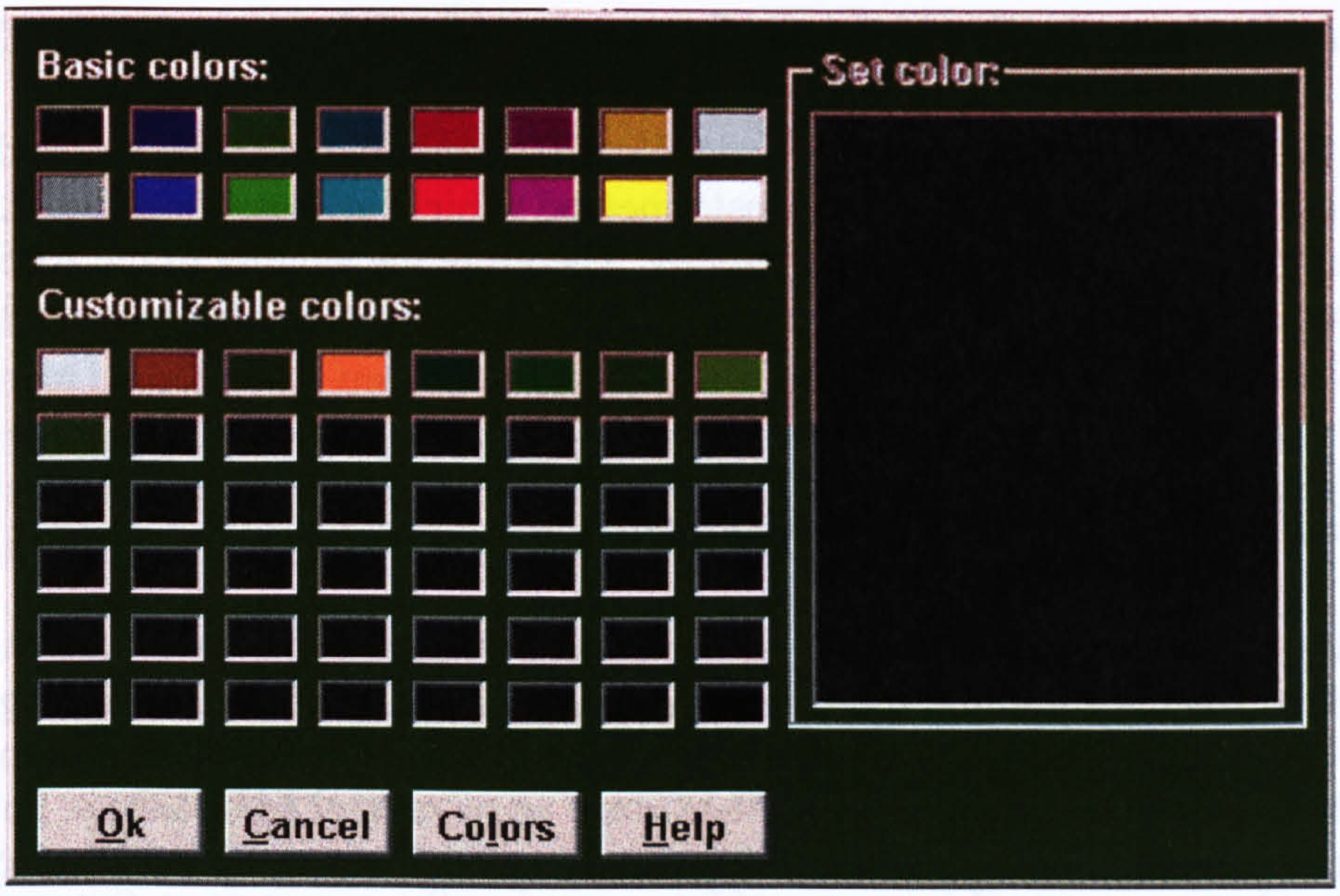
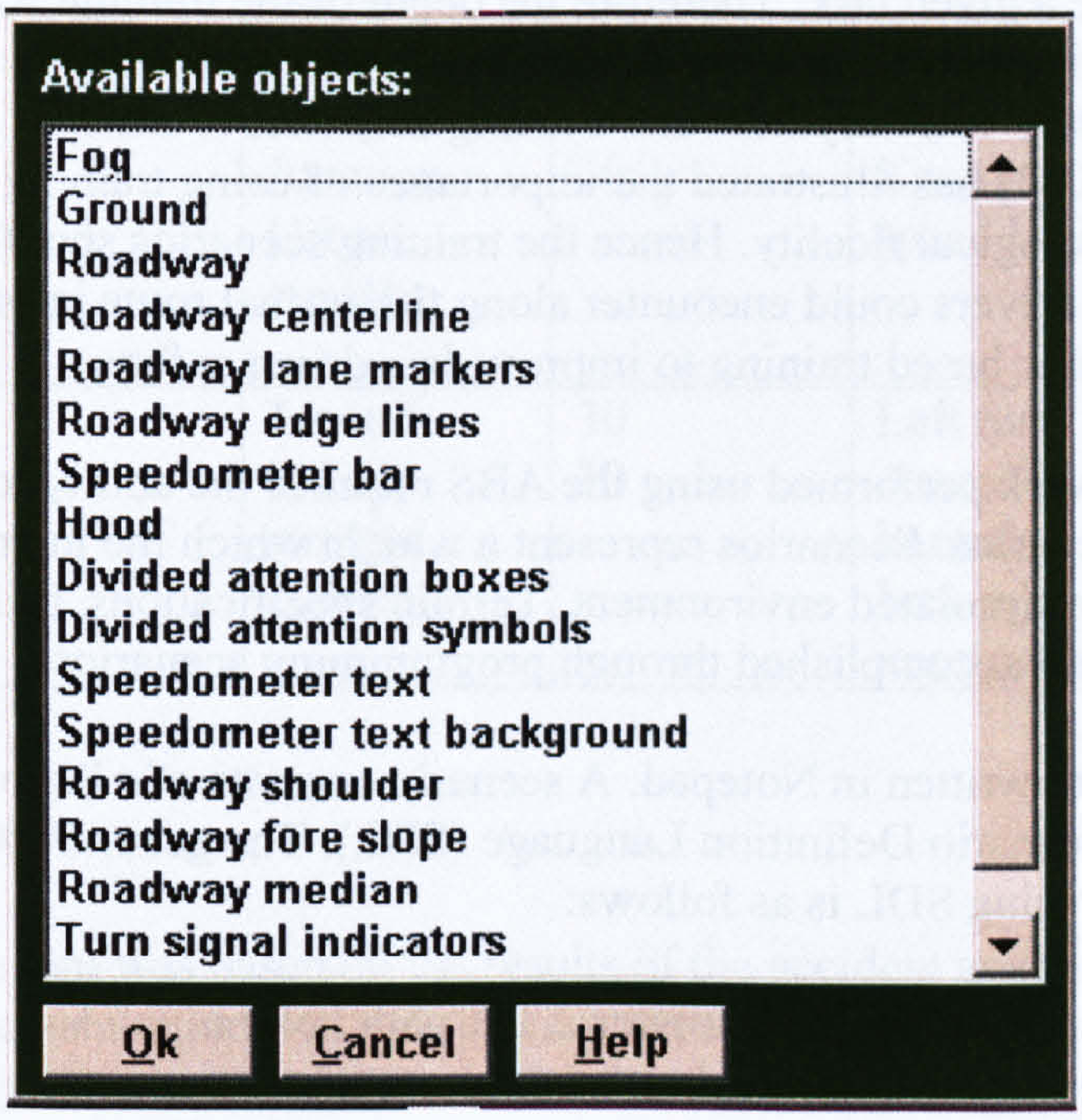


Figure 51 **ABS Colour Configuration**

Figure 51 shows the palette of colours available for use in the simulation.


Available objects:

- Fog
- Ground
- Roadway
- Roadway centerline
- Roadway lane markers
- Roadway edge lines
- Speedometer bar
- Hood
- Divided attention boxes
- Divided attention symbols
- Speedometer text
- Speedometer text background
- Roadway shoulder
- Roadway fore slope
- Roadway median
- Turn signal indicators

Figure 52 **ABS Colour Assignment**

Figure 52 shows the list of objects in the roadway environment. The final step was to assign colours to these objects.

6.2.2 Limitations to the Vehicle Dynamics Model

Duncan (1995) and Harms (1996) proposed that differences between the size and capabilities of the engine of the real or instrumented vehicle and the simulated vehicle model may result in a lack of absolute validity. Therefore the validity of the ABS may be compromised by the fact that the vehicle dynamics model of the ABS is far simpler than the dynamics of an actual bus.

6.2.3 Training Scenario Development

The validity of a training simulator is task dependent (Kaptein, Theeuwes, and van der Horst, 1996). Since the training scenario is the environment in which the training activities are executed, training effectiveness is closely related to scenario design (Farmer et al, 1999). A simulated scenario is made up of several components. For ground vehicle simulations, each scenario has an associated terrain or road network and further specifications such as traffic, pedestrians, weather and road friction. It is imperative therefore that these elements are arranged in a scheme that supports the training objectives and that the simulated cues provide adequate information so that the driver can complete a given task. Therefore the detail of the training scenario needs to be sufficient for trainees to complete the tasks that are required and so the amount of detail that is necessary will vary between training activities (Farmer et al 1999). The work of Machin (2003) has illustrated the importance of using training materials with a high level of psychological fidelity. Hence the training scenarios should represent real life events that bus drivers could encounter along their usual route in order to provide high fidelity simulator based training to improve bus driver safety.

The experimental work performed using the ABS requires the ability to programme and develop driving scenarios. Scenarios represent a way in which the instructor can interact with and control the simulated environment. Terrain specifications, traffic events and data collection are all accomplished through programming scenarios.

STIsim scenarios are written in Notepad. A scenario consists of a list of events. Events are defined using Scenario Definition Language (SDL). The general syntax for designing an event using SDL is as follows:

```
on-distance, event, parameter 1, parameter 2, .... parameter n
```

```
100, A, 40, 400, 6, *1~8
```

The example above places a vehicle approaching (A) in the driver's opposite direction. It first appears after the driver has travelled 100 ft through the scenario, at a speed of 40 ft/second and is placed 400 ft ahead of the driver. It is 6ft to the right of the central dividing line, which just about places it in the middle of the right hand lane. The vehicle model will be randomly selected from the first eight models in the graphics database. SDL is used in this way to specify sequences of different events to create simulated training scenarios.

6.2.4 Scenario Description

6.2.4.1 Practice Session

Brock et al (2001) advise that drivers should be allowed to acclimatise to the simulated environment before being trained or tested to minimise discomfort and the potential for the confounding influence of simulator sickness on performance outcomes. Table 20 summarises the practice scenario, which gradually increased in terms of scene and task complexity.

Table 20 Practice Session Summary

Session	Approximate Duration (mins)	Road	Speed Limit (mph)	Tasks	Scene Complexity
1	2 3	Rural, straight Rural, curved	20 40 – 60	Keep to speed limit	Low: speed limit sign
2	2 1 2	Rural straight Junction Urban, straight	60 30 30	Bus stops Right turn Keep to speed limit	Medium: bus stop, tress, pedestrians, few vehicles
3	1 4	Junction Urban, straight, curves	30 30	Left turn Attend to hazards, braking, accelerating	High: tress, vehicles, buildings, pedestrians, hazards

6.2.4.2 Test Session

The test session design was based on the results of the accident analysis (chapter 5) and was developed in consultation with bus driving experts. It was a short 30000ft route that took approximately 10 minutes to drive in the simulator and was based on a section of a real bus route. The figures show how the fidelity of the simulated scenarios compares with photos of the real route. It began with a clear road that was signposted with national speed limits (50mph for a bus). As the drivers progressed they encountered a slow moving vehicle (30mph) where they had to decide firstly whether to overtake immediately but in the face of oncoming vehicles, secondly to overtake safely a bit later on in the scenario or thirdly not overtake at all. The road led into a residential area (30mph limit), past some major road works and then a pelican crossing, with a pedestrian who stepped out of the road. They then had to negotiate a three lane junction, followed by a parallel bus stop. They then encountered another pelican crossing, but this time there were no pedestrians (Figure 53). Next there was the potential hazard of a car waiting to turn right, then a zebra crossing with no pedestrians waiting. They then encountered a lay by bus stop with a passenger waiting to board (Figure 54). They then pulled out onto a wide road with a 40mph speed limit. This was followed by a left turn into a road with a 30mph limit and cars that were parked quite close to the junction, which made the task of turning more difficult. The route took them past a school, with a recommended 20mph speed limit at this location. The bus drivers then had to negotiate a set of traffic lights that changed from green to amber as they approached (Figure 55). This was followed by the task of pulling into a parallel bus stop so that passengers could alight (Figure 56). The route then progressed along a wide curving road with cars parked on either side. Next the bus drivers had to negotiate a tight right turn in the face of oncoming vehicles into a busy high street (Figure 57 and 58). There the driver had to negotiate a pelican crossing, parked cars and a white van that pulled out suddenly as the bus driver approached. The route ended as the bus went round a bend in the road and over a hill into a wide road with a 50mph speed limit.

Figure 53 **Pelican Crossing**

Figure 54 **Lay by Bus Stop**

Figure 55 **Traffic Lights Changing to Amber on Approach**

Figure 56 **Parallel Bus Stop**

Figure 57 Approaching Right Turn

Figure 58 Turning Right

6.2.5 Bus Driver Performance Data Collection

For simulator based training to be effective, it is necessary to be able to assess and evaluate trainee performance (Farmer et al, 1999). However, Vreuls and Obermayer (1985, cited in Farmer et al, 1999) recognised that many advanced simulators of their time did not measure operator performance sufficiently. Farmer et al (1999) cite sources that have investigated problems encountered when trying to establish simulator-based (objective) performance measures and conclude that both objective and subjective measures are needed in simulator training performance assessment. For example, driver behaviour in real and simulated conditions can be measured by a large number of performance parameters and judgements about driving performance are based on evaluating these driving parameters, which are taken when drivers perform certain driving tasks. Driving parameters include measures of driver behaviour such as braking, speed, steering wheel reversals, lateral and longitudinal distance, and acceleration in all axes, head movements and lane position. In addition to these parameters, measures of total system performance such as time taken to complete a task and errors may also be taken. Most researchers take several measures of driving parameters during one study. For example, Duncan (1995) took measures of speed, acceleration, braking, lateral distance and longitudinal distance to leading car to calculate stopping distances, plus responses to a secondary in car task to validate the TRL driving simulator. The ability to record data from a simulation then is critical to research and training with the simulator. However, although simulators are typically designed to recreate the real system, perhaps only one or two simulator measures are used to feed back to trainers – even in flight simulation (Farmer et al, 1999).

The situation in the ABS is very different, with over 50 different driver performance and scenario parameters that are available to be fed back to the trainer or driver. This is accomplished both through programming within the scenario to specify which driving variables should be sampled and by writing post data collection conversion programmes. The first step in data collection is to create a condition that specifies the frequency at which data should be recorded during the simulation. Frequency can be in time or distance depending on the needs of the instructor and the type of work being conducted; for these studies the ABS was configured to record data at five-foot intervals to account for individual variations in speed. The second step is to define the driving performance measures that will be collected, which again depends on the task objectives and needs of the instructor. Driving performance will change in response to changing task demands as the driver adapts to situations presented in the scenarios (Cnossen, Rothengatter and Meijman (2000). The following sections describe the parameters collected in the ABS and some of the potential limitations with using this data.

6.2.5.1 Longitudinal Control

The ABS is capable of taking measures of longitudinal control including speed, braking, acceleration, and headway choice and time-to-collision estimations. Speed is implicated in approximately one third of all road traffic accidents (West, French, Kemp and Elander, 1993). Speed variation is therefore considered to be a superior predictor of accident involvement (Wåhlberg, 2003). A driver's age and experience influences their speed choice. For example, older drivers tend to drive more slowly on average than younger drivers (Duncan, 1995). Since the ultimate motivation behind the development of the ABS is to train bus drivers to drive safely in order to reduce accidents, measuring a driver's speed at various points throughout the simulation seems to be paramount. Mean speed, speed variation (or variance) and speed relative to other vehicles in front and to the side may be used as speed related measures of driver performance. However, in comparison with driving on a real road, higher speeds are usually observed in the simulator both on straight roads (Blaauw, 1982) and curved roads (Duncan, 1995; Tornos, 1998).

Acceleration and braking performance are important measures of bus driver behaviour because braking or accelerating too harshly can be uncomfortable for passengers and may lead to passenger injuries from falling. Acceleration behaviour is considered to be a stable measure of driver performance and a tentative link between acceleration behaviour and bus accident rates has been found (Wåhlberg, 2003; 2004). Hence braking and acceleration pressure will be recorded. However, Duncan (1995) and Kaptein et al (1996) found that braking over a long distance is one of the most demanding aspects of simulated driving. Duncan (1995) observed that participants tended to overcompensate, use the brake more frequently and generally stopped short of the target. Olsen & Andre (1996) also found that participants used the brake more frequently in simulated conditions. However over shorter distances Kaptein et al (1996) found that braking manoeuvres are not more difficult in simulated conditions.

6.2.5.2 Lateral Control

The ABS is capable of recording several driving parameters that measure a driver's ability to laterally control a vehicle. Steering behaviour is related to the control of the vehicle. Hence, steering behaviour is sensitive to variations in workload (Matthews and Desmond, 2002) and driver distraction. For example, Wikman, Nieminen and Summala (1998) examined the length of drivers' glances away from the road while performing a secondary in-car task during on-the-road driving and showed that longer glances were associated with greater lateral displacement of the vehicle. Measures of steering behaviour include steering wheel reversals rate, steering wheel position and steering wheel angle. However, Blaauw (1982) found that participants steer at higher frequencies in the simulator than in the real world on straight roads. Other lateral control measures include lane position and standard deviation of lane position, which can be considered as a measure of car swerving (Cnossen, Rothengatter and Meijman (2000). Blaauw (1982), Harms (1996) and Wade and Hammond (1998) revealed significant differences in lateral lane position in the simulator and real world. However, Alm (1995) did not find significant differences between mean lateral lane positions in real and simulated environments but did find a significant increase in lateral position variation compared to driving on a real road.

The seemingly conflicting results regarding lane position variance may be attributed to differences in choice of route comparison. Some researchers take curves into consideration, whereas others do not. Another explanation may be differences in the complexity of the simulated environment. For example, Harms (1996) suggested that lateral position is sensitive to the presence of other road users and objects in the visual display so greater variation in lateral position may be expected in a simulator with a more complex visual display.

6.2.5.3 Interaction with other Vehicles

Measuring headway choice can indicate whether a driver is engaging in risky behaviour. For example, younger drivers have been observed to have closer following distances than older drivers (Baxter, Manstead, Stradling, Campbell, Reason and Parker, 1990). However Duncan (1995) observed that fixed and safe headway choice and mean and minimum following distances were greater in the simulator than on the test track and his participants reported that this task was particularly difficult in a simulator.
A time-to-collision (TTC) parameter estimates the time it would take for a collision to occur if drivers maintained their current course. However, under simulated conditions for both wide and narrow FOV, a driver's TTC estimates are greater at high speeds, but at 30mph, TTC estimates are no different in simulated and field trials (Kaptein et al, 1996). Given this, the ABS will use two measures, TTC and Range to indicate the distance between the driver and other vehicles in the scenario.

The following table presents the parameters that represent the variables that were collected from the ABS during the simulated scenarios. Means and standard deviations were used to evaluate longitudinal control, lateral control and interaction with other vehicles in the scenario.

Table 21 Driving Performance Parameters Collected in the ABS

Driver Summary Variables	Total longitudinal distance that the driver has travelled since the beginning of the run (feet)
	Elapsed time since the beginning of the run (seconds)
	Running compilation of the number and type of crashes that the driver has been involved in:
	1 - Vehicle collisions
	2 - Off road collisions
	3 - Collisions with pedestrians
	Horn indicator, 0 if horn button is pressed
	Left turn signal indicator, 0 if turn indicator is on
	Right turn signal indicator, 0 if turn indicator is on
Longitudinal Control	Driver's longitudinal acceleration (feet/second^2)
	Longitudinal acceleration due to the throttle (feet/second^2)
	Longitudinal acceleration due to the brakes (feet/second^2)
	Driver's longitudinal velocity (miles/hour)
	Current transmission gear
Lateral Control	Driver's lateral lane position with respect to the roadway dividing line, positive to the right (feet).
	Vehicle heading angle (degrees)
	Steering wheel angle input (degrees)
	Steering wheel rate (radians/sec)
Interaction with Other Vehicles	TTC in-lane
	Range in lane
	TTC opposing lane
	Range opposing lane
Scenario Data Parameters	Longitudinal position of the roadway vehicle with respect to the driver's vehicle (feet)
	Lateral position of the roadway vehicle with respect to the roadway's dividing line (feet)
	Current traffic signal light position:
	0 - No signal light present,
	1 - Green light,
	2 - Yellow light,
	3 - Red light

6.2.6 Limitations of the ABS Data Collection

New software versions have been introduced throughout the development of the ABS to try and enhance fidelity and therefore performance. However the implementation of new software versions was not always accomplished by the complete removal of old versions, thus some bugs in the old software remained which affected the way that the ABS collected performance data.

Firstly, the data was not recorded at exactly five feet intervals. This is because the distance that the vehicle travels is based on the speed of the vehicle and the frame refresh rate. For example, if the driver was driving at 40 ft/second (30mph) and the frame rate is 20 hz, which means it refreshes every .05 seconds, the driver may have travelled a further two feet before the data is saved..

Secondly, some parameters were not collected accurately due to bugs in the software; specifically brake pressure was monitored incorrectly due to the fact that the equations underlying the braking configuration were not correct. However, since the error was consistent across participants, differences in braking between participants can still be meaningfully interpreted although the absolute validity of the braking component of the simulator when compared with a real bus is certainly questionable.

One final concern is the fact that the lane widths in the simulated route were programmed to be wider than in real life to compensate for difficulties in manoeuvring the bus around corners due to deficiencies in the steering wheel components of the ABS. Again, this is consistent across participants so relative differences in behaviour can still be meaningfully interpreted, although the absolute validity of the positioning variables is questionable.

6.3 Summary of ABS Construction

The level of fidelity built into the ABS was driven by the cognitive and behavioural requirements of the bus driving task, which were determined by an analysis of bus accidents (chapter 5). The ABS then is a fixed-base moderate fidelity system built to present a wide field of view to facilitate the requirements for novice bus driver training. The next step then is to determine the value of the ABS by investigating the trainees' performance.

7 Face Validity Evaluation of the Arriva Bus Simulator

7.1 Rationale for the Study

A pre-requisite for the introduction of a new programme for training is acceptance by the trainee. There is little value in designing a new training solution if it is never used. Since user acceptance is apparently dependent on the level of fidelity of the simulator (Salas, Bowers and Rhodenzier, 1998), bus driver's acceptance of the ABS was investigated by assessing face validity. Although low face validity may not directly affect the validity of the results obtained from the simulator during training, it may affect driver's motivation and acceptance of the simulator as a training device.

The study reported here involved evaluating the perceived degree of similarity between the components, layout, and dynamic characteristics of the bus simulator and its real world counterpart and the potential value of the simulator as a training device.
It begins with a brief rationale for the study and a review of the pertinent literature, followed by the development of a comprehensive face validity questionnaire. The results of the study are described and discussed.

7.2 The Importance of Face Validity in Training Simulators

The term face validity refers to the subjective assessment of the similarity between the simulator and real task environment (Blana, 1999). Simulators are often evaluated subjectively by having an expert/instructor use it then provide an assessment. (Rolfe, Cook and Durosel, 1996). When evaluating flight simulations, pilots are often asked their opinions as to whether they 'like' or believe in the device they are using (Salas, Bowers and Rhodenzier, 1998). In contrast, there has been little investigation into the face validity of driving simulators because achieving behavioural validity is considered to be more desirable. With reference to driving simulators, face validity refers to whether the trainees using the simulator think that it is a good representation of real driving. If a driving simulator has good face validity it means that the driver perceives that the simulator replicates the driving environment sufficiently to seem like a real vehicle (e.g. the simulator brake pedal appears to have the same resistance as the real brake pedal). In general, face validity increases with the more cues that are replicated by the simulator. For example more complex visual scenes and moving bases make the simulator seem more realistic. User acceptance is therefore related to the level of fidelity of the simulator (Salas, Bowers and Rhodenzier, 1998). For example, Korteling, Van der Bosch and Van Emmerik (1997) found that participants in their experiments were more motivated to perform a simulated task when the simulator closely resembled the real situation. Korteling and Sluimer (1999) also reviewed several validation methods and concluded that face validity is an important consideration because if people do not believe in the validity of the simulator they are not likely to use it properly. Yet face validity is not necessarily related to the absolute or relative behavioural validity of the simulator, which indicates the correspondence between behaviour in the real and simulated environment. Low face validity may not directly affect the validity of results obtained from the simulator; however if it affects driver's motivation this may in turn affect validity (Blana, 1996). It should not be assumed that increasing face validity enhances the behavioural validity of the simulator. As previously discussed in chapter 2, simulator fidelity is one of the factors that may influence the face validity and drivers' acceptance of the simulator. Therefore the issue of realism is central to the face validity of the simulator.

The realism of the simulator is usually ascertained using questionnaires to gather information about the impressions and opinions of the people driving the simulator. Of the driving simulator validation studies reviewed for this thesis, four of them collected data relating to the face validity of the driving simulator as an adjunct to their behavioural validation study (Blana & Golias, 1999; Blaauw, 1982; Riemersma et al, 1990; Wade and Hammond, 1998). Wade and Hammond (1998) asked participants to complete a questionnaire to rate the realism of the Wrap-Around-Simulator based at the Human Factors Research laboratory in the University of Minnesota in comparison to a real vehicle. According to their responses, participant's found the simulator to be comfortable and quite realistic. Riemersma et al (1990) compared the assessments of the face validity of the Daimler-Chrysler moving based simulator under two sets of instructions. Participants were required to: 1) Drive in a relaxed unhurried manner and 2) Drive as quickly as road conditions allow. Face validity was established as participants found it easy to judge their speed in the simulator. Drivers in the time pressure condition rated the simulator as more realistic. The reason for this is unclear but it may be because they paid less attention to the surrounding environment or because they felt more subjective stress similar to that experienced in real-world driving.

Blana and Golias (1999) took this one step further and used subjective data from questionnaires to obtain information about the relative contributions of the different components of the simulator to the overall realism and the ease of controlling the simulator. Overall, participants thought that the Leeds Advanced Driving Simulator was quite realistic with good graphics (Blana and Golias, 1999). They commented that the least realistic features were braking and steering. Driving on straight roads was rated as more realistic than driving on curved roads in terms of speed and lateral position. Speed control was rated as being easier on straight than curved roads although no actual behavioural difference in the ease of controlling lateral position on straight and curved roads was found. Blaauw (1982) elicited subjective evaluations of the simulator through two questionnaires. One questionnaire assessed task difficulty in terms of attention and monotony on a continuous scale (0-100), and one assessed motion sickness and the realism of the simulator by asking participants to compare manoeuvres in the simulator and the instrumented car (multiple choice). Overall, all participants judged tasks in the simulator to be more difficult than the instrumented car (task difficulty, required attention and monotony) with the exception of longitudinal control (driving straight with no other traffic). Experienced drivers generally rated the simulator more favourably than novice drivers with the exception of monotony, which they reported was due to the lack of road signs, curvature, scenery and other traffic in the simulation. There were no incidences of motion sickness. This can be explained by the lack of complexity in the visual scene. From these studies, face validity assessments appear to depend on the level of fidelity of the simulated vehicle, the level of difficulty of the task being performed in the simulator and the amount and type of driving experience of the assessor.

7.3 Measuring Face Validity

Fidelity can be measured in two ways: by analysing the extent to which a simulator model generates an output that falls within standard engineering tolerances of the real model or by rating the accuracy of the simulation by means of a users commentary and/or rating scales (Mudd, 1968). Although the ABS is capable of producing detailed performance data, it is not feasible to directly compare the dynamics of the ABS to the dynamics of a real Arriva bus because the simulator model is simplified. Plus, not all cues are replicated, for example it is a fixed base system so motion cues are not available. Therefore it is essential to derive information about simulator performance from the driver's commentary in order to gain some idea about the accuracy of the simulator and the parameters responsible for any deviation from the real vehicle.

If the only aim of the present study were to ascertain driver's opinions regarding the realism of the bus simulator then it would be sufficient to simply ask participants to rate the realism of the simulator. However, the secondary aim of this study was to improve the face validity of the bus simulator in accordance with driver's comments, so it was necessary to obtain detailed accounts of the realism of different components with respect to the operational components.

The model below illustrates the process of evaluating the face validity of the simulator (adapted from Mudd, 1968).

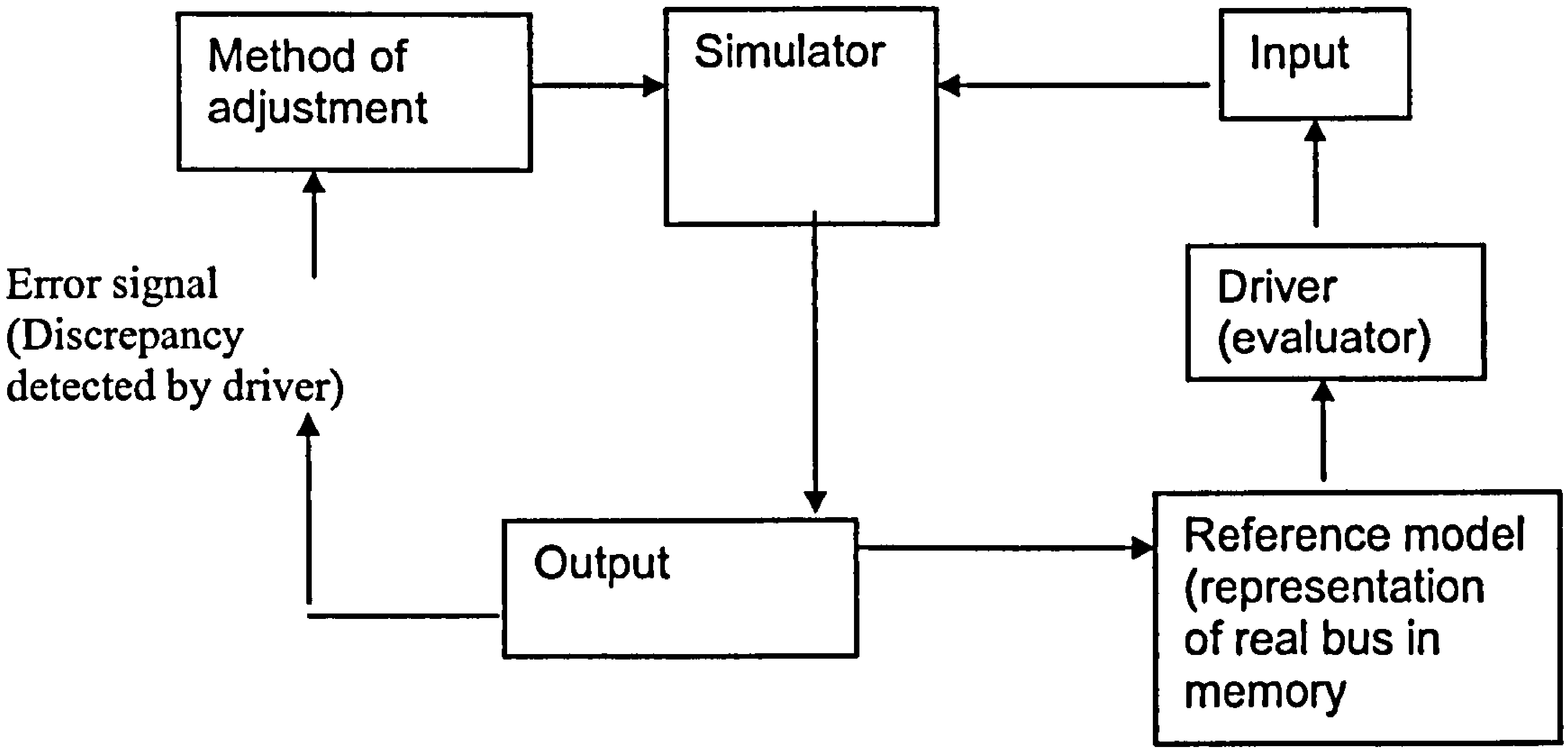


Figure 59 **Simulator Evaluation Loop**

For a given manoeuvre of the simulator the input to the control system of the simulator is the same as that to the reference model. In other words the driver operates the simulator as if it were real. The driver then compares the output of the simulator to the reference model, which is the representation of how a real bus operates, and an error signal is generated if the driver perceives that there is a discrepancy in the outputs. This output serves as an input to the simulator manager, who performs the analysis necessary to make adjustments to the parameters in the various elements of the simulator model so the error signal is reduced. In other words, the driver does not note a discrepancy between the reference model and the simulator in subsequent runs.

In order for this process to be effective, the bus driver must hold an accurate mental representation of the look, feel and behaviour of the real vehicle to which the simulator can be compared. The error signal in this study is in the form of verbal reports that requires translation into engineering parameters. It is beyond the scope of this thesis to develop a process whereby the error signal generated is in the same form as the input/output to the system and the fidelity of the simulator can be assessed by the magnitude of the error signal as Mudd suggested. However, considerable improvements can be made to the method by which verbal reports and subjective ratings are obtained. Hence a comprehensive questionnaire was designed to aid the conversion of data relating to the fidelity of the simulator into engineering parameters so that the necessary adjustments could be made. For example, when deciding whether to increase or decrease the responsiveness of the brakes in the bus simulator, a comment like 'braking is the least realistic feature' is not as useful as 'brakes are too responsive' or 'braking in the simulator is more responsive than braking in a real bus'.

The face validity of the ABS was assessed by asking both experienced and novice bus drivers if they felt that the ABS adequately and completely replicated bus driving. Since this method of face validity assessment involved the bus driver's use of a reference model of the bus, analysing differences between novice and experts face validity assessments may provide some insight into their respective mental models of the bus.

7.4 Method

7.4.1 Questionnaire Development

7.4.1.1 Face Validity Questionnaire

The following section describes the development of the face validity questionnaire (appendix B).

Two depot managers, each with over five years bus driving experience assisted with the preparation of the face validity questionnaire. The first stage was to identify the aspects of the simulation that could be adjusted and the information that would be required to inform any adjustments. The depot managers drove the bus simulator and commented on various features. For example, 'the brakes are too heavy make them more responsive' and 'the steering is too light, make it twice as heavy'. Adjustments were then made accordingly and they drove the ABS again and commented whether the changes were adequate. Thus, a list of features that required adjusting was produced. The list was then transformed into items in a questionnaire that were rated on a five-point likert scale.

The questions in section 1 related to the overall perception of the realism of the simulator. Section 2 involved comparing the experience in the simulator to the experience in a real bus. Section 3 involved comparing the events that happen during a real bus route with the events that happened during the simulated route. In section 4 participants were required to compare performing manoeuvres in the simulator to performing the same manoeuvres in a real bus. The questions in section 5 assessed the accuracy of the simulated environment. Section 6 contained questions relating to the users experience of learning how to handle the simulator. Section 6 also required participants to comment on the responsiveness of the simulator. In section 7 participants had to rank the steering, braking, visual display, sound system, gear change, acceleration, cab, wing-mirrors, hazards and the illusion of motion in order of how realistic they thought the features were. A score of 10 indicated that they considered the feature to be the most realistic and a score of 1 was the least realistic feature. Section 8 was qualitative and gave participants the opportunity to comment on whether they would make improvements to specific features of the simulator and any additional features of the simulator that they thought were missing, distorted or misleading. It was thought that a mix of qualitative and quantitative data gathering would enrich the evaluation of the ABS.

7.4.1.2 Pre-drive Questionnaire Development

A pre-drive questionnaire was designed to collect demographic information and to be used as a screening method to identify participants with a history of motion sickness so that they could be excluded from the study in order to reduce the problem of participants dropping out due to simulator sickness. The following items were included to get information about their driving particulars: payroll number, company/depot, age, number of years held PCV license/number of days spent in training, and number of years worked for Arriva. They were also asked whether they had any visual impairment that may have impinged on their driving performance, whether they were taking any medication that could affect their performance and whether they had experienced any dizziness in the past. Drivers who were taking medication for epilepsy and those who had experienced spells of dizziness were discouraged from participating because the flicker of the wide screen may have induced symptoms.

Drivers were asked about their history of motion sickness. They answered ‘always’, ‘sometimes’, ‘rarely’ or ‘never’ to whether they felt sick in the following situations: Driving a car, driving a bus, riding as a passenger, during plane trips, during fair rides, and on boats. Drivers who answered ‘always’ to one or more of the situations were discouraged from participating to minimise disruptions to the study. Drivers were also asked to answer ‘always’, ‘sometimes’, ‘rarely’ or ‘never’ to whether they experienced claustrophobia. Drivers were also asked to indicate whether they suffered from panic attacks, aggression and fatigue while driving on the same scale. Participants who answered ‘always’ to whether they suffered from claustrophobia were encouraged to view the room before they consented to participate in the study because of the fact that the simulator training room was enclosed and darkened.

7.4.2 Participants

57 drivers (B1-B57) were recruited for the face validity study, of which 29 were experienced bus drivers and 28 were in training to acquire a PCV licence. The experienced bus drivers had a mean age of 41.78 years (range = 26-64, SD = 10.7), an average of 10.94 years bus-driving experience (range = .5-38, SD = 8.97), and had worked for Arriva for an average of 8.08 years (range = 0.5-38, SD = 9.26).
The novice bus drivers had a mean age of 38.84 years (range = 19-58, SD = 10.76), and an average of 14 days bus-driving experience (range = 3-30, SD = 7.13).

7.4.3 Experimental Procedure

Participants were contacted by way of a letter in which their consent to participate in the study was requested. The pre-drive questionnaire was included with the letter and participants were asked to complete the form and return it if they consented to take part. The questionnaire related to their driving experience, health and motion sickness prior to the study. Participants with a high propensity towards motion sickness were excluded from the study. Upon arrival at the simulator participants were briefed as to what was required of them. They signed a consent form and confidentiality agreement.

The simulated drive comprised a practice session and a main route. The practice session involved driving on a straight road with low scene complexity, then on a curved road with higher scene complexity. Then they practiced pulling into two lay by bus stops and practised two right and two left turns at junctions. This was so that drivers could acclimatize to the simulated driving environment to minimize discomfort and the potential for simulator sickness (see Brock et al., 2001). It was also an opportunity for the driver to ask questions and to ensure that they performed according to their normal standard of driving.

Participants were given the following instructions prior to the driving of the simulator:

"This first session is a practice drive so that you may get used to the feel and control of the simulator. Please drive the way you would on a real road and deal with the conditions as if they are really happening. If you hear one bell it means that you should stop at the next bus stop. You must wait at the bus stops until you think it is OK to move away. In the event of a collision the simulator will reset your position in the road and you must carry on driving. Please stop at junctions and listen for my instructions to turn left or right. Feel free to ask any questions."

After completion of the practice trial, participants drove a short 30000ft route (approx 10 mins) in the simulator with the following instructions:

"This next session is the main drive. Please drive the way you normally would on a real road and deal with events as if they were really happening. To successfully negotiate the route you must follow the instructions given to you on the road signs. Please continue straight across any junctions you come to, unless you hear spoken instructions to turn left or right. If you hear one bell it means that you should stop at the next bus stop. You must wait at the bus stops until you think it is OK to move away. After the session you will be asked to compare the simulator to a real bus."

The last instruction was given to focus participant's attention on the virtual environment and to reduce driver expectations of 'being tested' on the simulator. After the drive participants completed the face validity measure.

7.4.4 Treatment of Results

Descriptive statistics were computed for each of the face validity items using SPSS. T-tests were performed on the face validity measures to determine whether there were any differences between the novice and experienced bus drivers' responses. The chi-squared statistic was used to assess differences in spontaneous comments made by experienced and novice bus drivers. ANCOVA statistics were computed to control for age effects. ANCOVA statistics were conducted to assess whether face validity influenced simulated driving performance on the ABS, controlling for age and experience.

7.5 Results

The descriptive statistics are given in appendix B.

7.5.1 Order of Realism of Simulator Features

Table 22 **Ranking Order of Realism of Simulator Features**

Rank	**Feature**	
	Novice	**Experienced**
Most realistic	Cab	Cab
↓	Mirrors	Acceleration
	Acceleration	Gear change
	Illusion of motion	Illusion of motion
	Hazards	Mirrors
	Gear change	Visual display
	Visual display	Hazards
	Sound system	Sound system
	Braking	Steering
Least realistic	Steering	Braking

In order of realism, novice drivers rated the cab and mirrors as the most realistic, followed by the acceleration, illusion of motion, hazards, gear changes, visual display and sound. They ranked braking and steering as the least realistic aspects of the simulator hardware. On the other hand, experienced drivers rated the cab and acceleration as the most realistic features of the simulator, followed by the gear change, illusion of motion, mirrors, visual display, hazards and sound. They ranked steering and braking as the least realistic aspects of the simulator hardware.

7.5.2 Bus Drivers Opinions about the ABS

Table 23 Comparison of Frequencies of Spontaneous Comments

Comments	Frequency		
	Novice N=28	Experienced N=29	significant
Steering	27	15	<.0001
Braking	13	11	
Wider field of view	2	0	
Resolution of Graphics	12	0	<.05
More hazards	4	4	
Motion/vibration	3	1	
Cab	2	3	
Acceleration	4	1	
Deceleration	6	6	
Mirrors	4	4	
Blind spots	1	1	
Difficult to judge distances	11	4	<.05
Difficult to judge speed	2	2	
Need to see vehicle length	1	5	<.10
Include cab in display	1	3	
Indicator in wrong place	1	0	
Bus pivots in the wrong place	2	0	
Experienced dizziness	1	0	
Position of bus in road is not right	1	0	

The results showed that more novices commented on the steering compared with experienced bus drivers ($\chi 2$ (2, N=55) 14.682, p<.0001. 96% novices, vs. 52% experienced drivers).

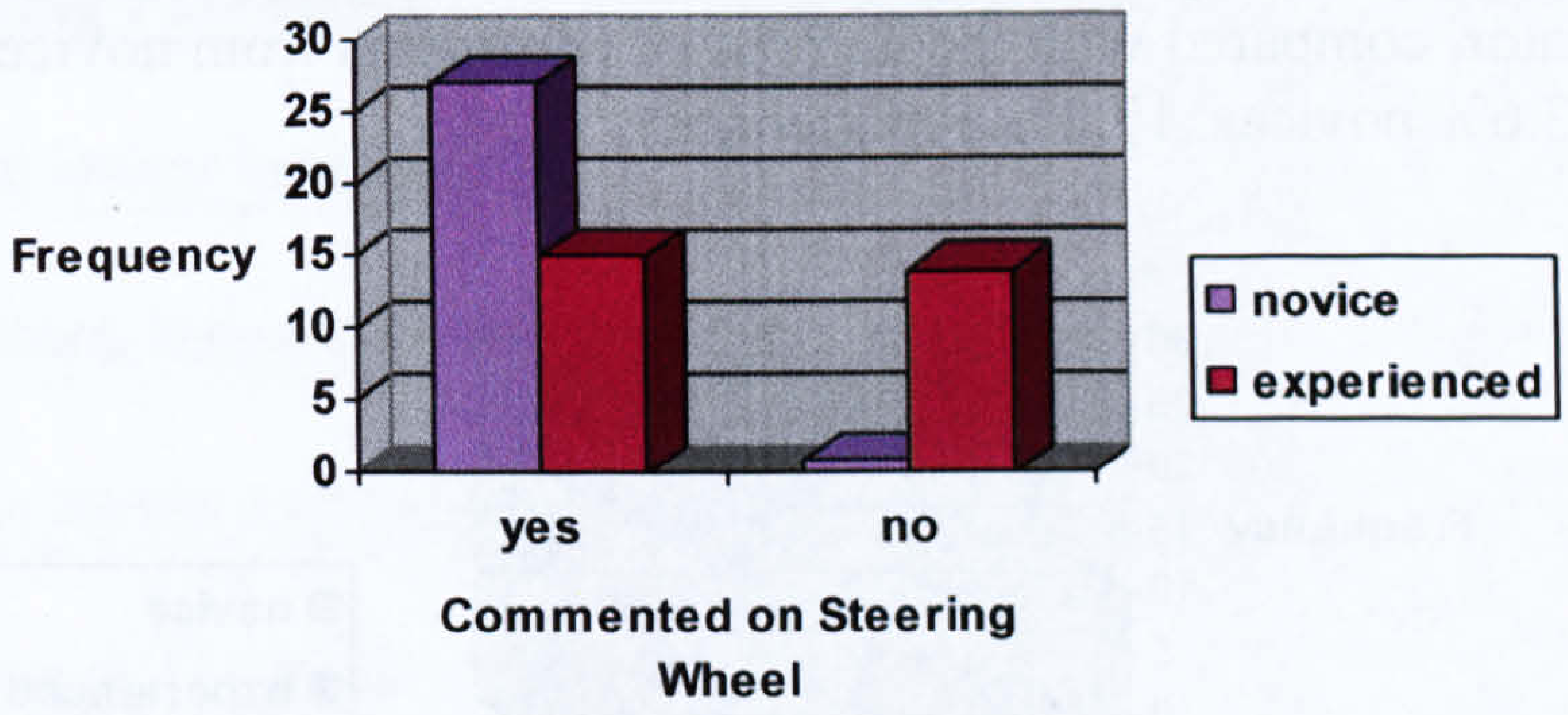


Figure 60 Frequency of Comments about Steering

The results also showed that more novices commented on the resolution of the graphics compared with experienced drivers (χ2 (1, N=57) 15.743, p<.05. 42.9% novices, 0% experienced).

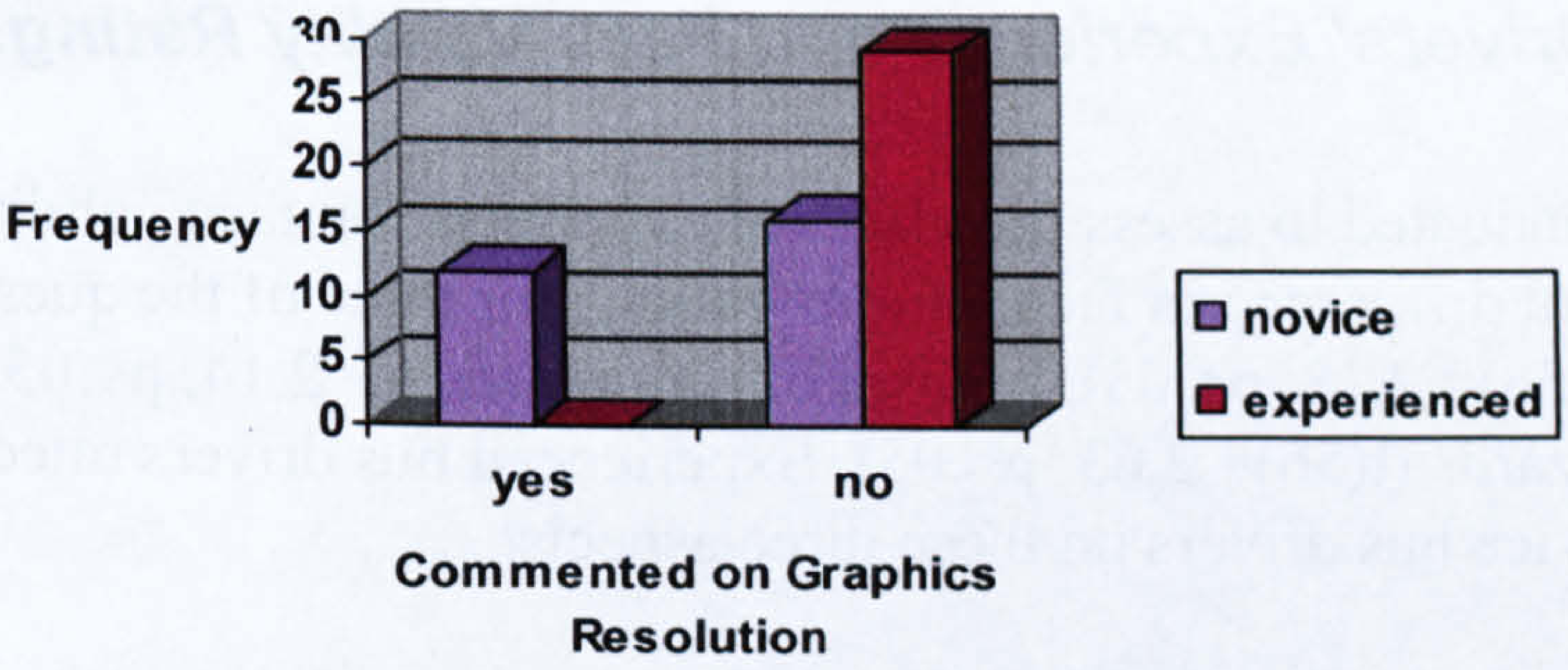


Figure 61 Frequency of Comments about Graphics Resolution

It was found that more novices commented that it was difficult to judge distances in the simulator compared with experienced bus drivers (χ2 (1, N=57) 4.774, p<.01, 39.3% novices, 13.8% experienced).

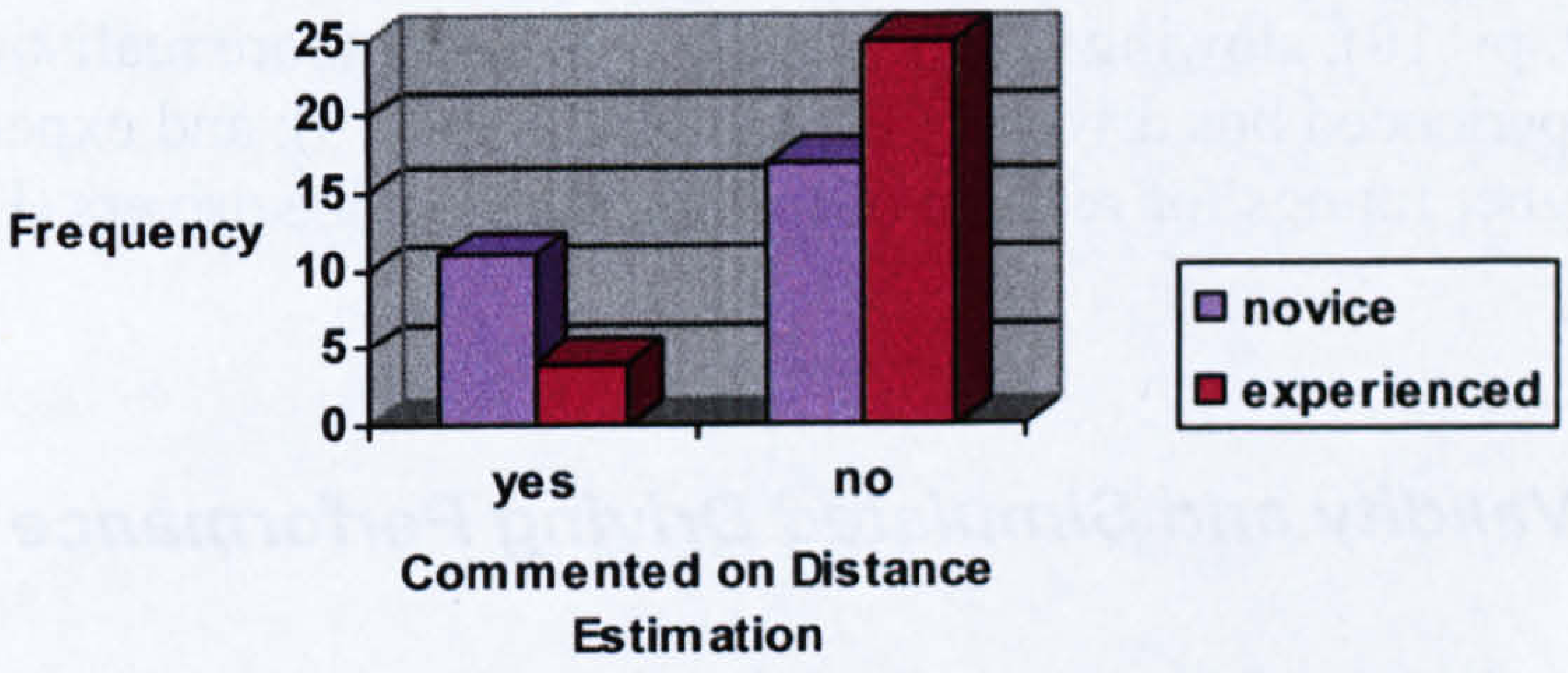


Figure 62 Frequency of Comments about Distance Estimation

Experienced drivers made significantly more comments that they should see vehicle length in simulator, compared with the number of comments from novice drivers ($\chi 2$ (1, N=57), p<.10, 3.6% novices, 17.2% experienced).

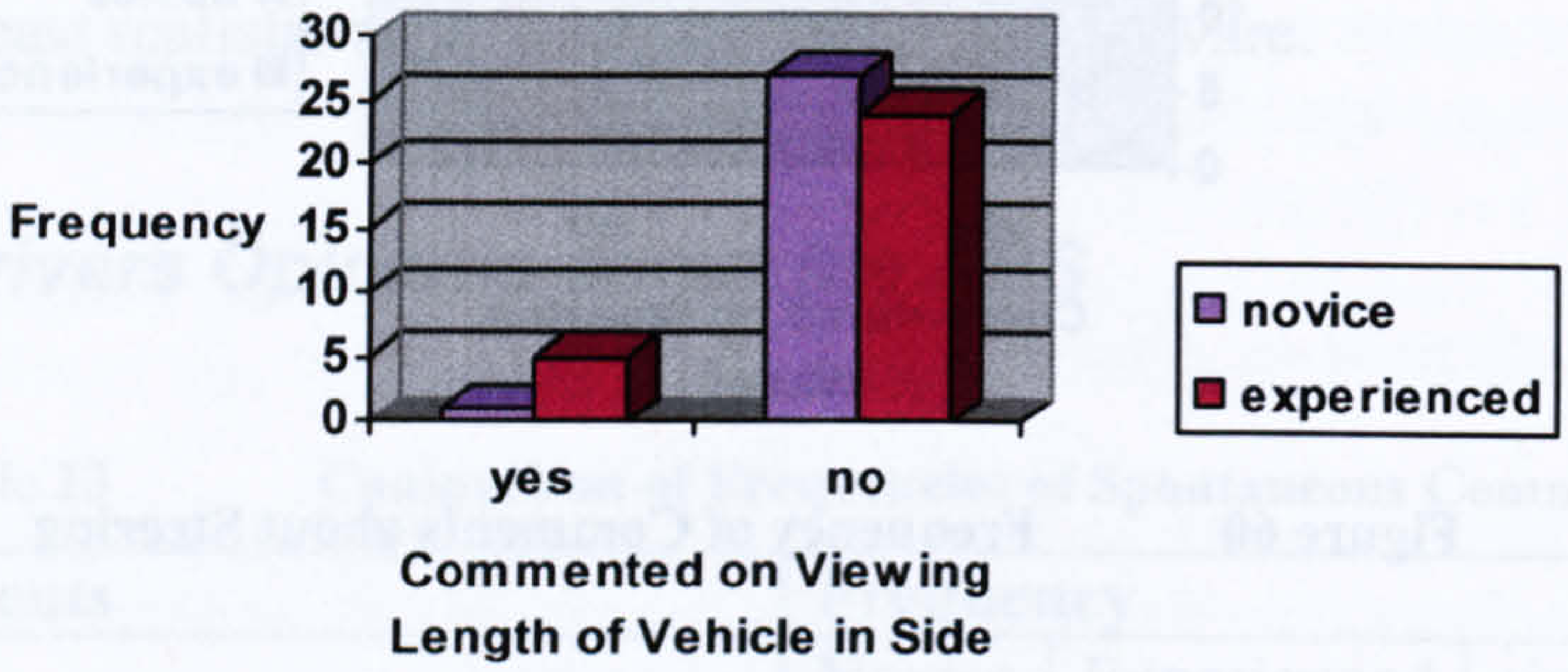


Figure 63 Frequency of Comments about View of Bus in Side Mirror

7.5.3 Bus Drivers' Experience and Face Validity Ratings

T-tests were conducted to assess the effect of experience on face validity ratings. There was a significant difference in face validity ratings for three of the questions: realism of accelerating (t(56)= 2.18, p<.05); realism of turning (t(56)=2.14, p<.05); and accuracy of detecting hazards (t(56)= 2.63, p<.05). Experienced bus drivers rated the ABS more highly than novice bus drivers on these three aspects.

ANCOVA's, controlling for the influence of age on face validity ratings revealed significant differences in ratings of the realism of pulling into bus stops (F(2, 56) =7.611, p<.05); and the accuracy that you can see other objects (F(2, 56)=5.084, p<.05). Novices gave higher ratings to pulling into bus stops than experienced bus drivers did, more experienced bus drivers rated the accuracy that you could see other objects more highly than novice bus drivers.

The following approached significance at the 10% level: Accuracy of hazard detection was rated more highly by experienced bus drivers in comparison to novice drivers (F(2,56)=3.009, p<.10); slowing down was rated as being more realistic by novice bus drivers than experienced bus drivers (F(2, 56)=4.022, p<.10); and experienced bus drivers gave higher ratings for realism of turning than novice drivers (F(2, 56)=3.279, p<.10).

7.5.4 Face Validity and Simulated Driving Performance

The table shows the descriptive statistics for high and low face validity ratings and measures of simulated driving performance.

Table 24 Face Validity Ratings and Mean Simulated Driving Performance

Driving Parameter	Realism Rating	Mean	Std. Deviation
mean lateral lane position	Low	-7.55	0.60
	High	-7.71	0.70
sd lateral lane position	Low	4.70	1.27
	High	5.10	1.67
mean forward velocity (mph)	Low	28.54	4.17
	High	28.23	3.61
sd forward velocity	Low	9.36	1.94
	High	9.94	1.82
mean steering wheel angle	Low	-0.88	2.43
	High	1.12	6.22
sd steering wheel angle	Low	50.51	14.80
	High	59.17	29.82
mean heading angle	Low	-5.57	1.89
	High	-6.37	2.35
sd heading angle	Low	34.60	0.68
	High	34.34	0.67
mean steering wheel rate	Low	0.00	0.01
	High	-0.21	1.09
sd steering wheel rate	Low	0.48	0.11
	High	0.49	0.13
mean throttle acceleration	Low	1.68	0.16
	High	1.68	0.16
sd throttle acceleration	Low	1.99	0.48
	High	2.12	0.44
mean brake deceleration	Low	-0.91	0.41
	High	-1.00	0.19
sd brake deceleration	Low	0.97	0.77
	High	1.03	0.71
mean longitudinal acceleration	Low	0.06	0.11
	High	0.05	0.09
sd longitudinal acceleration	Low	2.31	0.58
	High	2.45	0.53
mean forward velocity (ft/sec)	Low	41.84	6.10
	High	41.40	5.30
sd forward velocity	Low	13.73	2.85
	High	14.57	2.66
mean gear	Low	2.62	0.31
	High	2.56	0.28
sd gear	Low	0.77	0.11
	High	0.80	0.10
mean TTC in-lane	Low	268.28	49.42
	High	262.30	32.78

Driving Parameter	Realism Rating	Mean	Std. Deviation
sd TTC in lane	Low	384.71	32.90
	High	499.05	577.06
mean Range in-lane	Low	964.86	225.47
	High	933.95	201.86
sd range in lane	Low	873.38	51.40
	High	882.28	32.23
mean TTC opposing lane	Low	288.55	17.11
	High	287.16	17.87
sd TTC opposing lane	Low	449.47	8.41
	High	448.78	8.82
mean Range opposing lane	Low	894.75	42.22
	High	890.31	45.71
sd Range opposing lane	Low	1045.53	17.40
	High	1044.69	16.89

ANCOVA statistics were conducted to assess whether face validity influenced performance on the ABS, controlling for age and experience. The independent variable was face validity with two levels, high and low. The dependent variables were global measures of simulated driving performance. The relationship between face validity and mean steering wheel angle approached significance ($F(1, 52) = 3.463, p<.10$). There were no significant effects of face validity on other measures of simulated driving performance.

7.6 Discussion

The face validity of the ABS was assessed by asking novice and experienced bus drivers to compare various aspects of the simulator to real bus driving in terms of accuracy and realism after driving a simulated bus route. Overall, the bus drivers gave a medium rating to the accuracy and realism of the ABS. Drivers felt that they were immersed in the simulated environment and thought that they drove the simulator in a similar way to how they drove a real bus. The ABS met drivers expectations quite closely, some commented that it exceeded their expectations, whereas others were a little bit disappointed.

The realism of the cab was rated highly, particularly the indicators, horn and side mirrors. The cab was a replica of an actual bus cab to encourage the bus drivers to drive as they would on the road. The sound of the horn and indicators were based on real sound recordings and the side mirrors had a realistic view of the road and sides of the bus. However, the rear view mirror was rated as being less realistic because in a real bus you would position it so that you could observe passengers. This was not so in the ABS. The hazards encountered and the traffic environment was also rated as being ‘almost realistic’. In particular, driving on straight roads, through traffic lights and across zebra crossings were ‘almost realistic’ features of the simulated environment; other aspects of the simulated environment, such as bus stops were rated as being quite realistic. The manoeuvres performed in the ABS were rated as quite realistic, with the exception of

turning and slowing down which had a low rating. Stopping distances also had lower ratings of realism. The accuracy of the driving environment was rated as being quite accurate, including hazard detection, speed and distance estimations. Bus drivers felt that lane positioning was 'almost accurate'.
The realism ratings are what are expected of a simulator like the ABS which has medium fidelity. Improvements to fidelity could include the addition of a motion base which might improve the perception of steering and braking responses. However there is no guarantee that this will improve its training value (Bürki-Cohen, et al., 2000; Konnce, 1979; O'Hare and Roscoe, 1990; Waag, 1981), and may in fact be detrimental (McCauley, 1984).

There were subtle differences in novice and experienced bus drivers' ratings of face validity. In order of realism, novice drivers rated the cab and mirrors as the most realistic, followed by the acceleration, illusion of motion, hazards, gear changes, visual display and sound. They ranked braking and steering as the least realistic aspects of the simulator hardware. On the other hand, experienced drivers rated the cab and acceleration as the most realistic features of the simulator, followed by the gear change, illusion of motion, mirrors, visual display, hazards and sound. They also ranked steering and braking as the least realistic aspects of the simulator hardware, which is concordant with Blana and Golias (1999) and Duncan (1995). Both of the simulators used in these studies were also fixed-based so low ratings of steering and braking is likely to be due to the absence of a motion platform, which means that drivers are not receiving the proprioceptive motion cues that accompany braking and turning manoeuvres in a real vehicle (Blaauw, 1982; Harms, 1996; Reymond and Kemeny, 1999). Bus drivers typically commented that the steering was too light and too responsive but there were differences in the bus driver's experience of turning in the simulator: Novice bus drivers tended to focus on problems with the steering as reflected in the spontaneous comments they made, however experienced bus drivers felt that turning was a more realistic experience than novice drivers did. The bus drivers commented that the braking was harsher than the braking motion in a real bus; however novice bus drivers gave higher ratings than experienced bus drivers for the realism of slowing down and pulling into bus stops. When the effects of age were statistically controlled for, experienced bus drivers rated the accuracy with which they could see other objects in the simulator and the accuracy of hazard detection more highly than novice bus drivers did, although novice drivers ranked the realism of the hazards more highly than experienced bus drivers did. Novice drivers commented on the resolution of the graphical display, which may have influenced their appraisal of hazard perception.

The differences in face validity ratings are likely to reflect differences in the accuracy of the mental representations of a real bus. For example, Blaauw (1982) found that overall, experienced drivers rated their experience in a driving simulator more favourably than novice drivers did. Based on the research by Bailley, Bellet and Goupil (2003) and Underwood et al (2002) on driver's mental models of the traffic environment, it is reasonable to suggest that experienced bus drivers have more detailed mental models of the operation of the bus built up over their years of experience negotiating buses in traffic. Novice bus drivers on the other hand are just learning how to handle the bus and so have had less opportunity to build up an accurate mental model of the driving environment. In addition to this, training buses are typically smaller and are likely to have more years of operation and may perhaps behave a little bit differently to the buses that they will eventually use in service. A further point is that experienced bus drivers did not comment on the resolution of the graphics, while novice bus drivers did. This suggests that novice bus drivers may have been more inclined to draw comparisons with the simulator and video games, rather than a real bus. Again this supports the proposal that novice bus drivers have less accurate mental models of bus driving. In terms of face validity assessment, bus driver's expectations of the simulator outputs are based on their reference model. However, novice and experienced bus driver's reference models differ in terms of accuracy and available information. Therefore, when they compare the output of the simulator to their model, they have a different error signal, which leads to the observed differences in realism ratings.

The analysis shows that bus drivers who gave low ratings to the realism of the simulator did not differ from drivers who gave high ratings to the overall realism of the simulator in terms of their driving performance in the simulator, with the exception of mean steering wheel angle. This indicates that face validity assessments did not significantly influence simulated driving performance. The slight effect of realism on steering may be due to usability problems with the steering wheel, similar to those reported in Duncan's (1995) study as participants there also had a tendency to overcorrect steering responses in the simulator at the Transport Research Laboratory (TRL). This effect is not enough to suggest that the relationship between simulator fidelity and performance would significantly influence training outcomes, because the feel of the steering wheels on real buses also vary in terms of usability. Nevertheless, it is still important to investigate the behavioural validity of the simulator.

7.7 Implications for Training

The analysis shows that novice bus drivers gave lower ratings to the realism of acceleration and turning when compared with experienced drivers and also rated their hazard detection as being less accurate than experienced bus drivers. This provides a further indication of the training requirement for novice bus drivers to improve their hazard perception and vehicle handling skills.

Although the face validity questionnaire did not directly assess the training value of the ABS, the results show that the bus drivers thought that the ABS has good face validity. They also thought that they drove the ABS in a similar way to a real bus, which is a good indication that bus driver training will not be compromised by a lack of motivation to use the ABS. However, the face validity results clearly indicate that the bus drivers feel that the steering and braking responses require some attention to make them seem more realistic. The addition of a motion base is one way to improve the kinaesthetic feedback perceived by the bus drivers when they make these manoeuvres. Also the addition of an accurate vehicle dynamics model is another way to make improvements to the accuracy and realism of response of the ABS under different conditions, as the dynamics model is based on the actual mechanical and aerodynamic properties of a real bus. However, the additional cost must be balanced against the additional training benefits that the addition of a motion base and accurate vehicle dynamics would afford. The fact that there were no significant differences in simulated driving performance of participants with high and low ratings of realism suggest that improving the face validity in this way may not improve the behavioural validity of the ABS to the extent that the cost would be justified. A further consideration is the type of training that the ABS is intended for. The ABS is not intended to replace traditional in-vehicle bus driver training because vehicle manoeuvres are best taught in the real vehicle. Rather, the ABS is intended to be used as a tool to enhance hazard perception and cognitive skills in the traffic environment, which the bus drivers actually rate quite highly in terms of realism. Therefore investing in the time and facilities to make improvements to the steering and braking in the ABS possible may in fact have no additional benefits to training outcomes. Had the realism of the graphical display been poorly rated, this would have had a stronger influence on training bus drivers to accurately perceive road signs and objects in the distance for the development of hazard perception skills.

However, focussing on discrepancies in the handling characteristics of the simulator may distract trainees' attention from the task of improving their hazard perception skills. Therefore the drivers' responses to the ABS were used to make some low cost improvements to some aspects of the simulation. Firstly, the function of the steering wheel was improved by fitting a more powerful torque motor to provide force-feel. Secondly, the braking function was improved by increasing the physical resistance of the pedals and adjusting the configuration so the brakes were less responsive.

8 The Effects of Experience and Stress on Simulated Bus Driving

8.1 Rationale for the Study

The aim of this study is to investigate whether bus drivers' emotional responses to a simulated bus driving environment are comparable to the emotional responses of driving a real vehicle. If this is achieved it will provide a behavioural validation of the ABS. In other words, drivers will have a similar emotional response to driving the ABS as they do in the real world.

8.2 Evaluating Behavioural Validity

An important step in evaluating the training value of the ABS is to establish whether or not it has behavioural validity. A simulator has behavioural validity if it is capable of inducing the same perceptual, cognitive and motor responses that a driver would perform in the same situation in real life (Jamson, 1999). Researchers distinguish between absolute validity and relative validity (Kaptein, Theeuwes, and van der Horst, 1996). A simulator has absolute validity for a given task if the quantitative measurements of real life and simulated performance correspond exactly (Kaptein et al., 1996). On the other hand, a simulator has relative validity if the same trend of an effect for a given task is seen within the simulator and in real life. Although absolute validity is ultimately preferable, relative validity is viewed by most researchers as an adequate demonstration of simulator validity. Kaptein et al (1995) also distinguish between internal validity and external validity. Internal validity refers to the relationship between the simulator components and the observed effect and is therefore related to simulator fidelity. A simulator may have limited internal validity if behaviour is affected by the physical limitations of the simulator, for example a limited field-of-view that makes it impossible to perform right and left turns. External validity refers to the extent to which behaviour in the simulator relates to real driving.
The validity of a training simulator is dependent on the task that it is designed to support (Kaptein, Theeuwes, and van der Horst, 1996). Task dependency of validity is associated with the extent to which the simulated cues provide adequate information to the driver for the purpose of completing a given task, and therefore is also associated with the fidelity of the simulator. Since the ABS has been designed to support bus driver training, it is important to determine whether bus drivers respond in a behaviourally valid way to the cues generated within the simulated environment.

8.3 Experience and Driving

Previous research has shown that driving simulators can successfully discriminate between drivers with different levels of training and experience (Dorn and Barker, 2004; Dorn, 2005; McKenna and Crick, 1994; Parkes and Reed, 2005). For example, Parkes and Reed (2005) showed that older truck drivers took longer to complete a simulated route and were also more efficient with regards to their fuel consumption than younger truck drivers, suggesting that they drove more conservatively in comparison. McKenna and Crick (1994) successfully used a simulator-based hazard perception test to distinguish between novice and experienced and expert police drivers (matched for age and exposure). They found that hazard perception improves with experience and training so that the response latencies to the onset of hazards are reduced in trained and more experienced drivers.

Dorn and Barker (2004) investigated whether professional police drivers demonstrated safer driving styles in a driving simulator than drivers who had not been professionally trained. In this study, drivers completed a simulated trial in which they were required to overtake a bus and then to maintain visual contact with another vehicle in an urban environment without compromising safety. The results revealed that in comparison to untrained drivers, professionally trained police drivers exhibited potentially safer driving behaviour. Specifically, police drivers positioned themselves towards the centre of the lane on urban roads and when waiting at traffic lights, presumably to gain a clearer view of the road ahead. They also showed more caution when performing an overtaking manoeuvere by pulling out further in the lane to aid their observation of the road ahead and were significantly less likely to cross the central division at unsafe locations when overtaking. They also adopted a safer, steadier lane position whilst following a lead vehicle, while untrained drivers weaved in and out of traffic. Also, more police drivers reduced their speed in response to a pedestrian hazard when compared with untrained drivers. Dorn and Barker (2004) suggested that a driving simulator then has value in its ability to assess the beneficial effects of experience and training. However, there is little work to evaluate the effects of bus driver experience and training on simulated bus driving performance, although previous research has shown that there are clear differences between novice and experienced car drivers in terms of the skills necessary for driving. For example, novice drivers have difficulty in coordinating steering, lateral positioning and maintaining the appropriate speed (Blaauw, 1982, Mayhew and Simpson, 1996). Other studies have concluded that novice drivers are more likely to engage in risky behaviours, such as speeding, tailgating, accepting shorter gaps, and adopting shorter headways (Evans and Wasielewski, 1983; Jonah, 1986; McKnight and Stewart, 1990; Staplin and Lyles, 1991; Mayhew and Simpson, 1996). These behaviours may be discernable in a driving simulator if behaviour in the simulator approximates real life.

Therefore one of the main aims of the present study was to examine the effect of bus driver experience on simulated bus driving performance as a first stage in the validation of the ABS for novice bus driver training. If the ABS is a valid representation of real bus driving experienced bus drivers will demonstrate safer driving styles and better hazard perception skills than novice bus drivers, for example by driving at lower speeds, by driving more centrally to get a better view of the road ahead and by leaving greater safety margins between themselves and other vehicles to allow themselves more time to respond to hazards.

8.4 Stress, Fatigue and Driving

Another major aim of the present study is to consider whether the bus simulator elicits emotional responses similar to those experienced in a real vehicle. Bus driving is known to be a stressful and demanding occupation (Aronsson and Risler, 1998; Brunet et al, 1998; Carrere et al, 1991; Evans and Carrere, 1991; Netterstom and Hansen, 2000; Raggatt and Morrissey, 1997). For example, traffic congestion (Evans and Courtney, 1985), work overload (Rydstedt, Johansson and Evans, 1998), time pressures (Greiner et al, 1998; van der Hulst, Meijman and Rothengatter, 2001; Meijman and Kompier, 1998), perceived lack of support from management (Duffy and McGoldrick, 1990), little decision latitude (Ragland, Krausse, Greiner and Fisher, 1998), and shift work (Meijman et al, 1995; Pokorny, Blom and van Leeuwen, 1987) are all potential sources of stress and fatigue arising from factors intrinsic to the job of being a bus driver.

Previous research has suggested a link between stress and accident involvement (Evans et al, 1987; Katwal and Kamalanabhan, 2001; Matthews, Dorn and Gelndon, 1991; Matthews, Desmond, Joyner, Carcary and Gilliland, 1996; Selzer and Vinokur, 1974). However, it is thought that the level of subjective stress experienced by individual bus drivers is largely determined by their personal appraisal of job and driving-related events; in other words, the nature of the processing elicited by the demands of driving determines the symptoms experienced (Matthews, 2001). For example, in response to the urgency imposed by timetables, bus drivers who tend to prioritise punctuality over safety or customer service may have higher risks of impaired health (Meijman and Kompier, 1998). Stress symptoms may also include negative moods, worry and lack of motivation, which may impact on driver behaviour by provoking changes in task strategies, including manoeuvres, attentional factors and effort. For instance a driver may become distracted by negative cognitions, or may choose to adopt risky driving strategies (Mathews, 2001). For example, Haigney (1999) investigated the link between moods (measured by UWIST Mood Adjective, Mathews et al, 1996) and simulated driving. Risk-taking behaviours, such as small headways, spending more time in the right hand lane in the face of oncoming traffic and more accidents, were associated with negative mood states, such as low hedonic tone. Cognitive stress may also precede dangerous driving behaviour by interfering with the components of the driving task, including psychomotor control and hazard perception (e.g. Matthews, Dorn and Glendon, 1991), which then increases the risk of accidents.

Previous research has shown that different types of stress-vulnerable drivers exhibit different patterns of impairment and might be most at risk in differing traffic situations (Matthews, 2001; Matthews, Dorn and Glendon, 1991). For example, Mathews, Dorn and Glendon (1991) found that certain behavioural or personality styles measured by the Driving Behaviour Inventory (DBI) may increase a drivers' vulnerability to an accident because of their perception of and reaction to a stressor. For example, Dislike of Driving (DIS) is the strongest predictor of stressed mood, related to reduced control skills and caution in overtaking (Matthews, Dorn, Hoyes, Davis, Glendon and Taylor (1998). Although this study showed that DIS has no net effect on accident risk, one possible interpretation is that there is a trade-off between increased risk of accidents due to diverting attention away from vehicle control and a reduced risk of accidents caused by increased caution. On the other hand, increased aggression measured by the DBI is associated with hazardous confrontational coping strategies that are detrimental to safety, e.g.tail-gating or risky overtaking (Matthews, Dorn and Glendon, 1991).

Driver drowsiness, compounded by high workloads and stress is another major cause of accidents (Brown, 1994; McGwin and Brown, 1999), which is relevant to bus driving. For example, Sluiter, van de Beek and Frings-Dresen (1999) reported that out of 363 coach drivers surveyed on occupationally induced ill-health, 75% felt that fatigue affected their driving and 38% reported that they had almost fallen asleep at the wheel on at least one occasion. Fatigue may be defined as a transient state associated with difficulties in maintaining task-directed effort and attention (Brown, 1994). Fatigue may also be defined as a mode of control of information processing in high workload conditions, characterised by difficulties in applying effort to maintain task performance and is therefore managed by changing task goals to lower the effort required (Matthews and Desmond, 2002). Meijman et al (1995) defined mental fatigue as the deterioration of the efficiency of information processing, defined by means of the changing cost-benefit ratio in mental task performance.

It is widely recognised that fatigue has a detrimental effect on driving performance (Brown, 1994). For example, fatigue is associated with reduced lane tracking ability, degraded judgement and reaction times, more accidents and sleep episodes in simulated driving (Rimini-Doering et al, 2001). Mathews and Desmond (2002) found that fatigue induction increased heading error, reduced steering activity and reduced perceptual sensitivity in a simulated driving task. Brown (1994) observed that the main time-on-task effect of fatigue is the gradual withdrawal of attention from road and traffic demands. This is particularly true in familiar environments (Nelson, 1997). It is thought that in response to fatigue, drivers can invest greater effort in order to protect their performance. For example, Van der Hulst, Meijman and Rothengatter (2001) found that although fatigue was associated with decreased motivation and inaccurate control actions, drivers also adopted a safer driving strategy by increasing their safety margins; hazard avoidance also remained a priority. However after long hours combined with sleep loss, performance is no longer protected by effort (Meijman, 1995) because the driver loses their awareness of performance impairment (Mathews and Desmond, 2002). A driver's response to fatigue can also be influenced by their goals. For example, Van der Hulst, Meijman and Rothengatter (2001) found that an externally imposed time pressure overrides other goals in driving, such as safety and disrupts the adaptivity of task performance strategy. Specifically, drivers who are time pressured are reluctant to increase safety margins when fatigued and are also more likely to continue driving even if they have an aversion to do so.

This research is particularly relevant to bus driving, which is characterised by long shifts, monotonous routes and, of course, time pressures.

8.5 Measuring Stress: The Dundee Stress State Questionnaire

Evaluating the causes and magnitude of an individual's stress levels is not a simple process. Physiological or biochemical data is often used to provide an indication of an individual's level of stress and fatigue at a particular time (Aronsson and Rissler; Carrere et al, 1991; Netterstom and Hansen, 2000; Raggatt and Morrissey, 1997;

Rimini-Doering, 2001). While short term physiological reactions will continue for some time after a stressful event, the confidence with which one can assess an individual's stress levels will decline over time and become vulnerable to the effects of subsequent events. Significant physiological and biochemical reactions to stressful events may also accumulate over a long period of time and again it can be difficult to confidently identify the specific causes of any changes. Physiological and biochemical measures are also relatively intrusive and their applications may involve logistical and privacy issues. On the other hand, self reports are relatively unobtrusive and focus more on an individual's perceptions or experience of stress (Lazarus and Falkman, 1984; Matthews et al, 1999). These measures are usually taken as soon after the stressful event as is possible to avoid a decline in the accuracy of responses.

Self reports are concurrent with transactional models of stress, which emphasise the importance of the individual in terms of their interactions, perceptions and attitudes towards the stressors in question. According to the transactional approach, driver stress and subsequent driving performance, are determined through interactions between: a) the driver's assessment of the task environment (e.g. traffic density, weather); b) their assessment of their ability to cope with those conditions; and c) their selection of a behavioural strategy. Integral to this approach is an acknowledgement of the impact of `cross-situational' stressors, i.e. stress experienced not specifically in relation to driving, as contributing to overall levels of driver stress (Gulian, Glendon, Matthews, Davies & Debney, 1990).

The Dundee Stress State Questionnaire (DSSQ) was developed by Matthews et al (1999) and is based upon a transactional approach and has already been shown to be a valid indicator of driver stress (Matthews, Sparkes and Bygrave, 1996) and fatigue (Desmond and Matthews, 1997). The DSSQ is designed to measure three areas of mental functioning: Affect (represented by mood), Conation (represented by motivation) and Cognition. It is comprised of four sections: Mood state, Motivation, Thinking style and Thinking content. Within each section there are a range of items on which participants give a rated response, which gives an indication of the person's stress state at that particular moment in time.

Table 25 Description of DSSQ Scales

DSSQ Scale	**Description**
Energetic Arousal	Contrasts vigorous and tired states
Tense Arousal	Contrasts nervous and relaxed states
Hedonic Tone	Contrasts positive (pleasant) and negative (unpleasant) perceptions
Anger/frustration	Separate anger scale (high/low)
Success Motivation	Motivation to excel in performance
Intrinsic Motivation	Interest in content of task
Self-focused Attention	State of preoccupation and reflection or private self-consciousness
Self-esteem	Beliefs about self worth, especially as evaluated by others
Concentration	Attention to task and ability to resist distraction
Control and Confidence	Beliefs about personal control over task success

Task-related Interference	Cognitive interference
Task-irrelevant Interference	Personal worries
Mental Demand	Amount of mental and perceptual activity required by the task
Physical Demand	Amount of physical activity required by the task
Temporal Demand	Amount of time pressure felt as a result of the pace of the task
Frustration	How insecure, irritated, discouraged, stressed and annoyed they felt about the task
Performance	How successful they thought they were in accomplishing the goals of the task
Effort	How hard they had to work (physically and mentally) to achieve their level of performance

Matthews et al (1999) factor analysed the results after administering the DSSQ to a sample of vehicle drivers and revealed that there are three elements that can explain most of the variation in stress state: Engagement, Distress and Worry.

Table 26 Description of DSSQ Factors

DSSQ Factor	Description
Engagement	Contrasts enthusiasm and interest in the task with fatigue and apathy
Distress	Relates to perceived control over the task
Worry	Relates to self-evaluation of competency

The first factor, Engagement, is affected by task demands. High scores indicate task-engagement, which is the capacity of the task to promote a commitment to effort and application. Low scores indicate disengagement, which is characterized by a lack of energy, motivation and concentration, and is theorized to be caused by tasks, which are not challenging and require vigilance. Secondly, Distress is characterized by tense arousal, unhappiness and a lack of confidence and control. It is said to be caused by tasks that are cognitively overloading. Emotion-focussed coping styles and negative appraisal of the task elevate distress. Thirdly, Worry is characterized by self focus of attention, low self-esteem and intrusive thoughts (both task-related and personal), and is caused by tasks which cause the individual to question their personal competency. Tasks with a high work load may leave insufficient time for self-evaluation, but in some cases aspects of the work environment, such as low autonomy or monotony, provoke self-reflection. An individual's stress state is composed of these three dimensions as measured by the DSSQ, based on three assumptions: firstly, that single responses cannot be reduced into a single dimension; secondly, the individual's perception of the performance environment may often be critical in determining their stress responses; thirdly, stress and performance are reciprocally linked. For example, Matthews, Sparkes and Bygrave (1996) observed state changes in simulated driving in black ice conditions, in which the car skidded uncontrollably. State change in stress was characterised by increased Distress and a large increase in task related interference, which is associated with Worry. Also Desmond and Mathews (1997) induced fatigue in simulated driving and observed an increase in Distress and a decrease in Engagement.

In light of the descriptions of the DSSQ and the validation research reported, it is possible to generate several hypotheses concerning the stress states that may be observed in bus drivers. Bus driving is a highly demanding task, which may increase the level of Distress experienced by the bus driver. Bus driving is also characterised by high work loads that leave insufficient time for self reflection and hence low scores on Worry may be observed while driving a bus. However, it is feasible that Worry may be elevated before shifts for some drivers in anticipation of the working day. The driving environment is dynamic and challenging, which suggests that Engagement scores would be high, however insufficient time for recovery after sustained effort may lead to a lack of motivation, energy and concentration, or Disengagement.

8.6 Measuring Fatigue: The Fatigue Scale

The Task-Induced Fatigue Scale (TIFS: & Desmond, 1998) comprises four monopolar scales for subjective fatigue states. Fatigue scales are calculated from 23 items rated on a 5-point Likert scale from 0 (Not at all) to 5 (Very much so); with numbers between 0 and 5 representing intermediate degrees of agreement. The subjective fatigue states assessed are: Boredom, Visual fatigue, Malaise, and Muscular fatigue. Scores on the Visual fatigue, Malaise and Muscular fatigue scales may be summated to give a global 'Physical fatigue' score. The TIFS is designed to be administered in the context of some task or activity and is available in pre- and post-task versions, differing only in the instructions given to the participant.

8.7 Hypotheses

Although this study is largely exploratory, some tentative hypotheses can be put forward to assess the behavioural validity of the ABS. Firstly, if the ABS effectively simulates bus driving, there should be a link between stress and simulated bus driving performance. Secondly, if the ABS is a valid measure of bus driving, it should also be possible to discriminate between trained experienced bus drivers and untrained novice bus drivers by the behaviours they exhibit in the simulator. Thirdly, it is expected that the level of subjective stress and fatigue experienced in the simulator will be different before and after driving the ABS. If there is no change in state, it can be concluded that driving the ABS does not approximate to driving a real bus. The possibility of interactions between stress, experience and simulated driving will also be explored in order to highlight any training needs in experienced bus drivers. According to the previous literature then, the following results are expected:

- Drivers with lower scores on stress, worry and fatigue factors and will drive more safely than drivers with higher scores on stress, worry and fatigue factors.
- Drivers with higher scores on task engagement will drive more safely than bus drivers with low scores on task engagement.
- Experienced bus drivers will demonstrate safer driving styles and better hazard perception skills in comparison to novice bus drivers, specifically:
  - Lower mean speeds for experienced bus drivers.

  - Experienced bus drivers will drive more centrally to get a better view of the road.
  - Experienced bus drivers will leave greater distances between themselves and other vehicles to allow themselves more time to react to hazards.
- Higher Distress scores after simulated bus driving to reflect the high task demands that are usually associated with bus driving.
- Worry scores will be lower after simulated bus driving to indicate that the driver had little time for self-reflection due to high task demands.
- Overall task engagement will be high after simulated driving to reflect responding to the challenges of a dynamic driving environment.
- Fatigue will be higher after simulated driving given that real bus driving induces fatigue.

8.8 Method

8.8.1 Participants

58 bus drivers volunteered to take part in this study. These drivers also took part in the face validity study previously reported. There were 29 novice bus drivers who had spent a mean of 14.4 days training with Arriva (1-30 days). The mean age of this group was 38.28 years, SD 10.77 (19-58 years). 29 bus drivers held a PCV licence. This group had a mean age of 41.7 years, SD 10.77 (Range: 26-64 years) and had worked for Arriva for 8.08 years, SD 9.27 (Range 0-38 years). The difference between the mean age of novice and experienced bus drivers was not statistically significant, (F(1, 57) =1.41, p>.05).

8.8.2 Measures

Arriva Bus Simulator (see chapter 7 for a full description).
Twenty-six global measures of simulated driving performance were recorded in the ABS: mean lateral lane position (scored from –12 to +12 with 0 being the centre line and 12 being the kerb), SD lateral lane position, mean forward velocity (mph), SD forward velocity, mean steering wheel angle (positive scores to the left and negative scores to the right), SD steering wheel angle, mean heading angle, SD heading angle, mean steering wheel rate, SD steering wheel rate, mean throttle acceleration, SD throttle acceleration, mean brake deceleration, SD brake deceleration, mean longitudinal acceleration, SD longitudinal acceleration, mean gear, SD gear, mean TTC in-lane, SD TTC in lane, mean Range in-lane (distance between driver and other vehicles in the same lane in the scenario), SD range in lane, mean TTC opposing lane, SD TTC opposing lane, mean Range opposing lane (distance between driver and other vehicles in the opposite lane in the scenario), SD Range opposing lane.

The DSSQ (Matthews et al, 1999) assessed mood, motivation, thinking style and thinking content. The mood scale consisted of 29 items that were rated on a 4-point scale. The motivation section consisted of 15 items rated on a 5-point scale. Thinking style consisted of 30 items rated on a 5-point scale and thinking content listed 16 'thoughts' that drivers rated on a 5-point scale. The post-task DSSQ also included a workload scale; drivers rated their mental workload, physical workload, temporal workload, performance, effort and frustration on a 10-pont scale. The table below provides information on scale scoring. The three higher-order DSSQ factors of Worry, Task Engagement and Distress were calculated from these scales using the formula (scale score-normative mean/normative SD of the normative sample). Normative means and standard deviations from a large British sample were obtained from Matthews et al, 1999.

Table 27 DSSQ Scale Score Calculations

Energetic arousal:	Summate 3, 5, 16, 22 (positive items), 7, 11, 19, 24 (negative items) in the mood section
Tense arousal:	Summate 6, 9, 10, 17 (positive), 4, 13, 15, 21 (negative) in the mood section
Hedonic tone:	Summate 1, 8, 18, 23 (positive), 2, 12, 14, 20 (negative) in the mood section
Anger/frustration:	Summate items 25, 26, 27, 28, 29 (positive) in the mood section
Motivation	Item 15 in the motivation section provides an overall motivation rating, if required.
Intrinsic motivation	Items 1 and 10 are positively-scored, whereas items 2, 3, 6, 11, and 12 are reverse-scored. Subtract each of the five reverse-scored item score from 4, and then summate all seven item scores in the motivation section.
Success motivation	Summate items 4, 5, 7, 8, 9, 13 and 14 on motivation.
Self-focused Attention.	Summate item scores on items 1-8 on thinking style.
Self-esteem.	Summate items 10, 11, 13, 15, 16, 17 and 18 on thinking styleand subtract total from 28. (This step ensures high scores indicate high esteem).
Concentration	Summate items 19-22 and 24-26 and subtract total from 28. High scores indicate good concentration.
Control and Confidence	Summate items 9, 12, 14, 23, 27, 28, 29 and 30 on thinking style.
Task-related interference	Summate scores on items 1-8 on thinking content.
Task-irrelevant interference	Summate scores on items 9-16 on thinking content.
Worry	(.038 * zscore energetic arousal)+(.022 * zscore tense arousal)+(.041 * zscore hedonic tone)+(.116 * zscore motivation) +(.398 * zscore self focussed attention)+(-.328 * zscore self esteem)+(-.18 * zscore concentration)+(.063 * zscore control and confidence)+(.278 * zscore task related interference)+(.245 * zscore task irrelevant interference)

Task Engagement	(.301 * zscore energetic arousal)+(.186 * zscore tense arousal)+(.1131 * zscore hedonic tone)+(.399 * zscore motivation) +(.01 * zscore self focussed attention)+(-.166 * zscore self esteem)+(.291 * zscore concentration)+(.098 * zscore control and confidence)+(.049 Zscore task related interference)+(-.195 * zscore task irrelevant interference)
Distress	(.080 * zscore energetic arousal)+(.443 * zscore tense arousal)+(-.373 * zscore hedonic tone)+(.051 * zscore motivation) +(-.157 * zscore self focussed attention)+(-.113 * zscore self esteem)+(.045 * zscore concentration)+(-.336 * zscore control and confidence)+(.137 * zscore task related interference)+(-.087 * zscore task irrelevant interference)

The Fatigue Scale (Matthews & Desmond, 1998) consists of 23 words and phrases which describe feelings. Bus drivers rated their agreement with each phrase on a scale from 0 (Not at all) to 5 (Very much so). Both pre- and post-task versions were scored as follows:

Table 28 Fatigue Scale Scoring

Boredom (range of scores 0-40).	Summate numerical responses on items 6, 7, 10, 12, 14, 17, 21, and 23.
Visual fatigue (range of scores 0-25).	Summate numerical responses on items 2, 8, 15, 19, and 20.
Malaise (range of scores 0-30).	Summate numerical responses on items 1, 3, 9, 16, 18 and 22.
Muscular fatigue (range of scores 0-20).	Summate numerical responses on items 4, 5, 11 and 13.

Scores on the Visual fatigue, Malaise and Muscular fatigue scales were summated to give a global 'Physical fatigue' score.

8.8.3 Design

A mixed design was used. The between-subjects factor was bus driving experience, which had two levels: novice APS bus drivers who had not yet gained their PCV licence and experienced APS bus drivers who had gained their PCV licence.

The within-subjects factors were emotional states assessed by questionnaire scores. Scores were then split into three categories based on percentile groups:

- Low: scores below 33rd percentile,
- Medium: scores between the 34th and 66th percentile
- High: scores above the 67th percentile.

The dependent variables were the 26 measures recorded by the driving simulator.

8.8.4 Procedure

Participants completed the pre-exposure DSSQ and pre-exposure Fatigue Scale presented in excel spreadsheet format on a computer prior to driving the ABS.

First, the bus drivers completed a practice session on the simulator. The practice session involved driving on a straight road with low scene complexity, then on a curved road with higher scene complexity. Next they practiced pulling into two lay by bus stops and practised two right and two left turns at junctions. This was so that the driver could acclimatize to the simulated driving environment to minimize discomfort and the potential for simulator sickness (see Brock et al., 2001). It was also an opportunity for the driver to ask questions and to ensure that they performed according to their normal standard of driving.

Participants were given the following instructions prior to the practice drive:

"This first session is a practice drive so that you may get used to the feel and control of the simulator. Please drive the way you would on a real road and deal with the conditions as if they are really happening. If you hear one bell it means that you should stop at the next bus stop. You must wait at the bus stops until you think it is OK to move away. In the event of a collision the simulator will reset your position in the road and you must carry on driving. Please stop at junctions and listen for my instructions to turn left or right. Feel free to ask any questions and let me know if you feel ill."

After completion of the short practice trial participants then drove a 30000ft bus route (approx 10 mins) in the simulator with the following instructions:

"This next session is the main drive. Please drive the way you normally would on a real road and deal with events as if they were really happening. To successfully negotiate the route you must follow the instructions given to you on the road signs. Please continue straight across any junctions you come to, unless you hear spoken instructions to turn left or right. If you hear one bell it means that you should stop at the next bus stop. You must wait at the bus stops until you think it is OK to move away. If you have an accident the simulator will reset you in the road. Please discontinue if you begin to feel ill."

The experimenter left the room and the bus drivers then drove along the simulated route. Driving performance was continually monitored and data was saved every five feet along the simulation. Distance rather than time was used as the reference point for data collection to ensure that data was collected at the same point in the simulation for each participant to allow for individual differences in speed preference etc.

Participants then completed the post-exposure DSSQ and Fatigue scales.

8.8.5 Treatment of Results

DSSQ factor scores and item scores were calculated. DSSQ state change scores were calculated by subtracting pre exposure scores (questionnaire scores taken before driving the ABS) from post exposure scores (questionnaire scores obtained after completing the simulated scenario). State change scores were used to control for differences in stress states before driving the simulator, and to ensure that the stress states were induced by simulated driving and not by any other factor.

SPSS partial correlations were used to correlate DSSQ state change scores with simulated driving factors, controlling for the effects of age and experience on the variables of interest.

T-tests were used to assess the effect of experience on bus driver stress by comparing experienced and novice driver's pre and post exposure scores and score state changes. T-tests were conducted to assess the main effect of experience on simulated bus driving. ANOVA's using SPSS GLM were conducted to assess the main effect of stress and the interaction between bus drivers' experience and emotional state on simulated bus driving.

DSSQ state change scores were compared to assess the effect of simulated driving on bus driver stress. Paired-samples t-tests were used to determine whether overall, the simulator induced stress and fatigue in the bus driver population by comparing pre- and post- exposure scores.

8.9 Results and Discussion

The first section describes the results of the exploratory factor analysis and the correlations between simulated bus driving factors and stress responses. The next section reports the main effects of experience on stress responses and simulated bus driving, the third section then reports the main effects of stress on simulated bus driving and the potentially mediating effects of experience on driving. The final section deals with changes in stress state as a consequence of simulated bus driving in order to determine whether bus drivers reacted to the ABS in behaviourally valid ways.

8.9.1 Exploratory Factor Analysis

In order to simplify the data, an exploratory factor analysis of the 26 driver performance variables was conducted in order to identify a representative set of driver performance variables to use in subsequent multivariate analysis that still retained the character of the original variables. Cattell's (1978) scree test and the interpretability of the factor solution were the criteria used to determine the number of factors to rotate.

Consequently seven factors were rotated using a Varimax rotation procedure with Kaiser normalisation. Factor loadings were used to identify variables for subsequent analysis. Since there were 58 cases a factor loading of .70 or above was necessary in order to obtain a power level of 80% or above and to achieve significance at .05 significance level (Hair, Anderson, Tatham and Black, 1998).

The Kaiser-Meyer-Olkin Measure of Sampling Adequacy (.67) indicates that the sample size was sufficient for the factor structure to be reliable (Hair, Anderson, Tatham and Black, 1998).

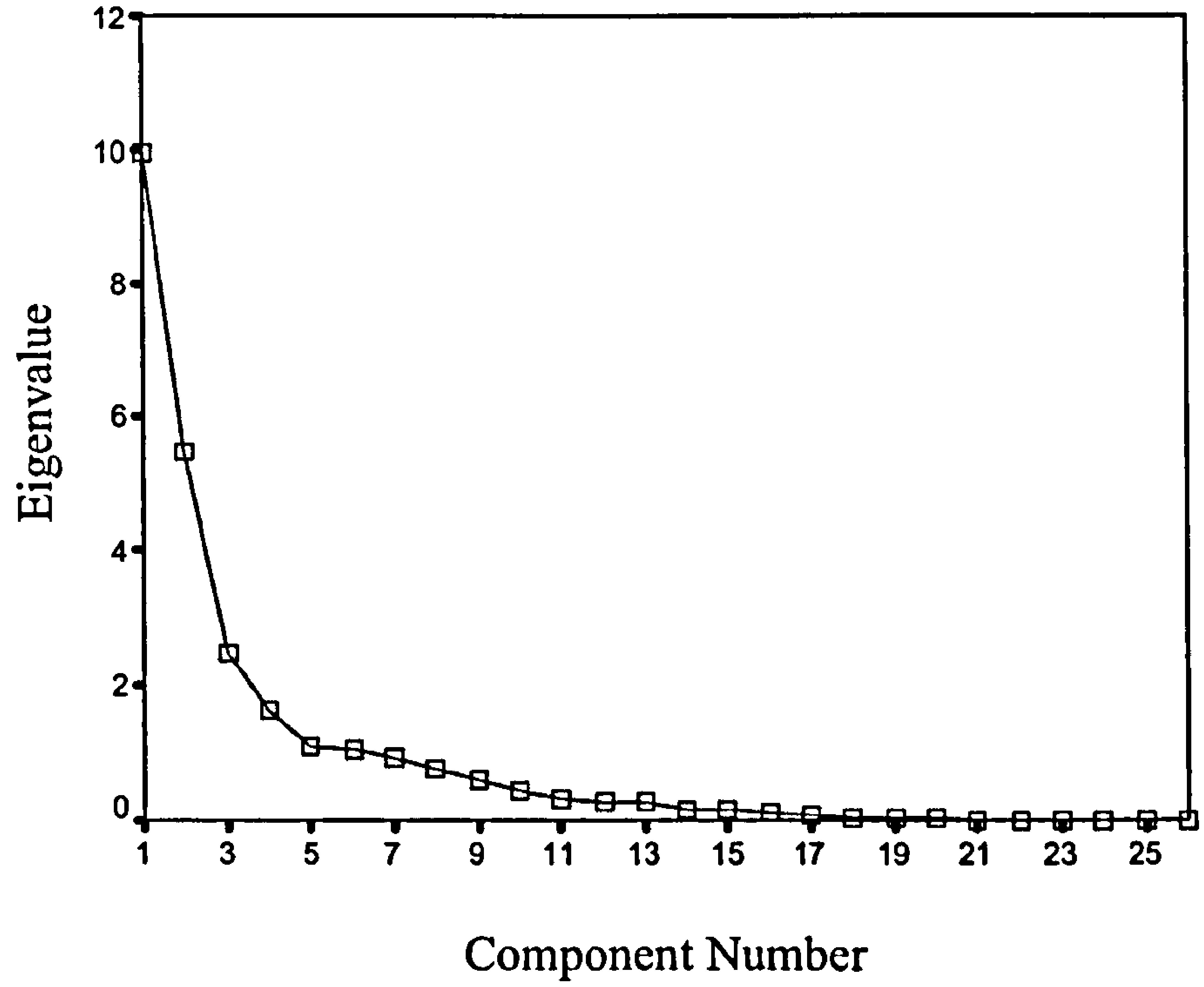


Figure 64 Scree Plot for Factor Analysis

The rotated factor matrix is shown in Table 29. This shows the correlations between each of the driver performance variables and the six rotated factors.

Table 29 Rotated Factor Matrix

Driver Performance	Factor Loadings (Communalities <.40)					
	Interaction with Traffic in Opposite Lane	Vehicle Control	Interaction with Vehicles In Lane	Acceleration Signature	Steering	Headway Choice
mean lateral lane position		.766				
sd lateral lane position	.413	-.794				

mean forward velocity (mph)	.342	.773		.336		
sd forward velocity	.731		.387	.317		
mean steering wheel angle	.366	-.848				
sd steering wheel angle	.355	-.867				
mean heading angle	-.594	.706				
sd heading angle	-.423	.742				
mean steering wheel rate					-.853	
sd steering wheel rate		-.534		.482		
mean throttle acceleration	.476	.336		.382	.557	
sd throttle acceleration				.910		
mean brake deceleration	-.374	.497				
sd brake deceleration	.734	-.495				
mean longitudinal acceleration			.355	.367	.600	
sd longitudinal acceleration	.400			.851		
mean gear	.377	.741		.351		
sd gear	.675			.311		.314
mean TTC in-lane			.939			
sd TTC in lane						.857
mean Range in-lane			.860			
sd range in lane			.709			
mean TTC opposing lane	-.935					
sd TTC opposing lane	-.925					
mean Range opposing lane	-.920					
sd Range opposing lane	-.918					

The first factor was labelled Interaction with Traffic in the Opposing Lane because Mean TTC opposing lane, SD TTC opposing lane, mean range opposing lane and SD range opposing lane were the variables that loaded most highly on this factor. The Interaction with Traffic in the Opposite Lane factor accounted for 26.3% of the item variance. The second factor was labelled Vehicle Control because the variables that loaded most highly on this factor were: mean lateral lane position, mean forward velocity, mean gear, mean heading, SD heading angle, SD steering wheel angle, SD lateral lane position, and SD steering wheel angle. This factor accounted for 23.9% of the item variance. The third factor was labelled Interaction with Vehicles In-Lane because mean TTC in lane, mean range in lane and SD range in lane loaded most highly on this factor. This factor accounted for 11.2% of the item variance. The fourth factor accounted for 10.5% of the item variance and was labelled Acceleration Signature because SD throttle acceleration and SD longitudinal acceleration loaded most highly on this factor. The fifth factor was labelled steering because mean steering wheel rate loaded most highly on this factor. Steering accounted for 7.2% of the item variance. Finally, the sixth factor, Headway Choice, was labelled so because SD TTC in lane loaded most highly onto this factor. Headway Choice accounted for 4.5% of the item variance.

Rotated factor scores confer the advantage of reducing measurement error and are correlated which avoids complications in the further use of multivariate techniques. Factor scores are more appropriate than summated scales because they do not need to be tested for reliability or validity because they will not be used in other samples. Therefore, rotated factor scores, representing a composite of all of the variables loading onto the factor, were computed for each participant.

8.9.2 Correlations between Emotional State and Simulated Bus Driving

Possible links between psychological states and driver performance were revealed by the correlation data. Correlations that were significant at the 10% levels are included because the study id exploratory and 10% effects may be of interest for future investigations. Table 30 shows correlations between simulated driving performance factors and DSSQ state change scores.

Table 30 Correlations between DSSQ Factor Scores and Simulated Driving

Factor Score	Worry	Distress	Task Engagement
Interaction with Traffic in Opposite Lane	ns	ns	ns
Vehicle Control	ns	ns	ns
Interaction with Vehicles in Lane	ns	ns	.23, p<.01
Acceleration Signature	.32, p<.05	ns	ns
Steering	ns	ns	ns
Headway Choice	ns	ns	ns

Correlations between stress factors and simulated driving factors indicated that higher scores on Worry were associated with higher scores on Acceleration Signature. It appears that increased acceleration is related to higher levels of worry (perhaps reflecting the drivers' concerns about their performance or accident risk). Higher scores on Task Engagement were associated with higher scores on Interaction with Vehicles in Lane, indicating that drivers who were focussed on the task had safer margins between their vehicle and other vehicles in their lane.

The table below shows the significant correlations between driver performance and fatigue scales.

Table 31 **Correlations between Fatigue Scale and Simulated Driving**

Factor Score	Boredom	Visual Fatigue	Muscular Fatigue	Malaise	Physical Fatigue
Interaction with Traffic in Opposite Lane	ns	ns	ns	ns	ns
Vehicle Control	ns	ns	-.37, p<.05	-.32, p<.05	-.27, p<.05
Interaction with Vehicles in Lane	ns	ns	ns	ns	ns
Acceleration Signature	ns	ns	ns	ns	ns
Steering	ns	ns	ns	ns	ns
Headway Choice	ns	ns	ns	ns	ns

The correlations indicated that higher scores on Muscular Fatigue, higher scores on Malaise and higher scores on Physical fatigue were associated with lower scores on vehicle control, suggesting that fatigue adversely affects drivers' ability to control their vehicle.

The table below shows the significant correlations between change in mood and driver performance.

Table 32 **Correlations between Mood and Simulated Driving**

Factor Score	EA	TA	HT	A
Interaction with Traffic in Opposite Lane	ns	.29, p<.05	ns	ns
Vehicle Control	ns	ns	ns	ns
Interaction with Vehicles in Lane	ns	ns	ns	ns
Acceleration Signature	ns	ns	ns	ns
Steering	.26, p<.10	ns	ns	ns
Headway Choice	ns	ns	ns	ns

Higher scores on energetic arousal were associated with higher scores on steering indicating that energetic drivers had greater variations in their steering behaviour. Higher scores on tense arousal were associated with higher scores on Interaction with

Traffic in the Opposite Lane, indicating that tense drivers drove more closely to other vehicles.

The table shows significant correlations between change in motivation scales and driver performance.

Table 33 **Correlations between Motivation and Simulated Driving**

Factor Score	Success Motivation	Intrinsic Motivation	Motivation
Interaction with Traffic in Opposite Lane	ns	ns	ns
Vehicle Control	ns	ns	ns
Interaction with Vehicles in Lane	ns	ns	ns
Acceleration Signature	ns	ns	ns
Steering	ns	ns	ns
Headway Choice	ns	.29, p<.05	.26, p<.01

Higher scores on Intrinsic Motivation were associated with higher scores on Headway Choice. Higher scores on Motivation were associated with higher scores on Headway Choice. These results suggest that motivated drivers vary their position and the distance they leave between themselves and the vehicles in front of them.

The table shows significant correlations between change in thinking style and driver performance.

Table 34 **Correlations between Thinking Style Scale and Simulated Driving**

Factor Score	Self focused Attention	Self Esteem	Concentration	Control and Confidence
Interaction with Traffic in Opposite Lane	ns	ns	ns	ns
Vehicle Control	ns	ns	-.25, p<.10	ns
Interaction with Vehicles in Lane	-.24, p<.10	ns	ns	.31, p<.05
Acceleration Signature	ns	ns	ns	ns
Steering	.24, p<.10	ns	ns	ns
Headway Choice	ns	ns	ns	ns

Higher scores on self focused attention were associated with lower scores on Interaction with vehicles in the same lane and higher scores on Steering. High scores on concentration were associated with lower scores on vehicle control. Higher scores on control and confidence were associated with lower scores on Interaction with vehicles in the same lane. These results indicate that there is a link between safer driving strategies and the level confidence that the drivers have in their ability to control the vehicle and events around them.

The table shows significant correlations between change in thinking content and driver performance.

Table 35 **Correlations between Thinking Content and Simulated Driving**

Factor Score	Task Related Interference	Task Irrelevant Interference
Interaction with Traffic in Opposite Lane	ns	ns
Vehicle Control	ns	ns
Interaction with Vehicles in Lane	ns	ns
Acceleration Signature	.28, $p<.05$	.39, $p<.01$
Steering	ns	ns
Headway Choice	ns	ns

Higher scores on task related interference were associated with higher scores on acceleration signature. Higher scores on task irrelevant interference were associated with higher scores on acceleration signature. This indicates that worried drivers may be inclined to accelerate more rapidly than drivers who are less worried.

The table shows the significant correlations between workload and driver performance.

Table 36 **Correlations between Workload and Simulated Driving**

Factor Score	Mental Workload	Physical Workload	Temporal Workload	Performance	Effort	Frustration
Interaction with Traffic in Opposite Lane	ns	ns	ns	ns	ns	ns
Vehicle Control	ns	ns	ns	ns	ns	ns
Interaction with Vehicles in Lane	ns	ns	ns	ns	ns	ns
Acceleration Signature	-.29, $p<.05$	ns	ns	-.28, $p<.05$	ns	ns
Steering	ns	ns	ns	ns	ns	ns
Headway Choice	-.31, $p<.05$	ns	ns	ns	ns	ns

Higher scores on mental workload were associated with lower scores on acceleration signature and lower scores on headway choice. Higher scores on performance were associated with lower scores on acceleration signature. The results suggest that in high workload conditions, drivers may adopt a less flexible driving strategy thereby decreasing their overall workload.

8.9.3 Discussion: Bus Driver Stress and Adaptations

Concordant with previous research (e.g. Matthews et al, 1999; Mathews and Desmond, 2002), the stress induced by fatigue, task disengagement and worry had different effects on driving performance. The results of the correlation analysis suggests that when bus drivers are attending to the driving task they tend to adopt safer more central positions in the road, which enhances their view of their surroundings and gives them a better opportunity to spot developing hazards. They also leave greater safety margins, which allows more time available to react to potential hazards. Bus drivers who report greater levels of attention to the task and also those who feel more confident and in control of their driving also tend to adopt these safer strategies.

Consistent with previous research, (e.g. Matthews and Desmond, 2002) tiredness in bus drivers is associated with reduced steering activity. However, experienced bus drivers (but not novice bus drivers) also drive more slowly and adopt safer more central lane positions when fatigued, presumably because they appraise fatigue as being harmful to their performance and try to compensate for the effects of fatigue by driving more carefully and allowing themselves a greater chance of spotting and responding to hazards. This behaviour supports the notion that hazard avoidance remains a priority in fatigued experienced bus drivers (Matthews and Desmond, 2002). Conversely, bus drivers leave smaller safety margins when they are apathetic and unconcerned about the driving task. Since disengagement is associated with fatigue and apathy, applying more effort may no longer protect driving performance (Meijman, 1995; Mathews and Desmond, 2002) and the dominant goal may be to arrive back to the depot for a rest. This pattern of behaviour is consistent with the notion that fatigue leads to the withdrawal of attention from the surrounding environment (Brown, 1994), which is particularly dangerous when driving because it may lead to accidents and loss of lives. Bus drivers who are worried and are distracted from the driving task tend to have greater variations in their acceleration behaviour because they are not focussing on the task of driving a bus. Preoccupations with external stressors have been shown to lead to accidents (Bruner, Boyer, Brillon, Ehrensaft and Stephonson, 1998; McMurray, 1970; Selzer and Vinokur, 1974). Tense, nervous bus drivers tend to drive closer to oncoming vehicles, which may increase the risk of an accident (Matthews, 2001).
Bus drivers who are more highly motivated have greater variability in headway choice than those who are less motivated. However, bus drivers who perceive that the workload is high demonstrate less variation in headway choice and less variation in acceleration than those who perceive lower workload conditions. This suggests that bus drivers in high workload conditions may attempt to lower the effort required by changing their driving strategy (see Mathews and Desmond, 2002). The analysis revealed an association between performance ratings and variation in acceleration. Better performance was associated with less variation in acceleration, which in reality would mean a smoother ride, especially for passengers.

The results above suggest that psychological states may influence the way in which bus drivers adapt their driving strategies to cope with the prevailing traffic conditions.

Since the bus drivers' primary task should be to maintain the safe control over their bus (Parkes, 1991), adpativity is important because it reflects the ability to cope with changes in the environment (Van der Hulst, Meijman and Rothengatter, 2001). Other researchers consider that SD speed and SD acceleration represent 'risk acceptance' behaviours (e.g. Matthews, Dorn and Glendon, 1991). They suggest that a decrease in these behaviours may be a response to a perceived increase in subjective risk, by attempting to moderate the level of their perceived exposure to risk contingencies (Haigney, Hoyes, Glendon, and Taylor, 1995; Haigney, 1999). It is important that bus drivers are consciously aware of adapting their driving to cope with changes in the traffic environment so that the strategies they select are appropriate and safe.
The results of the correlation analysis revealed that there were significant associations between simulated bus driving and stress factors. This provided a rationale for further investigation into the main effects of emotional state on simulated bus driving and interactions with level of bus driving experience.

8.9.4 Main Effect of Experience on Simulated Bus Driving

Rotated factor scores were computed for each participant. T-tests were conducted to assess differences between experienced and novice bus drivers in terms of their driving performance as measured by the factor scores. The following table shows the results.

Table 37 Mean Factor Scores and Significance Levels

Factor	Experience	Mean	Std. Deviation	t	df	Sig. (2-tailed)
Interaction with Traffic in Opposite Lane	novice	-.197	.675	-1.520	56	.134
	experienced	.197	1.225			
Vehicle Control	novice	.328	.497	2.625	56	.011*
	experienced	-.328	1.251			
Interaction with Vehicles in Lane	novice	.196	.928	1.510	56	.137
	experienced	-.196	1.046			
Acceleration Signature	novice	.047	.977	.358	56	.722
	experienced	-.047	1.04			
Steering	novice	-.189	.460	-1.457	56	.151
	experienced	.189	1.323			
Headway Choice	novice	.261	1.273	2.046	56	.045*
	experienced	-.261	.522			

(* = P<.05)

The results of the t-tests indicate that in comparison with experienced bus drivers, novice bus drivers had higher factor scores on Vehicle Control, ($t(56)=2.625$, $p<.05$). This indicates that novice bus drivers were less capable of controlling the vehicle indicated by larger variations in lateral and longitudinal control parameters. Novice bus drivers also had higher factor scores on Headway Choice, ($t(56)=2.046$, $p<.05$). This meant that novice bus drivers had larger variations in time to collision with vehicles in the same lane.

On the other hand, novice and experienced bus drivers were similar in terms of their Interaction with Traffic in the Opposite lane, Interaction with Traffic in the Same Lane, Acceleration Signature and Steering, all of which are central to successfully avoiding hazards.

8.9.5 Discussion: Effect of Experience on Simulated Bus Driving

Consistent with previous research (Dorn and Barker, 2004) the results showed that in comparison to novice bus drivers, experienced bus drivers exhibited a safer driving style. Lower scores on vehicle control indicates that experienced bus drivers tended to steer towards the centre of the road, keeping clear of the kerb and varied their position laterally within the lane, presumably in response to potential hazards, such as pedestrians and road side objects, unfolding in the traffic environment. A central road position means that experienced bus drivers are able to command a better view of the road ahead than novice bus drivers, which is particularly important when scanning for hazards and is typical of more advanced driving skills (Dorn and Barker, 2005).

For example, when the scanning patterns of experienced and novice car drivers are compared it is shown that novice drivers focus less on distant hazards (Mourant and Rockwell, 1972), and pay less attention to peripheral hazards (Crundall, Underwood & Chapman, 1999), while experienced drivers adapt their visual search strategy to the demands of the environment (Crundall and Underwood, 1995; 1998) and are able to engage and disengage attention to hazards more efficiently (Crundall, Underwood and Chapman, 1999). However, for the novice bus driver who is not yet fully aware of these hazards, keeping away from oncoming vehicles by tucking themselves into the kerb is a priority, which means that they are not in the optimum position to see unfolding hazards. Then again, perhaps novice bus driver's sense of relative positioning in the cab in relation to the width of the road is geared towards their more familiar experience of car driving. This would lead them to position themselves more towards the kerb than if their sense of spatial positioning had adapted to accommodate the increased width of the bus. Novice bus drivers also tend to drive at higher speeds and select higher gears, which puts them at an even greater risk of collisions because they have less time to respond to unfolding hazards. Similar findings have been found amongst less experienced police drivers who adopt significantly higher speeds in a simulator across a range of different road and traffic contexts compared with more experienced police drivers (Dorn, 2005). In comparison with experienced bus drivers, novice bus drivers have greater variations in headway choice. It could be that experienced bus drivers are able to judge safe distances to other vehicles more accurately in different circumstances based on their previous experience in traffic and have less need to vary their speed to maintain an optimal headway. Novice bus drivers may demonstrate greater variability in those headways because they have yet to establish what constitutes a consistently safe distance from other vehicles. This is concordant with other research that shows that novice drivers are more likely to engage in risky behaviours, such as speeding, tailgating, accepting shorter gaps, and adopting shorter headways (Blaauw, 1982; Evans and Wasielewski, 1983; Jonah, 1986; McKnight and Stewart, 1990; Staplin and Lyles, 1992; Mayhew and Simpson, 1996). The results also indicate that novice and experienced bus drivers behave similarly in terms of their interaction with other road users, and their acceleration and steering behaviour. These behaviours are important when responding to potential hazards. These results are encouraging because they suggest that novice bus drivers are not radically different to experienced bus drivers and so it may not take much training to encourage them to drive more in line with experienced drivers.

From these results it appears that the ABS successfully discriminates between experienced and novice bus drivers, thus suggesting that the ABS captures important aspects of bus driver behaviour. Furthermore this study suggests that novice bus drivers could be trained to drive more like experienced bus drivers (i.e. to drive more closely to the centre line to improve their chances of detecting hazards). Perhaps encouraging novice drivers to drive in this way in the simulator may reduce accident risk.

8.9.6 Main Effects and Interactions between Emotional States and Experience on Simulated Bus Driving

2x3 ANOVA's were conducted. The independent variable was level of bus driving experience with two levels: novice (non PCV licence holder) and experienced (PCV licence holder), and the second independent variable was emotional state with three levels: low (up to 33rd percentile), medium (34th to 66th percentile), and high (above 67th percentile). Separate analyses were performed for each of the variables representing emotional state: Energetic arousal, Tense arousal, Hedonic tone, Anger/frustration, Motivation, Intrinsic motivation, Success motivation, Self-focused Attention, Self-esteem, Concentration, Control and Confidence, Task-related interference, Task-irrelevant interference, Engagement, Distress, Worry, Boredom, Visual fatigue, Muscular fatigue and Total fatigue. The dependent variables were the six simulated bus driving factors: Interaction with Traffic in Opposite Lane, Vehicle Control, Interaction with Vehicles in Lane, Acceleration Signature, Steering, and Headway Choice.

The main effects of experience on driver performance are discussed separately. Here follows an account of the main effects of emotional state and interactions between experience and emotional state on simulated bus driving (measured by simulated bus driving factors).

8.9.6.1 Motivation

There was a significant interaction between experience and motivation on Headway Choice, ($F(2, 52) = 3.406$, $p<.05$). There was no significant effect of motivation in experienced bus drivers, however there was a significant effect in novice bus drivers, ($F(2, 26) = 5.60$, $p<.01$). Post-hoc comparisons using the bonferroni correction, revealed that novice bus drivers with high levels of motivation had greater scores on Headway Choice than novice bus drivers with medium (p<.01) and low scores on motivation (p<.05).

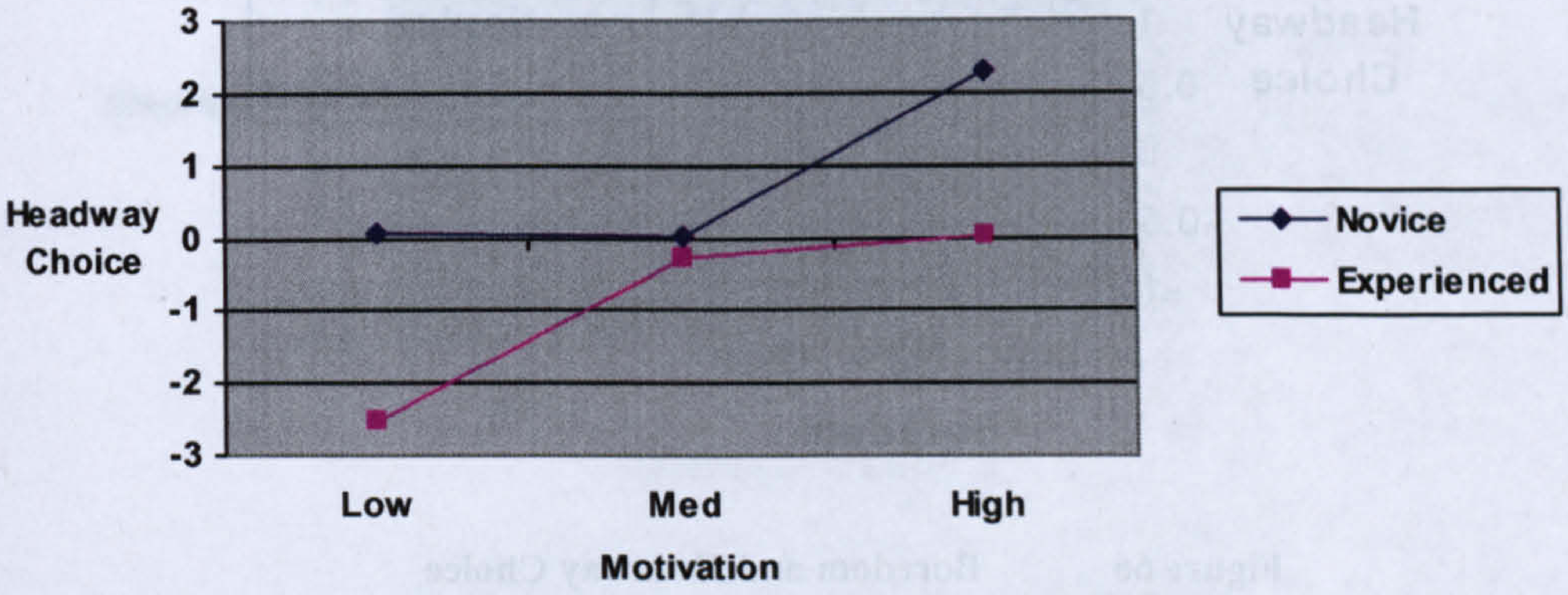


Figure 65 **Motivation and Headway Choice**

There was a significant main effect of motivation on headway choice, (F(2, 52) = 5.812, p<.01). Post-hoc comparisons using the bonferroni correction, revealed that bus drivers with high scores on motivation had higher scores on Headway Choice than bus drivers with low (p<.05), and medium scores on motivation (p<.01)

8.9.6.2 Boredom

There was a significant interaction between experience and boredom on Headway Choice, (F(2, 52) = 4.821, p<.05). Post-hoc comparisons using the bonferroni correction, revealed that this was due to a significant difference in headway choice for novice drivers with different levels of boredom, (F(2, 26) = 5.594, p<.01). Novice bus drivers with the lowest boredom scores had significantly higher factor scores on Headway Choice than bus drivers with medium (p<.01) and high levels of boredom (p<.05). Post hoc comparisons showed that Boredom also influenced headway choice in experienced bus drivers, (F(2, 52) = 6.526, p<.01). Experienced bus drivers with medium levels of boredom had lower factor scores on headway choice than experienced drivers with high levels of boredom (p<.01).

There was a significant main effect of boredom on Headway Choice, F(2, 52) = 8.396, p<.001. Post-hoc comparisons using the bonferroni correction, revealed that this was because bus drivers with low levels of boredom had higher factor scores on Headway Choice than bus drivers with medium levels of boredom (p<.01)

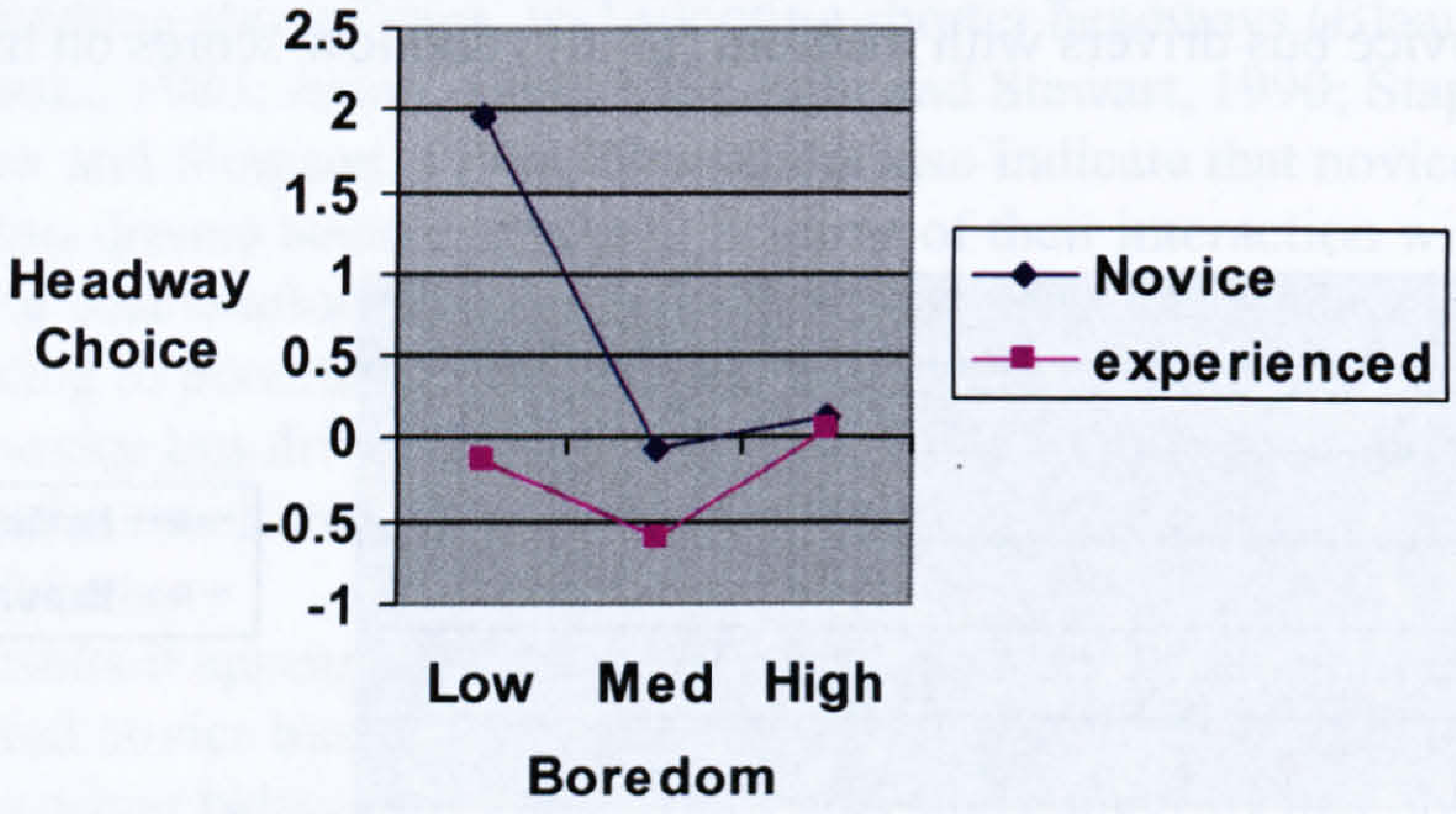


Figure 66 **Boredom and Headway Choice**

8.9.6.3 Mental Workload

The interaction between experience and mental workload was not significant. However, there was a significant main effect of mental workload on Interaction with Traffic in the Opposite Lane, (F(2, 52) = 3.484, p<.05). The graph indicates that bus drivers with low mental workload had higher scores on interaction with traffic in the opposite lane than bus drivers with medium mental work load scores. Post-hoc comparisons using the bonferroni correction, revealed that this difference approached significance, (p<.10).

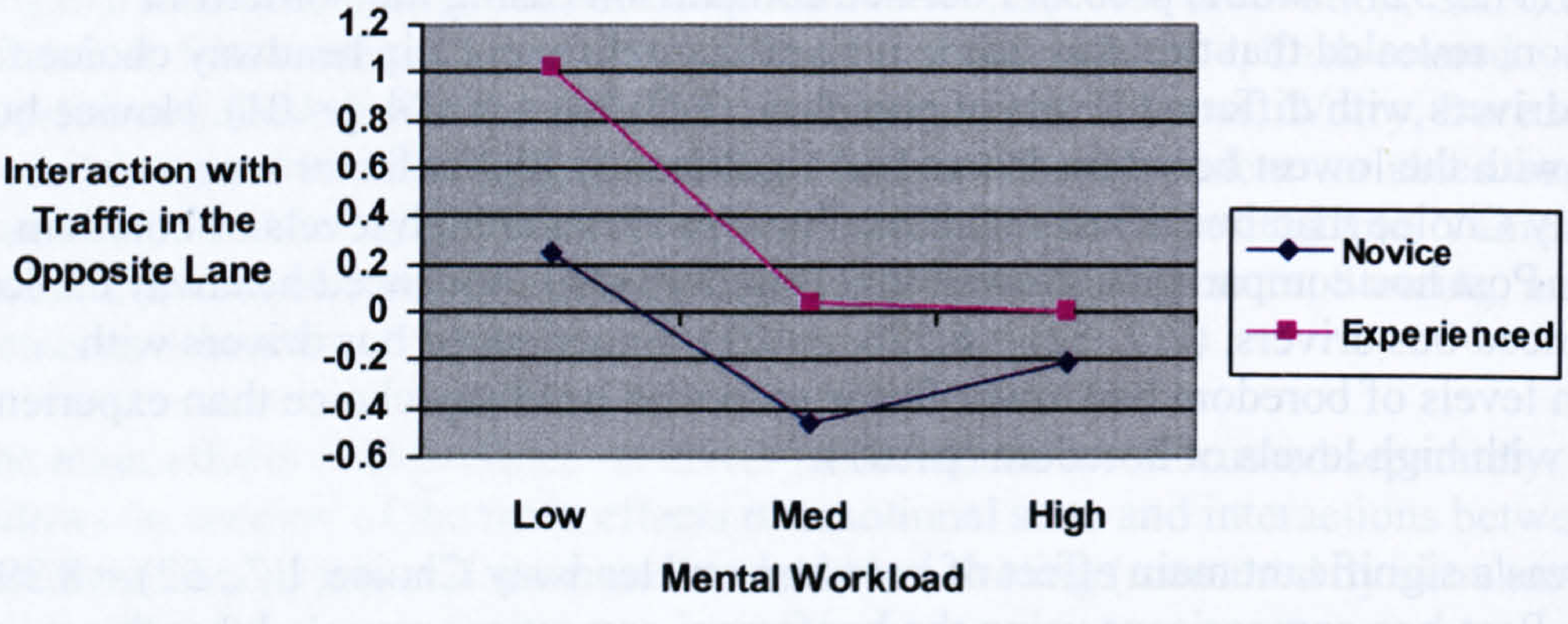


Figure 67 **Mental Workload and Interaction with Traffic in the Opposite Lane**

8.9.6.4 Temporal Workload

There was a significant interaction between experience and temporal workload on steering, (F(2, 52) = 3.846, p<.05). Post-hoc comparisons using the bonferroni correction, revealed that this there was not an effect of temporal workload on steering in novice bus drivers. However, for experienced bus drivers steering scores were lower for bus drivers with low (p<.10), and high (p<.10) scores on temporal workload when compared with bus drivers with medium scores on temporal workload.

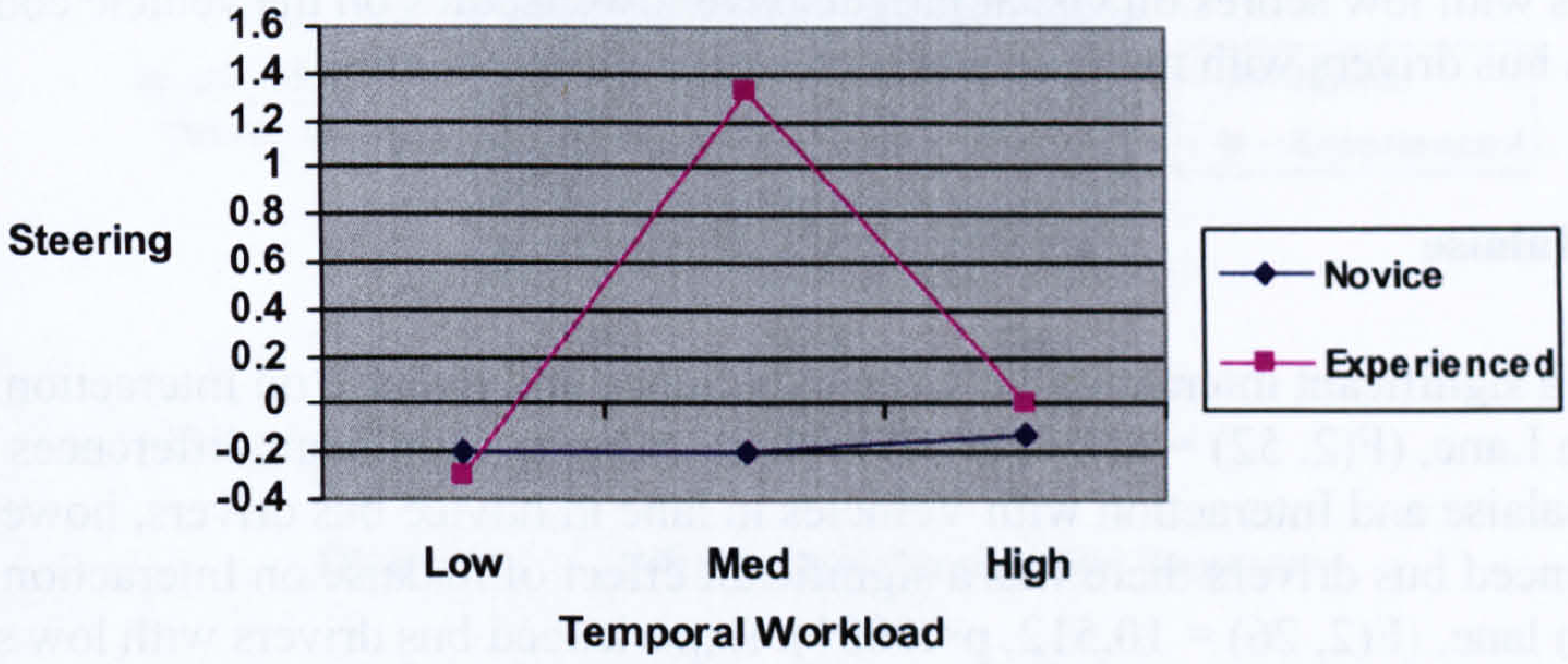


Figure 68 **Temporal Workload and Steering**

There was also a main effect of temporal workload on steering, (F(2, 52) = 3.38, p<.05), which is probably due to the fact that experienced bus drivers with medium scores on temporal workload had higher scores on steering than experienced bus drivers with low (p<.10) and high (p<.10) temporal workload scores.

8.9.6.5 Visual Fatigue

There was an interaction between experience and visual fatigue on Vehicle Control, (F(2, 52) = 4.81, p<.05). There were no significant differences between visual fatigue vehicle control in experienced bus drivers, however for novice bus drivers there was a significant effect of visual fatigue on vehicle control, (F(2, 26) = 4.270, p<.05). Post-hoc comparisons using the bonferroni correction, revealed that novice bus drivers with low scores on visual fatigue had lower scores on vehicle control than novice bus drivers with medium (p<.05) and high levels of visual fatigue (p<.05).

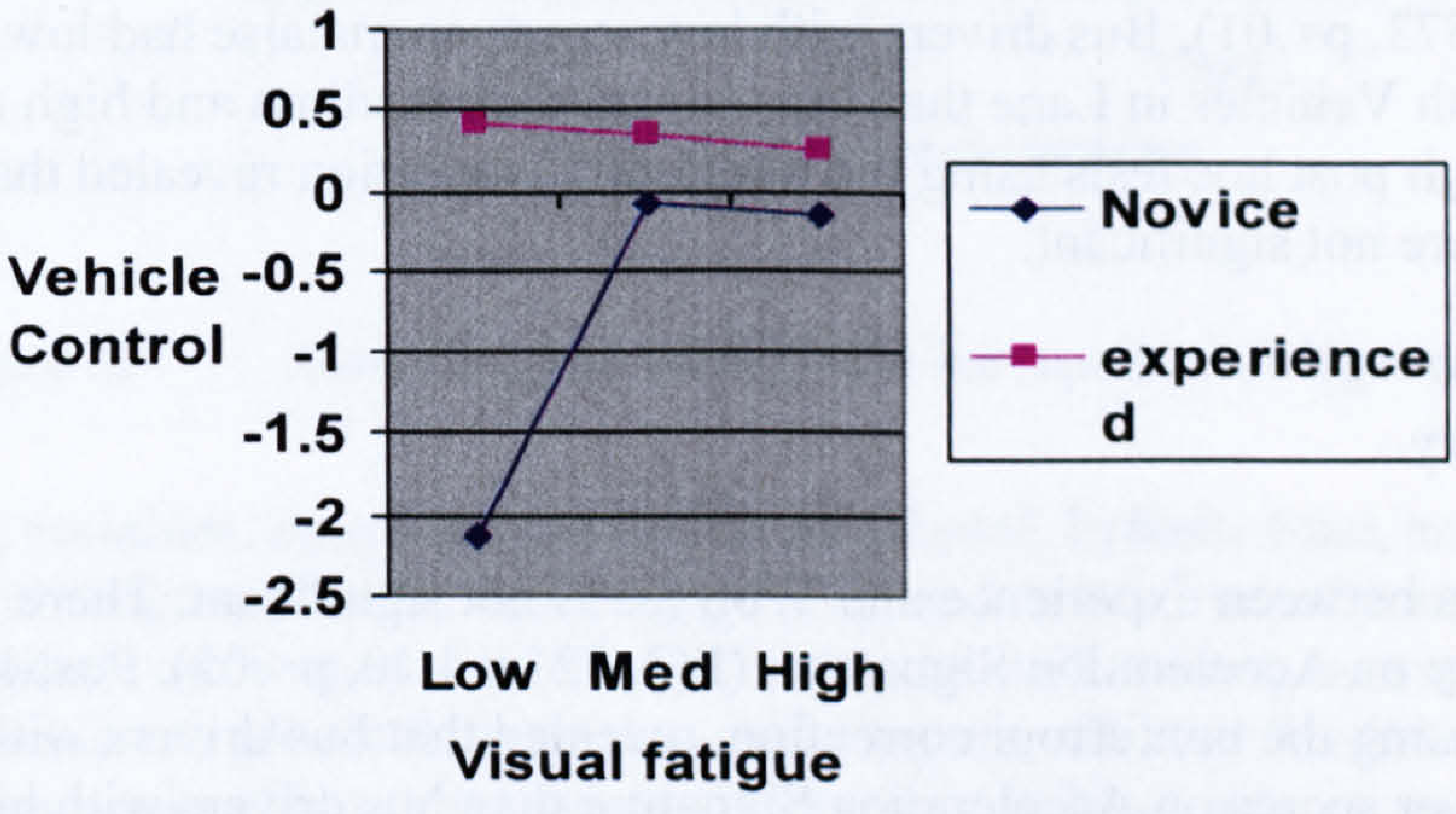


Figure 69 **Visual Fatigue and Vehicle Control**

There was a main effect of visual fatigue on vehicle control, (F(2, 52) = 3.821, p<.05). Bus drivers with low scores on visual fatigue have lower scores on the vehicle control factor than bus drivers with medium and high visual fatigue scores.

8.9.6.6 Malaise

There was a significant interaction between experience and malaise on Interaction with Vehicles in Lane, (F(2, 52) = 6.930, p<.05). There were no significant differences between malaise and Interaction with Vehicles in lane in novice bus drivers, however for experienced bus drivers there was a significant effect of malaise on Interaction with Vehicles In lane, (F(2, 26) = 10.512, p<.0001). Experienced bus drivers with low scores on malaise had lower scores on Interaction with other vehicles than experienced bus drivers with medium and high malaise scores. Post hoc tests could not be performed because there was only one experienced bus driver who had a low malaise score.

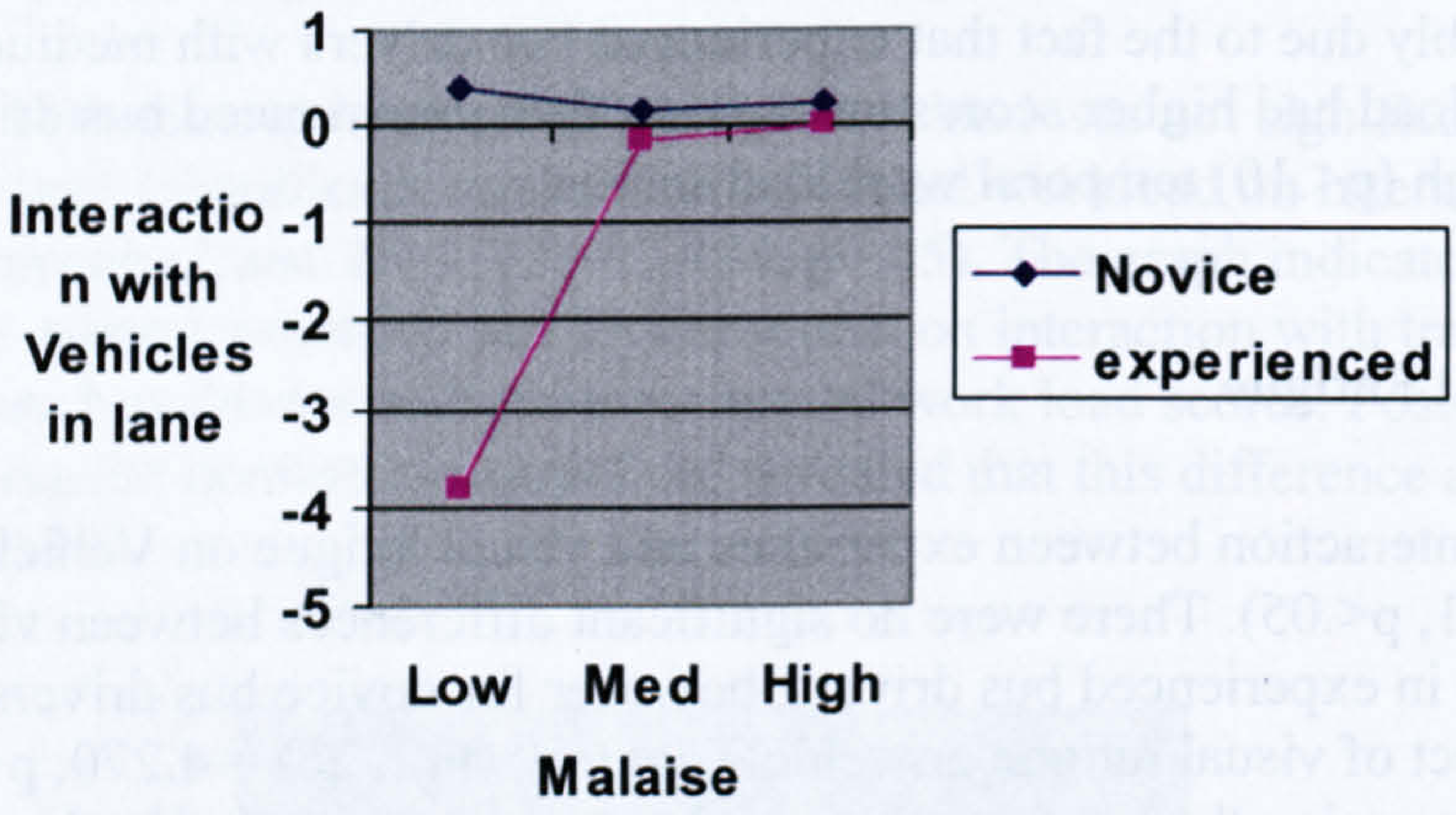


Figure 70 Malaise and Interaction with Vehicles in Lane

There was a significant main effect of malaise on Interaction with Vehicles in Lane, (F(2, 52) = 5.573, p<.01). Bus drivers with low scores on malaise had lower scores on Interaction with Vehicles in Lane than bus drivers with medium and high malaise scores, although post hoc tests using the bonferroni correction revealed that these differences were not significant.

8.9.6.7 Worry

The interaction between experience and Worry was not significant. There was a main effect of Worry on Acceleration Signature, (F(2, 52) = 4.40, p<.05). Post-hoc comparisons using the bonferroni correction, revealed that bus drivers with low worry scores had lower scores on Acceleration Signature than bus drivers with high Worry scores (p<.05)

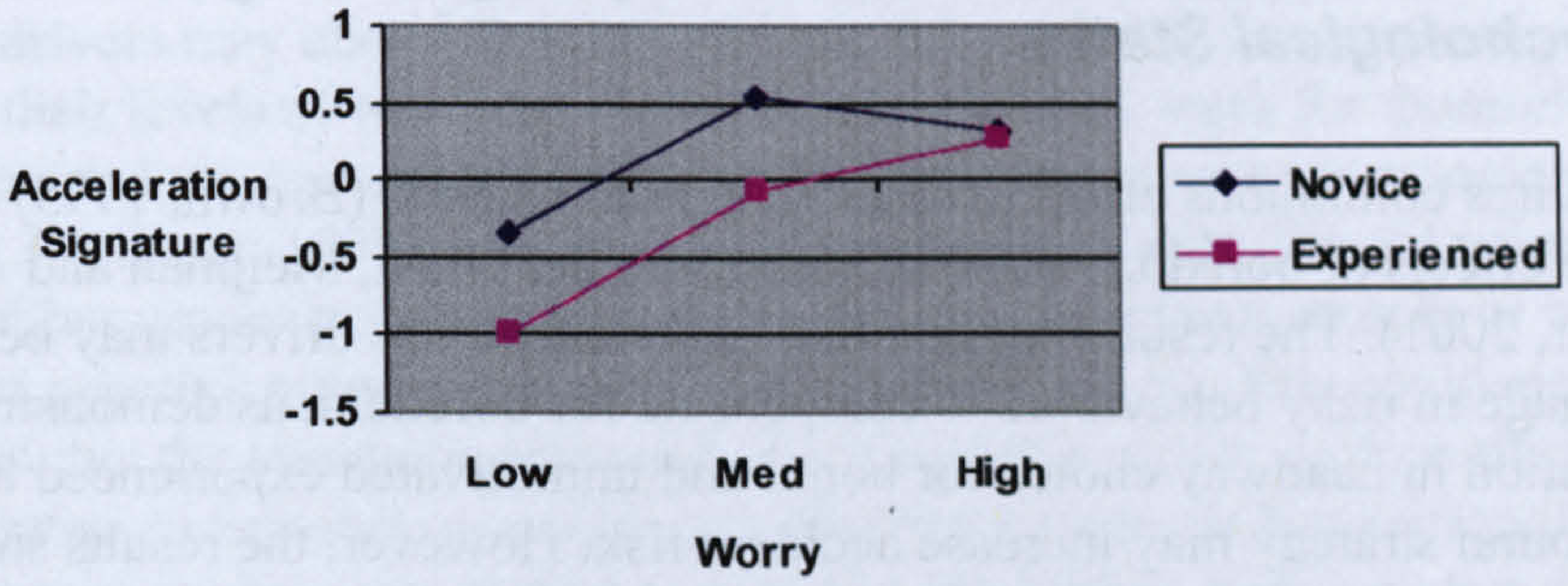


Figure 71 Worry and Acceleration Signature

8.9.6.8 Task irrelevant Interference

There was a significant main effect of task irrelevant interference on Acceleration Signature, (F(2, 52) = 5.197, p<.01). Post-hoc comparisons using the bonferroni correction, revealed that bus drivers with medium levels of task irrelevant interference had higher scores on Acceleration Signature than bus drivers with low levels of task irrelevant interference (p<.01), and high levels of task irrelevant interference (p<.05).

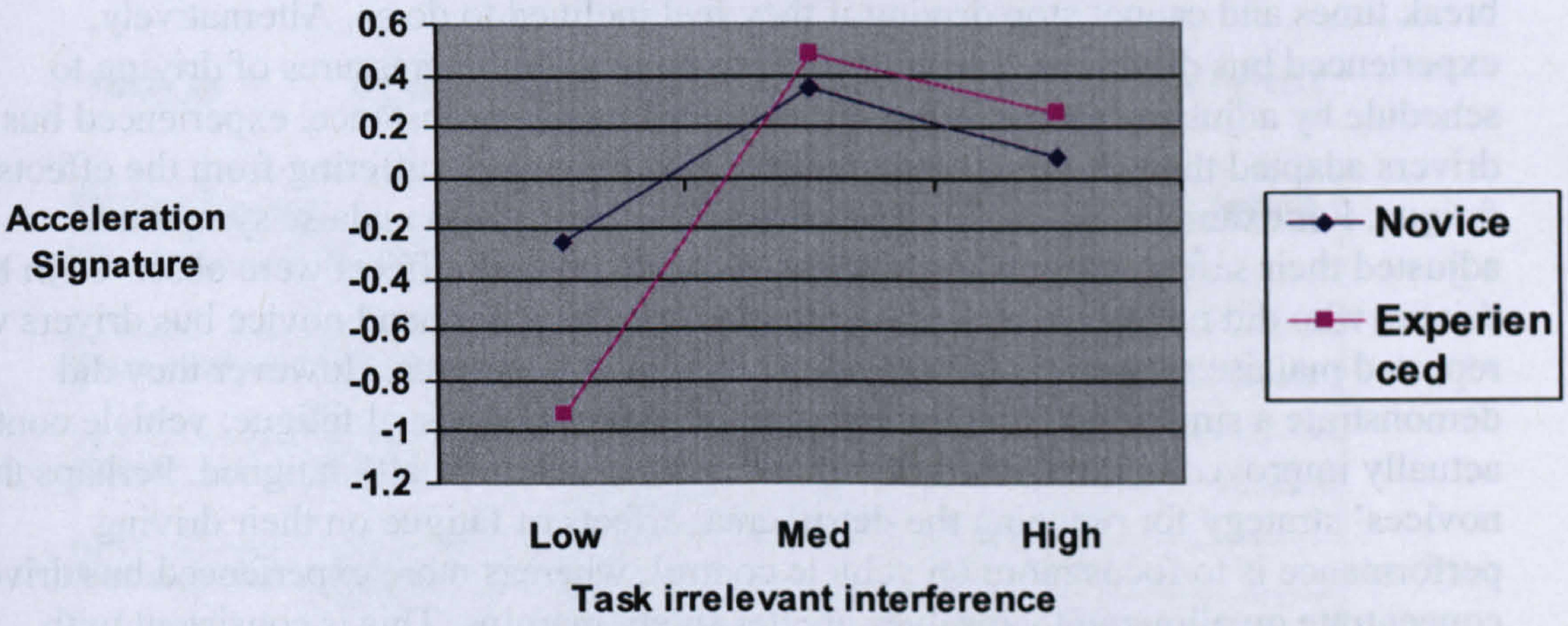


Figure 72 Task Irrelevant Interference and Acceleration Signature

The following variables: energetic arousal, tense arousal, hedonic tone, anger, muscular fatigue, physical fatigue, distress, task engagement, task related interference, success motivation, intrinsic motivation, self-focused attention, self esteem, concentration, control and confidence, physical workload, performance, effort or frustration, did not have a significant main effect or significant interaction with experience on simulated bus driving.

8.9.7 The Role of Experience when Adapting Driving to Changes in Psychological States

Driving requires continuous effort to detect potential hazards (Brown, 1995) and also to stave off the effects of boredom while driving (Van der Hulst, Meijman and Rothengatter, 2001). The results suggest that experienced bus drivers may be more likely to engage in risky behaviours to compensate for boredom, as demonstrated by a greater variation in headway choice for bored and unmotivated experienced bus drivers. This behavioural strategy may increase accident risk. However, the results show that highly motivated novice bus drivers demonstrate the greatest variability in headway choice. Engaging in this behaviour, although potentially more risky, may in fact enable more motivated novice bus drivers to establish what constitutes a consistently safe distance from other vehicles more quickly than their less motivated peers.
Bus drivers coped with high mental workloads by keeping further away from oncoming traffic. Increasing safety margins in this way allows the bus drivers to decrease the demands of the task and protects the adequacy of their collision avoidance strategies (Van der Hulst, Meijman and Rothengatter, 2001). However experienced bus drivers demonstrated less adaptivity in their steering behaviour in conditions of low and high temporal workload, while novice bus drivers did not change their behaviour in response to perceived temporal workload. Deterioration of steering performance is also associated with the development of an aversion to driving in fatigued drivers (Van der Hulst, Meijman and Rothengatter, 2001). Perhaps then a greater variation in steering indicates that the stressed bus drivers have developed an aversion to driving. This is particularly serious in bus driving because the bus drivers have no control over their break times and cannot stop driving if they feel inclined to do so. Alternatively, experienced bus drivers may have learned to cope with the pressures of driving to schedule by adjusting their driving styles accordingly. For instance, experienced bus drivers adapted their driving if they realised that they were suffering from the effects of fatigue. For example, experienced bus drivers suffering with malaise symptoms adjusted their safety margins to compensate while no such effects were observed in bus drivers who did not report malaise symptoms. On the other hand novice bus drivers who reported malaise symptoms did not adjust their safety margins. However they did demonstrate a similar pattern of adaptation in response to visual fatigue: vehicle control actually improved in novice bus drivers when they were visually fatigued. Perhaps then novices' strategy for reducing the detrimental effects of fatigue on their driving performance is to focus more on vehicle control, whereas more experienced bus drivers concentrate on allowing themselves greater safety margins. This is consistent with previous research that suggests that it is likely that experienced bus drivers adapt their behaviour so that they are still able to prioritise hazard avoidance when they are fatigued (Van der Hulst, Meijman and Rothengatter, 2001).

Worry is indicative of a perceived inability to cope with higher workloads (Matthews, Joyner, Gilliland, Campbell, Falconer and Huggins, 1999) and concordant with other research, the results of this study link worry with deterioration in driving performance (e.g. Matthews, Dorn, Hoyes, Davis, Glendon and Taylor, 1998). The bus drivers who were worried and who reported that they were distracted by thoughts that were not relevant to driving tended to show greater variations in their acceleration behaviour, while drivers who were not worried and who were not distracted tended to show less

variation. Since the task environment was the same for all participants, this suggests that worried bus drivers may choose less appropriate driving behaviours and may even have exacerbated their levels of worry by creating more physical work for themselves.
In contrast to previous research that showed that negative moods are associated with risky driving (Haigney, 1999), moods did not have a significant effect on simulated bus driving in neither novice nor experienced bus drivers. In fact this sample of bus drivers did not report negative mood states and were relatively happy. This could mean that a) they all found that the simulator was relatively pleasant to drive; b) they all coped well with any negative events that occurred; or c) if a negative event had occurred they had had enough time to calm down before completing the DSSQ. Similarly bus drivers did not report high levels of physical or muscular fatigue, which is not surprising since bus driving does not require a lot of physical exertion.

8.9.8 Main Effects of Experience on Stress States

Differences in pre exposure, post exposure and state changes in stress were analysed in order to determine whether novice and experienced bus drivers reacted to the ABS in expected ways. The results are presented in order of the effect of experience on DSSQ factors, DSSQ item scores, coping style (task irrelevant and task related interference) workload, mood and fatigue.

8.9.8.1 Responses on DSSQ Factors

The table shows the DSSQ factor scores for experienced and novice bus drivers.

Table 38 DSSQ Factor Means for Novice and Experienced Bus Drivers

DSSQ Factor	Level of Experience	Mean	Std. Deviation
Pre-exposure Worry	novice	.66	.94
	experienced	.17	.67
Post-exposure Worry	novice	-.03	.63
	experienced	-.05	.67
Worry state change	novice	-.69	.68
	experienced	-.22	.39
Pre-exposure Engagement	novice	.52	.54
	experienced	.03	.60
Post-exposure Engagement	novice	.38	.53
	experienced	.097	.56
Engagement state change	novice	-.14	.49
	experienced	.068	.37
Pre-exposure Distress	novice	-1.75	.73
	experienced	-1.88	.70
Post-exposure Distress	novice	-1.63	.91
	experienced	-1.21	1.22
Distress state change	novice	.13	.66
	experienced	.67	1.05

Novice driver's pre-exposure Worry was significantly higher than experienced drivers, (F (1, 56) =5.323, $p<.05$). This may have been in anticipation to the driving task. There was no difference between post exposure Worry for novice and experienced drivers, but Worry state change was significantly higher in novice bus drivers, (F(1, 56) = 10.553, $p<.05$) probably due to their elevated pre-exposure Worry.

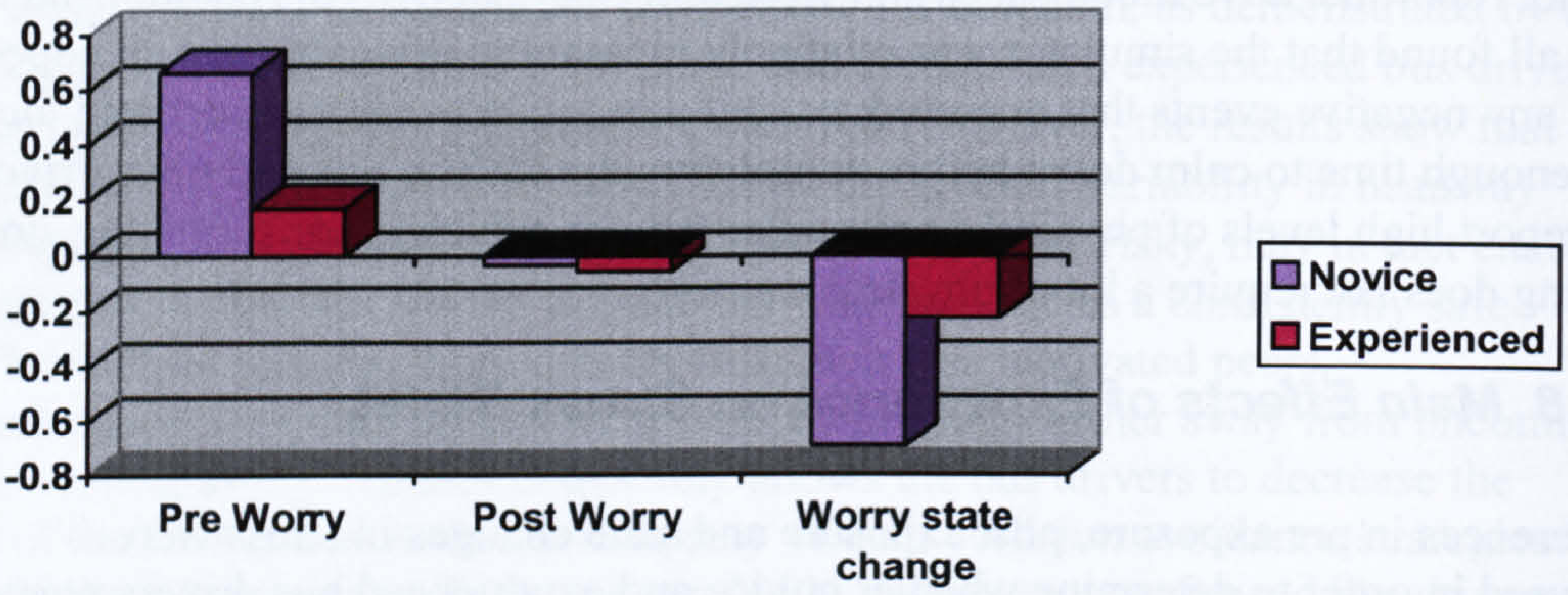


Figure 73 **Effect of Experience on Worry**

Novice driver's pre-exposure scores on the Engagement factor were significantly higher than those for experienced bus drivers, (F(1, 56) = 10.668, $p<.05$). This suggests that novice bus drivers were more enthusiastic about the task ahead.

Differences between novice and experienced bus drivers' post-exposure Engagement and the Engagement state change scores were not statistically significant. However, the differences approached significance, (F(1, 56)=3.87, $p<.10$) and (F(1, 56) = 3.40, $p<.10$) respectively.

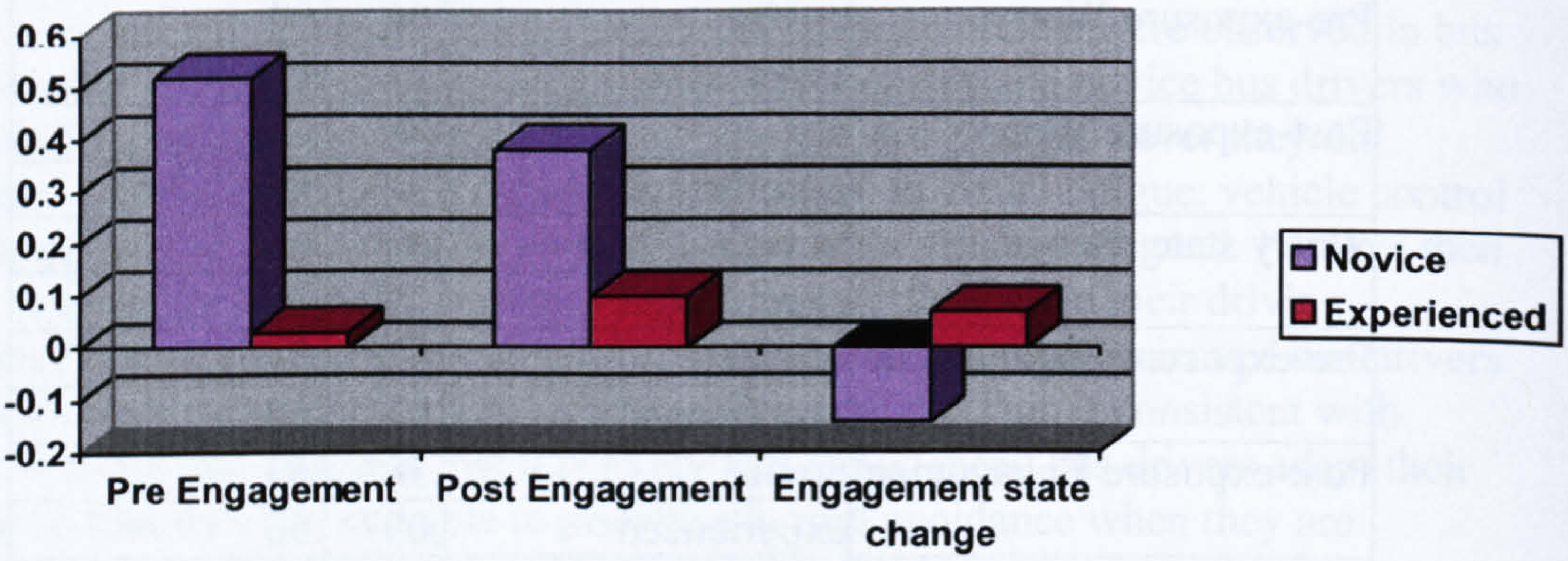


Figure 74 **Effect of Experience on Task -Engagement**

There were no significant differences between novice and experienced bus drivers in terms of their pre and post exposure levels of distress. However, the Distress state change was significantly greater for experienced bus drivers when compared with novice bus drivers, (F(1, 56)=5.52, $p<.05$) suggesting that experienced bus drivers were much less distressed after simulated driving.

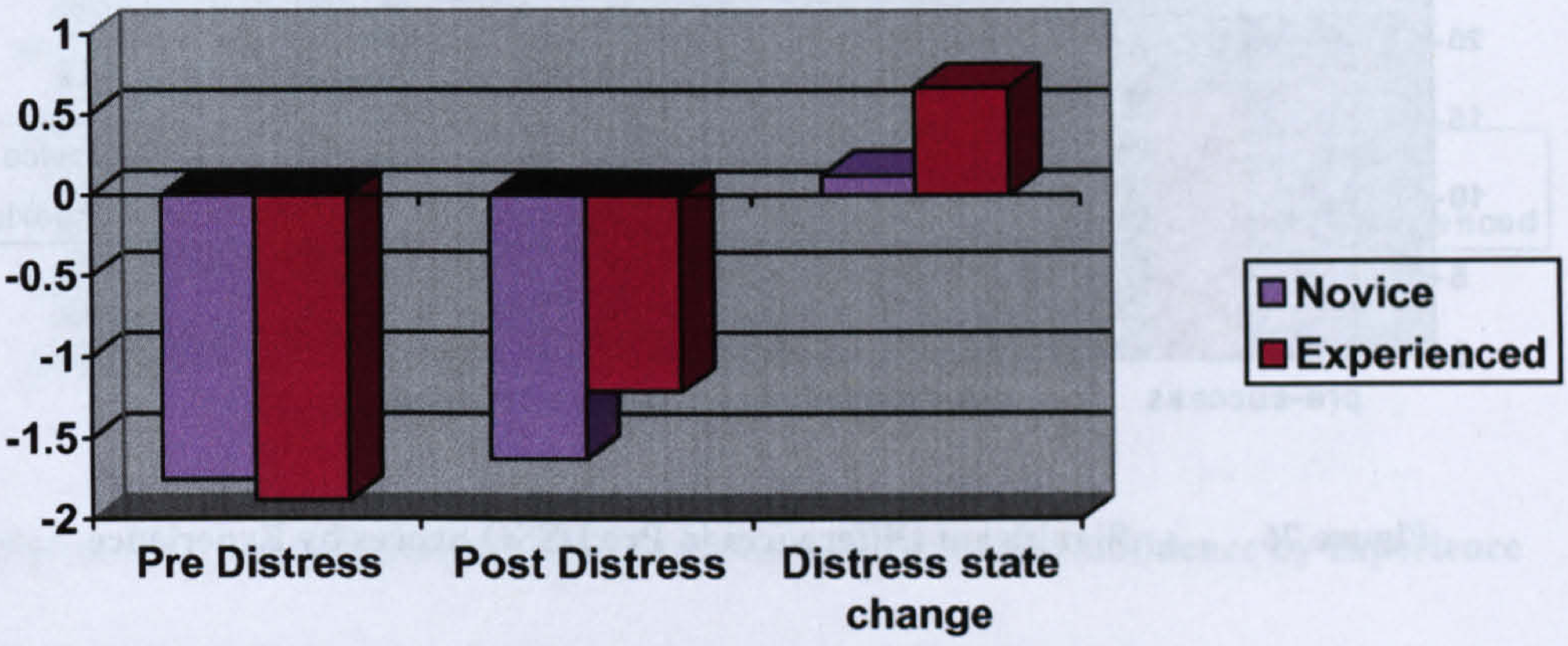


Figure 75 **Effect of Experience on Distress**

8.9.8.2 DSSQ Item Scores

The table shows the DSSQ scale scores for experienced and novice bus drivers before driving the ABS.

Table 39 **DSSQ Pre-exposure Item Scores**

DSSQ Pre exposure Item	experience	Mean	Std. Deviation
pre success motivation	novice	19.89	5.67
	experienced	16.89	5.65
pre intrinsic motivation	novice	24.86	2.91
	experienced	24.38	3.19
pre motivation	novice	3.48	.633
	experienced	3.0	.926
pre self-focussed attention	novice	8.07	5.59
	experienced	7.41	4.38
pre self esteem	novice	18.93	6.96
	experienced	23.45	4.60
pre concentration	novice	1.62	2.24
	experienced	2.10	2.39
pre control and confidence	novice	24.56	4.05
	experienced	23.69	5.09

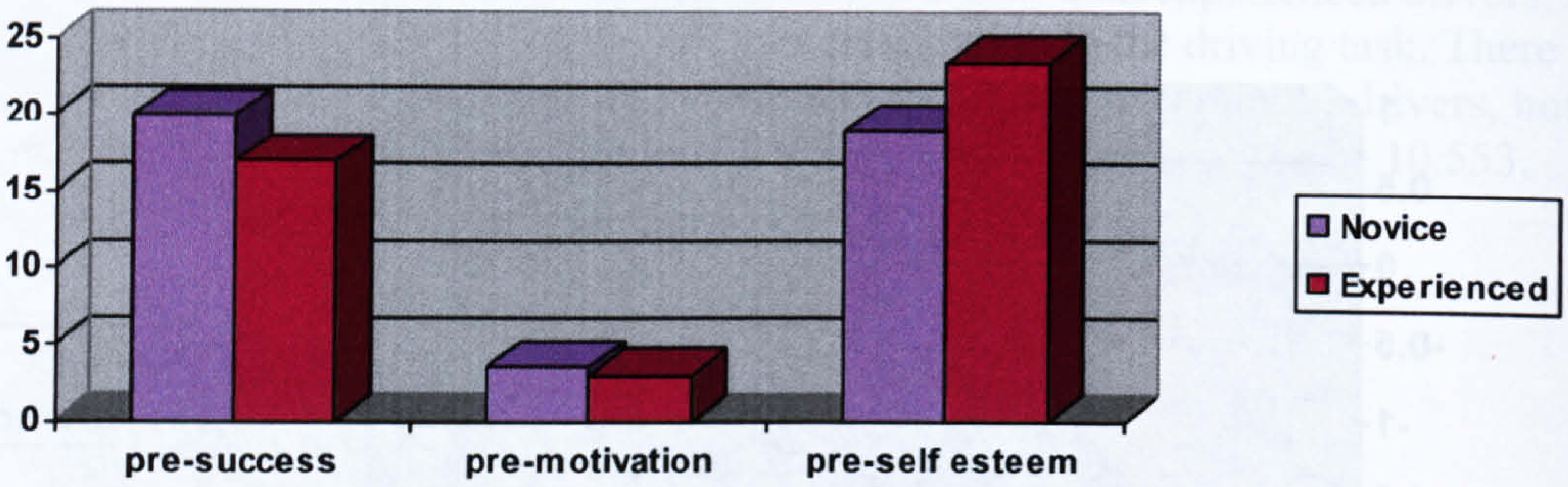


Figure 76 **Significant Differences in Pre DSSQ Scores by Experience**

Pre-exposure success motivation and overall motivation scores were significantly higher in novice bus drivers when compared with experienced bus drivers scores, (F(1, 56)=4.08, p<.05) and (F(1, 56)=5.37, p<.05) respectively. Pre exposure self esteem was significantly higher in experienced bus drivers than novice bus drivers, (F(1, 56) = 8.406, p<.05).

The table shows the DSSQ scale scores for experienced and novice bus drivers after driving the ABS.

Table 40 **DSSQ Post exposure Item Scores**

DSSQ Post exposure Item	experience	Mean	Std. Deviation
post success motivation	novice	18.79	7.13
	experienced	15.34	7.44
post intrinsic motivation	novice	25.10	4.16
	experienced	24.90	2.64
post motivation	novice	3.21	.68
	experienced	2.93	.96
post self-focused attention	novice	3.72	4.35
	experienced	5.17	3.75
post self esteem	novice	22.07	6.16
	experienced	23.41	5.41
post concentration	novice	1.0	2.35
	experienced	1.24	1.77
post control and confidence	novice	24.41	4.29
	experienced	21.07	6.49

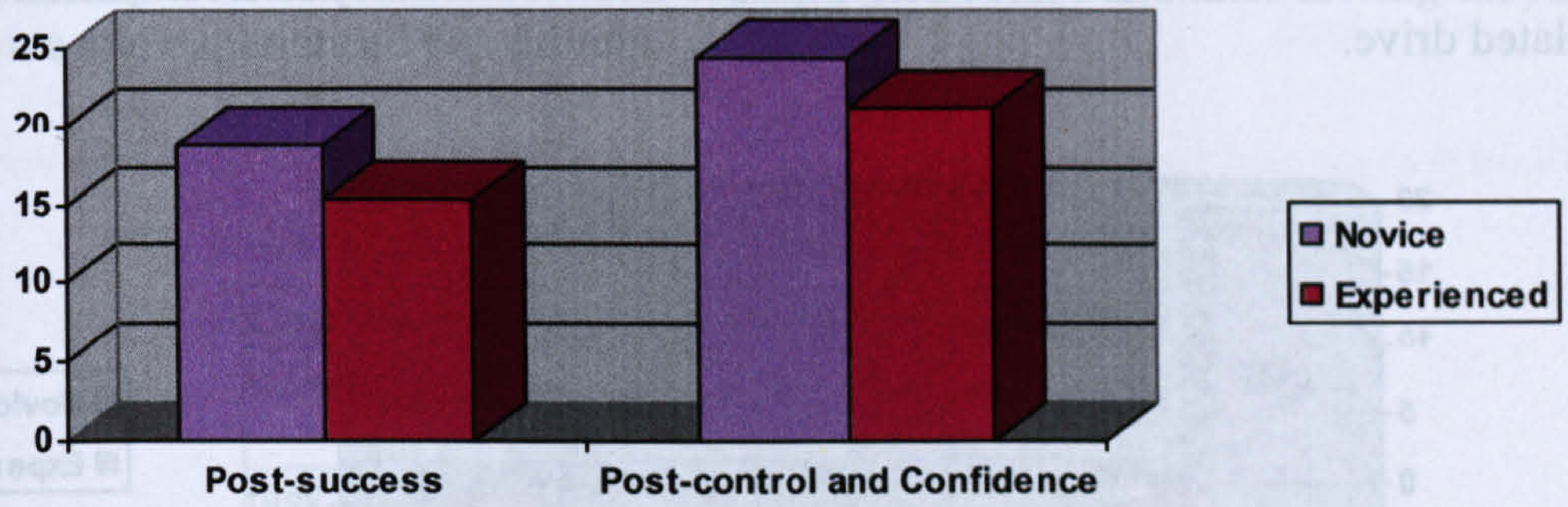


Figure 77 **Post-Success Motivation and Control and Confidence by Experience**

The difference between success motivation scores after driving the ABS approached significance, (F(1, 56)=3.247, $p<.10$); novice bus drivers had higher success motivation scores than experienced bus drivers. Post exposure measures of control and confidence were significantly different, (F(1, 56)=5.36, $p<.05$); experienced bus drivers were less confident than novice bus drivers after completing the simulated drive.

The table shows the difference between pre- and post-exposure DSSQ scale scores for experienced and novice bus drivers.

Table 41 **DSSQ Item State changes**

DSSQ Item State change	experience	Mean	Std. Deviation
success motivation	novice	-1.10	3.64
	experienced	-1.56	3.33
intrinsic motivation	novice	.24	3.41
	experienced	.52	2.06
motivation	novice	-.28	.751
	experienced	-.07	.651
self-focused attention	novice	-4.34	5.02
	experienced	-2.24	3.68
self esteem	novice	3.14	4.64
	experienced	-.035	3.96
concentration	novice	-.62	1.92
	experienced	-.86	2.23
control and confidence	novice	-.14	4.16
	experienced	-2.62	5.04

Novice bus drivers had significantly greater self esteem state change scores, (F(1, 56)=7.855, $p<.05$). Novice bus drivers had positive state change scores but experienced bus drivers had a negative state change score indicating experienced bus drivers have less self-esteem and novice bus drivers had more self-esteem after exposure to the simulated environment. Experienced bus drivers had greater state change scores on control and confidence than novice bus drivers, (F(1, 56)=4.19, $p<.05$), both novice and experienced bus drivers had less confidence and control after they had completed the simulated drive.

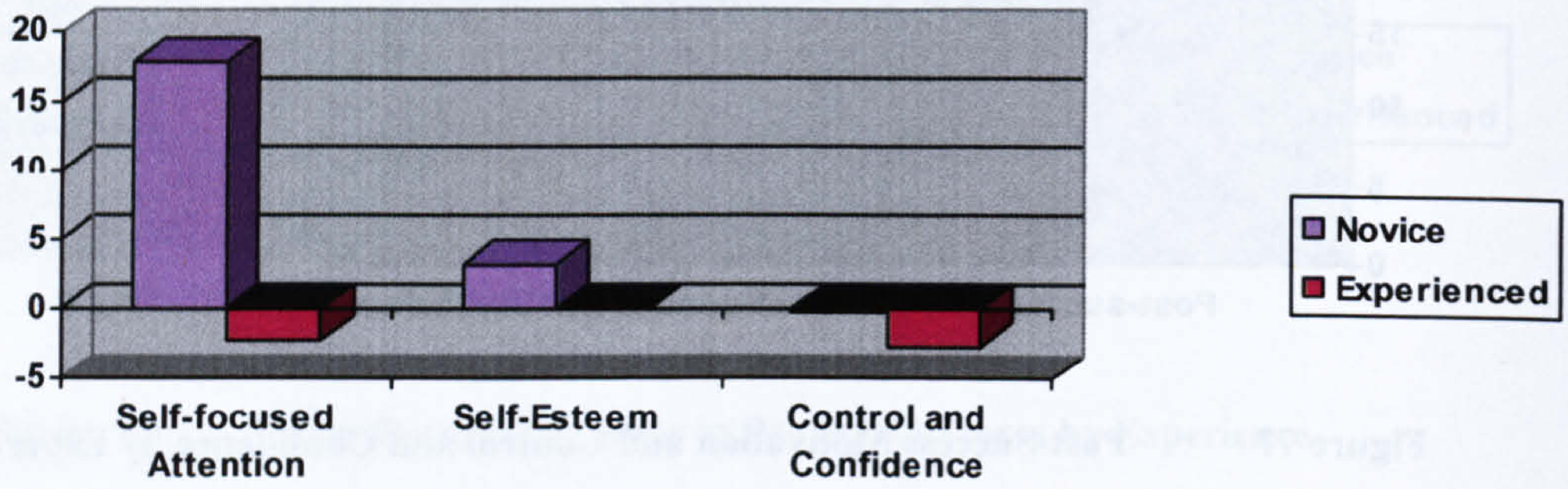


Figure 78 Effect of Experience on Thinking Style State Changes

8.9.8.3 Coping style

The table shows pre-exposure coping styles for novice and experienced bus drivers.

Table 42 Pre-Exposure DSSQ Coping Style

Pre exposure Coping Style	Experience	Mean	SD
pre task-related interference	novice	17.90	6.98
	experienced	14.38	5.36
pre task-irrelevant interference	novice	10.83	4.70
	experienced	11.76	4.93

Before beginning the simulated driving task, novice bus drivers reported more task-related interference than experienced bus drivers, (F(1, 56)=4.634, p<.05).

The table shows coping styles for novice and experienced bus drivers after driving the ABS.

Table 43 Post-exposure DSSQ Coping Style

Post exposure Coping Style	Experience	Mean	SD
post task-related interference	novice	14.24	5.13
	experienced	14.90	5.46
post task-irrelevant interference	novice	8.38	1.12
	experienced	9.07	2.64

There were no significant differences between post exposure coping measures.

The table shows the difference between coping styles before and after driving the ABS for novice and experienced bus drivers.

Table 44 DSSQ Coping Style State Changes

Coping Style State change	Experience	Mean	SD
task-related interference	novice	-3.65	5.65
	experienced	.517	3.63
task-irrelevant interference	novice	-2.44	4.14
	experienced	-2.69	4.58

Experienced bus drivers reported more task-related interference after exposure to the simulator while novice bus drivers reported less task-related interference after exposure, (F(1, 56)=11.203, p<.05). The graph illustrates the differences between novice and experienced bus drivers in terms of their coping styles.

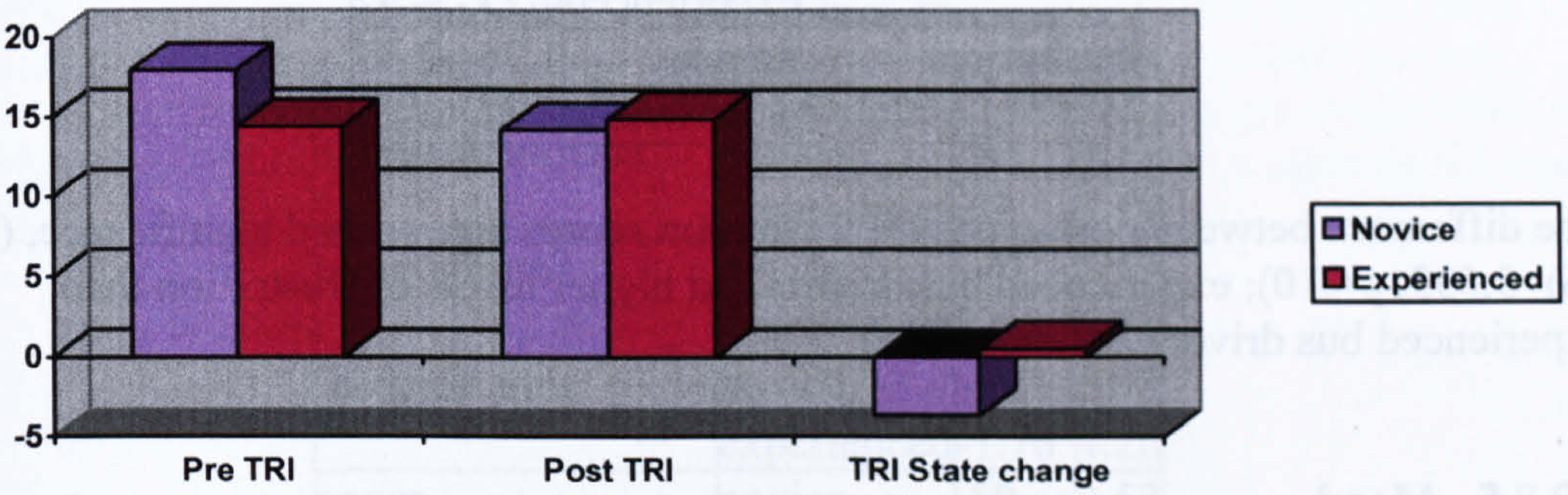


Figure 79 Effect of Experience on Task Related Interference

8.9.8.4 Workload

Workload was assessed after driving the ABS. The table below shows the workloads reported by novice and experienced bus drivers.

Table 45 Workload Reported After Simulated Driving

Workload	Experience	Mean	SD
mental demand	novice	7.31	2.55
	experienced	7.72	1.51
physical demand	novice	3.45	2.49
	experienced	4.00	2.27
temporal demand	novice	2.03	2.18
	experienced	2.90	2.23
performance	novice	7.22	1.36
	experienced	6.95	1.77
effort	novice	6.79	2.66
	experienced	7.21	1.92
frustration	novice	1.76	2.57
	experienced	3.21	3.26

The difference between post exposure frustration scores approached significance, (F(1, 56)=3.533, p<.10); experienced bus drivers had higher levels of frustration than experienced bus drivers.

8.9.8.5 Mood

The table below shows novice and experienced bus drivers' moods before they drove the ABS.

Table 46 Pre-exposure Mood

Pre exposure Mood	Experience	Mean	SD
pre energetic arousal	novice	26.72	3.62
	experienced	24.69	3.97
pre tense arousal	novice	12.90	4.19
	experienced	12.14	3.73
pre hedonic tone	novice	30.55	2.72
	experienced	30.33	3.06
pre anger	novice	5.90	2.45
	experienced	6.17	3.38

The following table shows bus drivers moods after they drove the ABS.

Table 47 Post exposure Mood

Post exposure Mood	Experience	Mean	SD
post energetic arousal	novice	27.62	3.89
	experienced	25.31	3.97
post tense arousal	novice	12.48	3.92
	experienced	14.79	5.44
post hedonic tone	novice	28.24	6.63
	experienced	28.56	4.36
post anger	novice	6.48	3.39
	experienced	6.72	3.01

The table below shows the changes in mood after driving the ABS for novice and experience bus drivers.

Table 48 Mood State Changes

Mood State change	Experience	Mean	SD
energetic arousal	novice	.90	3.13
	experienced	.62	3.19
tense arousal	novice	-.41	3.59
	experienced	2.66	5.55
hedonic tone	novice	-2.31	5.98
	experienced	-1.76	4.26
anger	novice	.59	2.53
	experienced	.55	4.27

Novice driver's energetic arousal scores were higher than experienced drivers when they arrived at the laboratory, (F(1, 56)=4.16, p<.05). After exposure to the simulated environment novice bus drivers scored more highly on energetic arousal than experienced bus drivers, (F(1, 56)=5.022, p<.05). The difference between post exposure measures of tense arousal approached significance, (F(1, 56)=3.44, p<.10); experienced bus drivers had higher levels of tension after completing the simulated drive when compared with novice drivers. There was a significant difference between tense arousal state changes, (F(1, 56)=6.25, p<.05). Experienced bus drivers had positive state change scores but novice bus drivers had a negative state change score indicating novice bus drivers were more relaxed after exposure to the simulator but experienced bus drivers were more tense after they had completed the simulated drive in comparison to novice bus drivers.

The graph illustrates the significant differences in the moods of novice and experienced bus drivers.

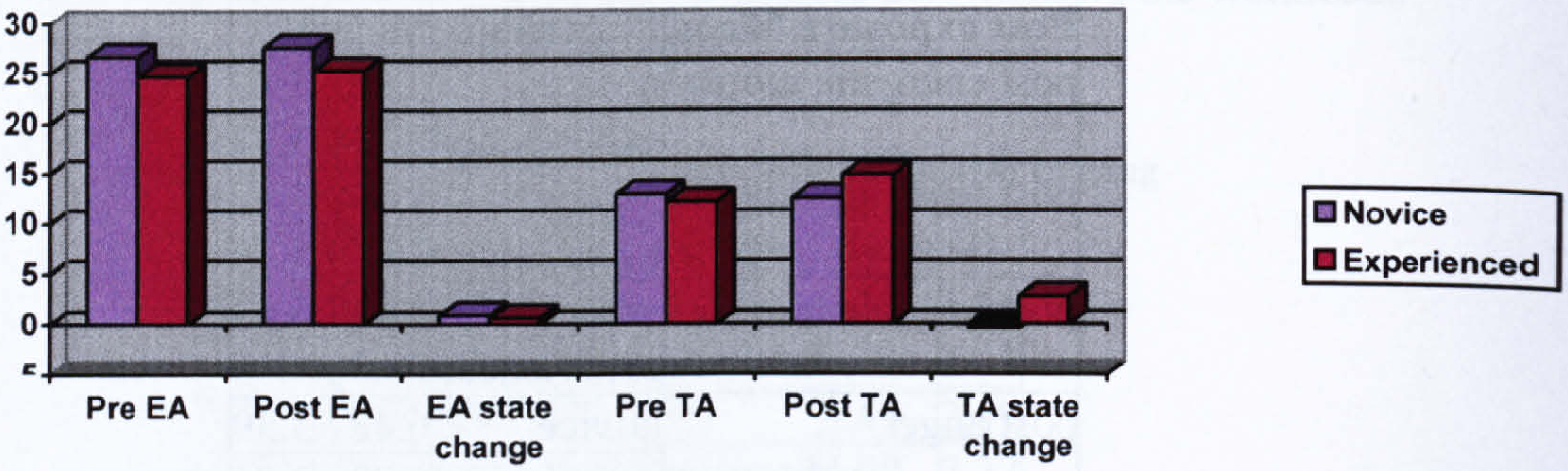


Figure 80 Effect of Experience on Arousal (Mood)

8.9.8.6 Fatigue Scale

The table shows measures of fatigue reported by novice and experienced bus drivers on their arrival at the ABS.

Table 49 Pre Exposure Fatigue Scale

Pre exposure Fatigue	Experience	Mean	SD
pre boredom	novice	1.48	3.02
	experienced	1.48	2.43
pre visual fatigue	novice	1.03	2.31
	experienced	1.76	4.03
pre malaise	novice	.345	1.01
	experienced	.414	1.05
pre muscular fatigue	novice	.48	1.60
	experienced	1.48	2.40
pre total fatigue	novice	3.34	7.23
	experienced	5.14	7.44

The difference in pre-exposure muscular fatigue approached significance, $(F(1, 56)=3.493, p<.10)$; experienced bus drivers reported greater levels of muscular fatigue than novice bus drivers.

The table below shows fatigue scores after driving the ABS.

Table 50 Post-Exposure Fatigue Scales

Post exposure Fatigue	Experience	Mean	SD
post boredom	novice	2.34	5.62
	experienced	1.59	2.23
post visual fatigue	novice	1.66	3.51
	experienced	2.90	4.74
post malaise	novice	1.07	3.34
	experienced	2.69	3.75
post muscular fatigue	novice	.76	2.73
	experienced	1.76	3.71
post total fatigue	novice	5.83	14.75
	experienced	8.93	11.90

Experienced bus drivers post exposure malaise scores were higher than novice drivers' malaise scores and the difference approached significance, (F(1, 56)=4.094, p<.10).

The table below shows the difference between fatigue measures before and after driving the ABS.

Table 51 Fatigue State Changes

Fatigue Item State change	Experience	Mean	SD
boredom	novice	.86	4.90
	experienced	.10	3.31
visual fatigue	novice	.62	2.65
	experienced	1.14	2.72
malaise	novice	.724	2.67
	experienced	2.28	3.15
muscular fatigue	novice	.276	2.10
	experienced	.276	1.98
total fatigue	novice	2.48	11.22
	experienced	3.80	7.34

Experienced bus drivers malaise state change scores were significantly higher than novice drivers' malaise score state changes, (F(1, 56)=4.094, p<.05).

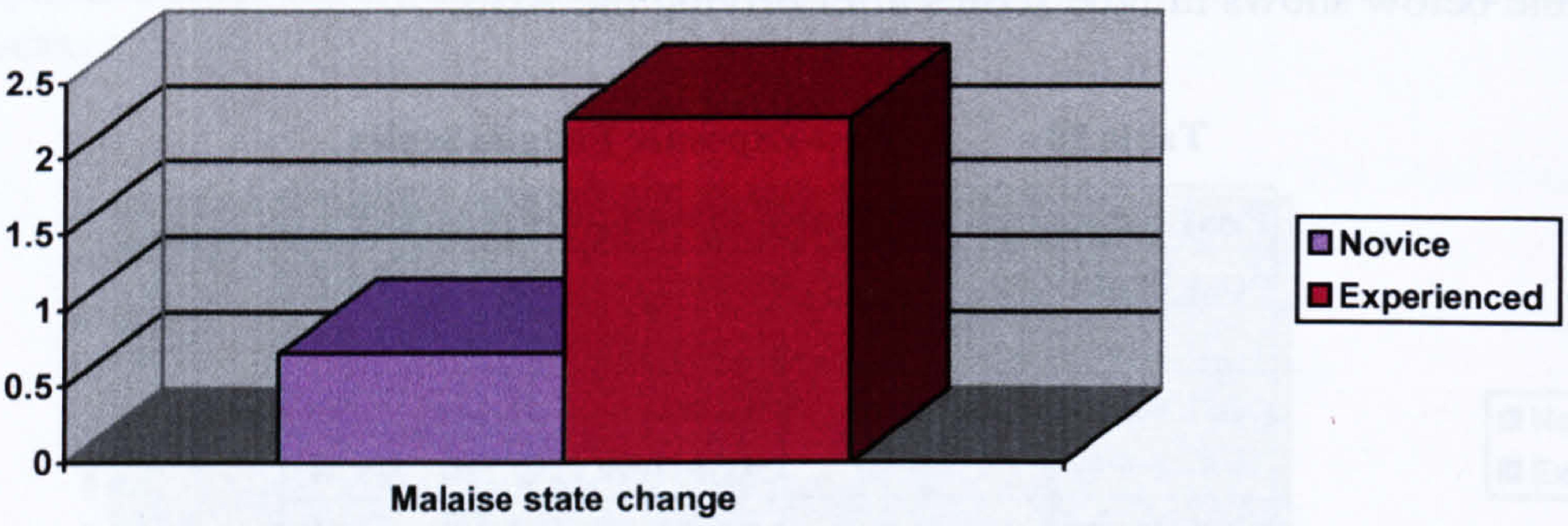


Figure 81 Effect of Experience on Malaise State Change

8.9.9 Discussion: Does the ABS Elicit Behaviourally Valid Responses?

Differences in stress responses before and after driving the ABS suggest that experienced and novice bus drivers are acting in a behaviourally valid way. To exemplify, novice and experienced bus drivers reported different stress states upon their arrival at the simulator laboratory. Novice bus drivers reported higher levels of Engagement and Worry, indicating that they were thinking more about the simulated task and had greater levels of energetic arousal and motivation than more experienced bus drivers, who were less worried and less inclined to think about the task ahead. This is not surprising as novice bus drivers are in training and have yet to establish a career as a bus driver with Arriva. Instead, more experienced bus drivers reported greater feelings of self-esteem. Although there is no direct evidence to support this in bus drivers, more experienced car drivers tend to have more confidence in their ability when compared to novice car drivers (Matthews and Moran, 1986). The experienced bus drivers, because of the benefit of their experience with bus driving, may have been more confident in their ability to drive a bus whether it is simulated or real and hence felt less apprehensive than novice drivers about the task ahead. Experienced bus drivers reported more muscular fatigue than novice bus drivers. Experienced drivers had probably spent more time driving in the period preceding the experiment than novice bus drivers and were therefore more fatigued. They probably also had less time to worry about the task ahead due to the high work loads and conflicting demands associated with driving a bus (Meijman and Kompier, 1998). This is because novice bus drivers typically train in groups of four and so spend less time behind the steering wheel than experienced bus drivers and also do not have to deal with passengers at this stage in their training. After performing the simulated driving task novice bus drivers were still more worried than experienced bus drivers, which again may have been due to their greater levels of task related interference or concern about their performance as trainees. This is further supported by increased self reported levels of task engagement in novice bus drivers, which may be due to higher motivation. The results show that novice bus drivers thought more about the task than experienced bus drivers. The higher engagement scores for novice bus drivers may also be an indication that they considered the simulated driving environment to be dynamic and challenging. However experienced bus drivers were more distressed than novice bus drivers after completing the simulated route. Usually Distress is indicative that the task has a high workload and participants may have felt that they had less control over their performance and were less able to cope with the demands of the environment (Matthews, Sparkes and Bygrave, 1996). Indeed, experienced bus drivers appeared to have had a more negative experience of the simulated environment. They reported feeling less in control of the task environment and also reported less self-esteem and more self-focused attention indicating that simulated driving had induced them to reflect on their bus driving ability. They were more frustrated, reported greater levels of tense arousal and also reported symptoms of malaise after driving the ABS.

The differences in appraisal of the simulated environment may reflect the differences in bus drivers' experience with a real bus. Experienced bus drivers are more confident in their ability to handle a bus in the real environment and so were not worried about their ability to handle a simulated bus, which may explain why, at first, they are less worried and more confident than novice bus drivers. However, novice and experienced bus drivers differ in their appraisal of the task. Experienced bus drivers have richer mental models of the operational environment (e.g. Underwood et al, 2002) and may therefore be better able to discern discrepancies between the operation of the simulated bus in a simulated environment and the real vehicle. If they feel that they are not able to perform as well in the simulator this may lead to greater feelings of distress and frustration and may cause them to question whether it is due to their ability or a fault of the simulator. These doubts may also lower their motivation and self-esteem. These results are concordant with Matthews et al (1999) who predicted that poor performance on a task of direct personal significance may threaten self worth.

On the other hand, novice bus drivers are well aware of their lack of experience with a real bus and so appear to be more apprehensive about their performance in the simulator. However, after driving the simulator they still report that they feel confident and motivated, presumably because they have less experience in a real bus against which they can compare their simulator performance. These findings are in concordance with Matthews et al (1999) who suggested that participants attending laboratory experiments probably have concerns about whether they will cope adequately with task requirements, but, typically, these concerns are reduced by successful compliance with the experimental protocol.

8.9.10 Changes in Stress Responses due to Simulated Bus Driving

Stress induced by the simulated driving task was by determined by calculating the difference between pre and post task scores. Table 52 shows scores for Worry, Distress, Engagement and Fatigue induced by the simulator for novice and experienced bus drivers (df=28).

Table 52 Paired Sample T-tests for DSSQ Factors

Experience	Stress Induced by Simulated Bus driving	Mean	SD	t
Novice	Fatigue	2.48276	11.22377	1.191
	Task Engagement	-.14208	.49073	-1.559
	Worry	-.69533	.67668	-5.534**
	Distress	.12544	.66096	1.022
Experienced	Fatigue	3.79310	7.34545	2.781*
	Task Engagement	.06823	.36934	.995
	Worry	-.22399	.39064	-3.088*
	Distress	.66520	1.04581	3.425*

(*=p<.01, **=p<.0001)

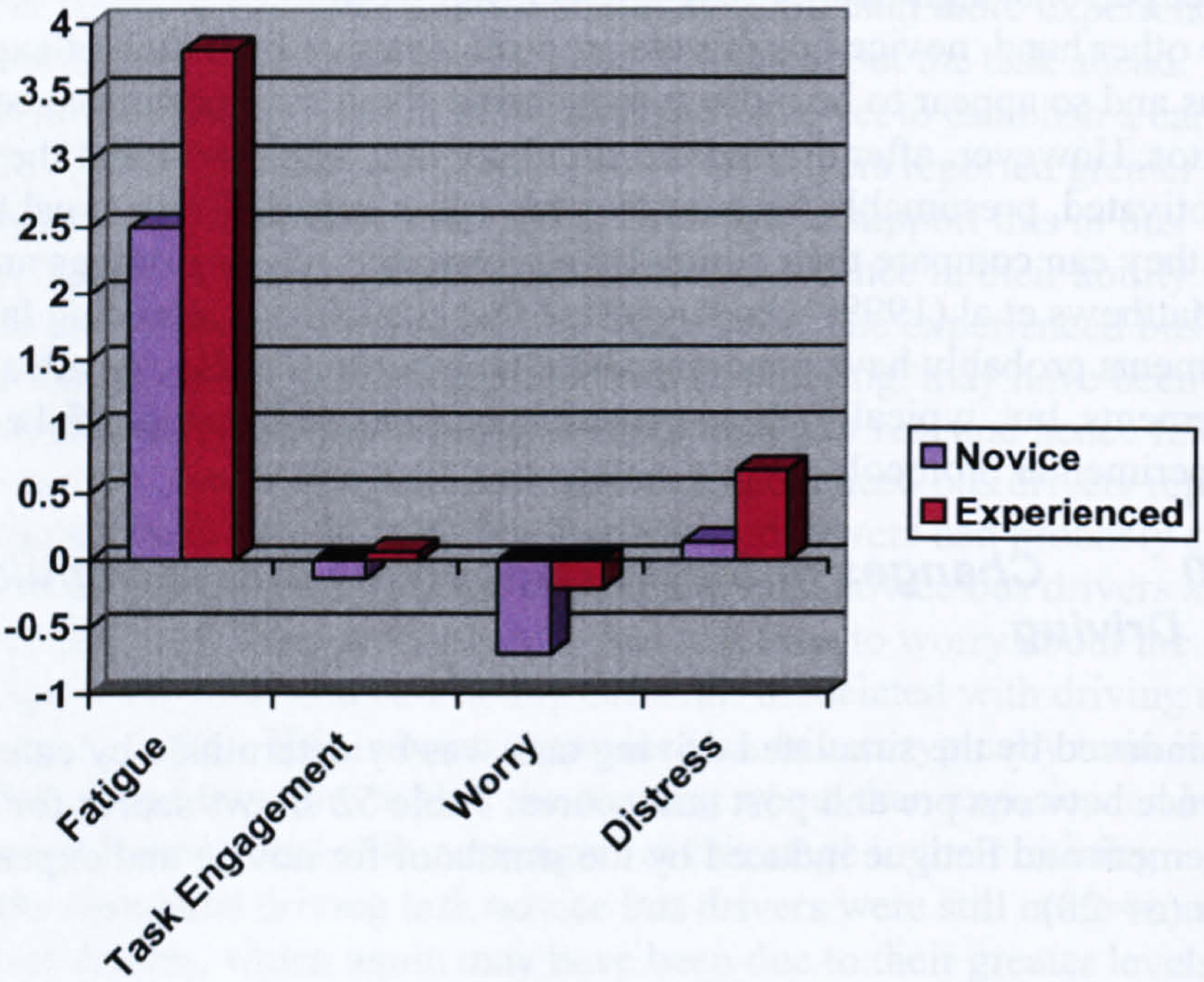


Figure 82 State Changes Induced by Simulated Bus Driving

Overall, the ABS induced a significant change in Worry, (t(28)=-5.53, p<.0001) in novice bus drivers but no change in distress, task engagement or fatigue. Experienced bus drivers were also less worried after driving the ABS (t(28)=-3.1, p<.01) but were more Distressed, (t(28)= 3.43, p<.01) and Fatigued (t(28)=2.78, p<.05) as a consequence of simulated bus driving. There was no significant change in Task Engagement as a consequence of simulated bus driving.

8.9.10.1 Discussion: Are State Changes Behaviourally Valid?

Overall, the state changes induced in the ABS were consistent with what is expected of real bus driving. Experienced bus drivers reported less Worry but increased Distress and Fatigue after driving the ABS, which is indicative of a highly demanding task with high work loads that leave insufficient time for self reflection while driving. However, since the simulated task took between 10-15 minutes to complete whereas real bus driving lasts for several hours, it is possible that the psychological state differences may be due to the intensity of the ABS environment rather than because it approximates the state effects of driving a real bus. For example, Alm (1995) and Burns and Dennis (1999) using the NASA-TLX found that driving in a simulator was generally more physically demanding, more effort demanding and more frustrating than driving in a real car under similar conditions. However, novice bus drivers did not report higher levels of distress and fatigue after the task which suggests that driving the ABS is not as demanding as learning how to operate a real bus. Without real world data it is difficult to say whether this pattern of results would also be expected of real bus driving.

8.10 General Discussion and Implications for Training

Novice and experienced bus drivers took part in a behavioural validity study to determine whether they responded in a behaviourally valid way to the cues generated within the ABS. Before the bus drivers commenced driving they completed the DSSQ and Fatigue Scale. Upon completing a 10-minute simulated bus route they completed the DSSQ, which also included a Workload Scale and the Fatigue Scale again. State change scores were calculated from pre-and post exposure measures and the results were analysed to determine group differences in subjective states of stress, workload and fatigue before and after the simulated drive and also to assess the influence of state changes on simulated bus driving. The following table provides a summary of the results that have been previously discussed:

Table 53 **Experience, Stress and Simulated Bus Driving Results Summary**

State	**Effect on Performance**	
	Novice Bus Drivers	**Experienced Bus Drivers**
Worry	Novice bus drivers were more worried than experienced bus drivers were before driving. Novice bus drivers who were more worried had greater variations in acceleration behaviour. They were less worried after driving the simulator.	Experienced bus drivers who were more worried had greater variations in acceleration behaviour. They were less worried after driving the simulator.
Distress		Experienced bus drivers were more distressed after driving the simulator but this did not impact their driving.
Engagement	Novice bus drivers who reported higher levels of task engagement had greater variations in headway choice than their less motivated peers.	No effects
Total Fatigue		Experienced bus drivers were generally more fatigued after driving the simulator.
Visual Fatigue	Poor vehicle control in visually fatigued novice drivers	No effects
Boredom	Bored novices may 'test their limits' by alternating between driving too close and very far away from other vehicles.	Boredom increases risk taking in experienced bus drivers as they attempt to stave off the effects of boredom by alternating the distance they keep from other vehicles.
Muscular Fatigue	No effects	Experienced bus drivers reported greater levels of muscular fatigue before driving.
Physical Fatigue	Physical fatigue is generally associated with poor vehicle control	Physical fatigue is generally associated with poor vehicle control

State	**Effect on Performance**	
	Novice Bus Drivers	**Experienced Bus Drivers**
Malaise	No effects	Experienced bus drivers suffered more from malaise after simulated driving. Malaise affected their interaction with other vehicles.
Motivation	More highly motivated novice bus drivers alternated between driving too close and very far away from other vehicles. Novice bus drivers had higher levels of success motivation after simulated driving but this was not linked to driving performance.	Experienced bus drivers were less motivated after completing the simulated drive
Control and Confidence	Novice bus drivers felt less confident before simulated driving, probably because they were nervous and they scored higher on worry. After completing the drive they felt more confident.	Experienced bus drivers were more confident than novice bus drivers before simulated driving, however they felt less confident and felt less in control after completing the simulated drive.
Self esteem	Self esteem was higher in novice bus drivers after completing the simulated drive.	Self esteem was lower in experienced bus drivers after completing the simulated drive, perhaps because they felt that they had not performed as well as they could have on a task that is important to them.
Task related interference	Novice bus drivers were more focussed on the simulated driving task before they drove. Higher levels of task related interference was also associated with greater variation in acceleration behaviour.	Experienced bus drivers were more concerned about the task after they had completed the drive. Higher levels of task related interference was also associated with greater variation in acceleration behaviour.

State	**Effect on Performance**	
	Novice Bus Drivers	**Experienced Bus Drivers**
Task irrelevant interference	Higher levels of task irrelevant interference was associated with greater variation in acceleration behaviour	Higher levels of task irrelevant interference was associated with greater variation in acceleration behaviour
Mental Workload	Low mental workload is associated with higher scores on interaction with oncoming vehicles.	Low mental workload is associated with higher scores on interaction with oncoming vehicles.
Physical Workload	No effects	No effects
Temporal Workload	Novice bus drivers did not adapt their driving behaviour to temporal workload	Experienced bus drivers demonstrated less adaptivity in steering in high and low temporal workload.
Performance	Novice bus drivers associated variations in acceleration with better performance.	No effects
Effort	No effects	No effects
Frustration	No effects	Experienced bus drivers were more frustrated after simulated driving.
Hedonic tone	Novice bus drivers tended to have high scores on hedonic tone, but this did not influence driving.	Experienced bus drivers tended to have high scores on hedonic tone, but this did not influence driving.
Tense arousal	Greater tension was generally associated with interaction with oncoming traffic	Experienced bus drivers were more tense after simulated bus driving. Greater tension was generally associated with interaction with oncoming traffic
Energetic arousal	Novice bus drivers were more energetic than experienced drivers.	No effects
Anger	Anger was associated with variations in steering behaviour.	Anger was associated with variations in steering behaviour.

The results show that bus drivers with greater training and experience select less risky driving strategies than novice bus drivers. They approach the simulated scenarios with better positioning, slower speeds, and a less variable distance from other vehicles when compared with inexperienced drivers. The findings suggest that the ABS has successfully discriminated between these two different categories of bus driver. Plus, bus driver's behaviour demonstrated in the ABS corresponds to what would be expected in a real bus. For example, bus drivers show performance deficits after simulated bus driving that are associated with different stress and fatigue states and which are supported by the results of studies conducted by other researchers (e.g. Desmond and Mathews, 1997; Matthews and Desmond, 2002; Matthews, Sparkes and Bygrave, 1996; Van der Hulst, Meijman and Rothengatter, 2001). There is reason to suppose then that the ABS may have potential as a driver training simulator. This study provides the first step in validating the benefits of the ABS.

However there are several limitations to this study that makes it impossible to draw definitive conclusions. Firstly, before entering the laboratory for testing the novice and experienced bus drivers had engaged in different types of activity. The experienced bus drivers had been driving a bus continuously for several hours prior to testing, whereas the novice bus drivers had been in training, which involved a lot less practical driving. This is reflected by different pre-exposure states, particularly the increased fatigue reported by experienced bus drivers. Although the potential confounding effects of pre-exposure state were statistically controlled for, it would be better if all the participants had not driven or had had the same amount of driving exposure on the day of the experiment. However, in spite of differences in baseline measures the study shows significant changes between pre and post exposure measures as a consequence of simulated bus driving, which are of particular interest for the present study. Future research would perhaps need to consider only testing bus drivers prior to their shift. Secondly, direct comparisons between the ABS and real bus driving can only be estimated from this study given that the simulated task was only 10 minutes duration whereas bus drivers' shifts last for several hours, with breaks every four hours. In addition to this, under simulated conditions, participant's attentional resources and capabilities are in greater demand (Alm, 1995; Burns and Dennis, 1999), which may compromise a driver's ability to control the car (Duncan, 1995). The differences observed in driving performance may be due to problems with steering feedback, restricted visibility and perhaps simulator sickness instead. Future research is needed to compare driving performance along a short bus route in the real world environment with the same short route programmed into the simulated environment.
Thirdly, although the changes in state that were observed after bus drivers drove the ABS were what was expected, the extent to which the magnitude of the changes reflect real bus driving is impossible to gauge without the support of equivalent data from on-the-road tests. Again future research would involve comparing performance at equivalent points along a real and simulated bus route.
Finally, the study may not be generalisable due to the relatively small sample of bus drivers used from one area. Arriva is a diverse passenger transport company with over 100 depots across the UK. A representative sample would need to be taken to ascertain whether these findings can be replicated across the other regions and within another sample of bus drivers. More definite conclusions about the validity of the ABS could then be made.

Matthews et al (1999) recognise that qualitatively different stress reactions require different interventions. For bus drivers, the stress induced by fatigue, worry and task disengagement, tension and arousal has different effects on driving performance. For example, fatigue effects vehicle control, worry influences acceleration behaviour, task disengagement affects headway choice and tension affects interaction with approaching traffic and arousal affects steering. Of particular relevance to bus driver training is the mediating effect of experience on the relationship between stress, fatigue and vehicle control. Although experienced bus drivers are susceptible to the deleterious effects of stress and fatigue on performance, they may try to compensate by adapting their driving strategy. For example, experienced bus drivers cope with fatigue by leaving larger safety margins and driving close to the centre of the road. On the other hand, novice bus drivers are less likely to adopt safer driving strategies when they are impaired and may even be more inclined to engage in risky behaviours. This is in line with other simulator based research that shows that experience with the driving task can override the influence of age and attentional skills on driver performance (Matthews and Desmond, 1995).

Since it is difficult for bus drivers to rest whenever they feel tired during their shifts, overtraining the driving task and the associated stressors could be an effective countermeasure for stress. For instance a training intervention that enables novice bus drivers to recognise the effects of fatigue and how to compensate for this by increasing safety margins and driving in a more central position may be beneficial. Furthermore, the results indicate that experienced bus drivers may also benefit from overtraining. For instance by learning how their acceleration behaviour changes when they are worried or distracted, especially since acceleration behaviour is an important factor in passenger comfort. They may also benefit from learning how feelings of tension can lead them to engage in risky behaviours, such as driving too closely to other vehicles that may lead to accidents. This is particularly important since crash involved bus drivers score significantly higher than non-involved bus drivers on measures of ineffective coping strategies (Dorn and Garwood, 2005). Simulator based training scenarios offer an ideal training environment to allow drivers to safely experience the effects of intermittent stresses on their health and driving ability and to learn how to apply safer methods of coping. Simulator based training scenarios are described in more detail in Chapter 11.

9 Simulator Sickness and the Implications for Training Transfer in the ABS

9.1 Rationale for the Study

Simulator sickness refers to unwanted side effects and after effects resulting from performing a task in a simulator for which performance of the same task in the real-world does not produce similar sickness or discomfort (Kennedy et al., 1987). These effects are similar to motion sickness symptoms and include nausea and dizziness as well as visual discomfort, such as eye strain or difficulty in focusing (Kennedy, Lane, Berbaum and Lilienthal, 1993; Kolanski, Goldberg, and Hiller, 1995; Raisler and Lampton, 2004). Simulator sickness is an important consideration in evaluating the viability of the ABS as a training device because simulator sickness may degrade training effectiveness despite the absence of severe symptoms such as vomiting. Firstly, discomfort in the simulator may distract the trainee from safely performing tasks and may compromise the validity of the training. In particular, lateral control of the vehicle may be affected as this is known to be sensitive to increased workload (e.g., Hicks & Wierwille, 1979, O'Hanlon et al., 1982, Green et al., 1993b). This may then lead to negative transfer of training if the trainees adopt behaviours that mitigate sickness in the simulator, but will be detrimental to performance if transferred to the operational vehicle. Secondly, after effects involving the sense of balance, such as postural disequilibrium (ataxia) or flashbacks might impair the trainees' ability to drive safely after leaving the simulator. Thirdly, the training value of the ABS will be reduced if simulator sickness forces a decrease in the frequency or duration of use of the simulator.

9.2 What is Simulator Sickness?

Kennedy and Fowlkes (1992) accepted that simulator sickness should be called a syndrome because of the complex signs and symptoms associated with it. They further noted that some people exhibit all the signs and symptoms, while others exhibit only a few and some exhibit no symptoms at all. In addition to this, no single symptom predominates in people who show symptoms. The polysymptomatic nature of simulator sickness makes it difficult to measure, however it has an advantage in that symptom differences and changes in symptomaticity may be diagnostic of faults with the simulator. For example, if an increase in eye strain is suddenly associated with the use of a particular simulator, it might suggest that something is wrong with the visual display.

Kennedy and Fowlkes (1992) also described simulator sickness as being polygenic since no single factor can be identified as the cause. Since many factors are involved, a comprehensive model of simulator sickness does not currently exist. At present, the most widely accepted explanation of simulator sickness is sensory conflict due to discrepancies between visual and vestibular cues (McCauley, 1984). In a fixed-base simulator the visual system senses motion while the vestibular system senses no motion, so according to the cue conflict theory a conflict results. This leads to simulator sickness symptoms, rather like motion sickness. In a moving-base simulator a conflict can still result because the visual stimuli experienced may not correspond exactly to the motion which the vestibular system registers. An alternative explanation for simulator sickness is the ecological theory proposed by Riccio & Stoffregen (1991), who hypothesized that sickness results when the individual lacks or has not yet learned strategies for maintaining postural stability. They argued that postural instability both precedes sickness symptoms and is necessary to produce symptoms. To support their theory, they described how several provocative environments involve postural instability and they also discuss various influences on stability. Riccio, Martin, and Stoffregen (1992) also discussed the results of several experiments in which no motion sickness was reported in what should have been a cue conflict situation and ascribe the lack of sickness in these situations as being supportive of their theory. The work of these researchers has been greatly summarized here, but they describe their theory and the theories leading to it in great detail. Although the ecological theory is a competitor to the cue conflict theory the latter remains the most widely accepted theory of simulator sickness and underlies most of the current research on the subject.

9.3 Individual Differences in Susceptibility to Simulator Sickness

Individuals who adapt quickly to the altered conditions in the simulated environment may avoid sickness whereas those who adapt slowly may become sick before completely adapting (McCauley & Sharkey, 1992). There are a multitude of individual differences in susceptibility to simulator sickness such as age, gender, ethnicity, experience with the real-world task, experience with the simulator (adaptation), illness and personal characteristics, the flicker fusion frequency threshold, concentration level, mental rotation ability, perceptual style, and postural stability (Kolasinski, Goldberg and Hiller, 1995). Of particular interest to this study is the influencesof experience on simulator sickness. To explain, experience with the real-world task plays a critical role in the cue conflict theory of simulator sickness in which conflicts are thought to occur between the actual pattern of stimuli and the expected pattern of stimuli. The expected patterns of stimuli are most likely to result from repeated experiences with the real world task, which Reason and Brand (1975) suggest may follow the same long-term learning pattern seen with other types of learning. Therefore, in military flight simulation, Kennedy, Hettinger and Lilienthal (1988) suggest that the pilot's increased experience with the sensory aspects of actual flight and the suggestion that they may rely more heavily on vestibular cues, might lead to greater sensitivity to the discrepancies between actual and simulated flight. For the cases in which a positive relationship between experience and sickness is not observed, Kennedy et al. (1988) suggested that the pilot's experience may result in protection through some mechanism of adaptation or that individuals who are susceptible to sickness may have been self-selected out of a career in aviation. The effect of experience with the real vehicle on sickness in driving simulators has not been specifically tested, although there is compelling evidence to suggest that older car drivers experience more severe sickness symptoms (e.g. Hagenmeyer and Sommer, 2004; Liu, Watson, and Miyazaki, 2000; Romano and Watson, 1994). A similar effect of experience and simulator sickness may be seen in bus drivers since driving involves interpreting both visual and kinaesthetic information (Groeger, 2000). Experienced bus drivers, like experienced pilots, may then be more susceptible to simulator sickness than novice bus drivers if they rely more heavily on vestibular motion cues when driving. This may make them more susceptible to sensory conflict when using the ABS.

Another factor of interest to this study is illness, which may increase a person's susceptibility to simulator sickness. Kennedy, Berbaum, et al. (1987) advised against simulator exposure for subjects who are not in their usual state of fitness. This includes subjects who are suffering from fatigue, sleep loss, hangover, upset stomach, emotional stress, head colds, ear infection, ear blocks, upper respiratory illness, or the flu; as well as those taking certain medications or had just received a flu vaccination. However, due to the nature of shift work it is possible that some of the bus drivers recruited for this study may be suffering from the effects of fatigue and sleep loss, and some may be under the influence of medication. A further consideration is the amount of time spent in the simulated environment. Prolonging the duration of immersion in the simulator tends to result in an increase in perceived negative physiological effects and will require longer adaptation periods (Jaeger and Mourrant, 2001; McCauley & Sharkey, 1992). Brock et al (2001) reported that people who experienced sickness on initial simulator sessions were able to rapidly adapt to the simulator on following sessions and so experienced less sickness over time. Thus, increased experience with the simulator (adaptation) generally leads to a decreased incidence of sickness. This could be the result of building a tolerance to sickness-inducing stimuli and learning adaptive behaviours to avoid sickness. However, adaptation may cause problems when the individual returns to the normal environment if the behaviours adopted to reduce sickness are detrimental to performance on the real world task.

9.4 Assessing Simulator Sickness: The Simulator Sickness Questionnaire

According to Kennedy, Lane, Berbaum, and Lilienthal (1993), simulator sickness can vary along two dimensions: the extent of the symptoms and the combination of symptoms. These two dimensions are measured by the Simulator Sickness Questionnaire (SSQ) developed by Kennedy et al (1993), and are computed as total severity scores and three subscale measures: Disorientation, Nausea and Occulomotor discomfort before and after exposure to the simulated environemnt. Typically only post-exposure data are scored since there is a high correlation between pre- and post-exposure scores. They also advised that individuals who are not at their usual level of fitness should not be included in the sample because cold, flu and hangover symptoms can increase their susceptibility to simulator sickness. These restrictions may not pose a problem with military flight simulators, because pilots tend to be in good physical shape and are usually in good health when they arrive for simulator training. However, McCauley and Sharkey (1992) observed that commercial users of simulators may differ from the typical user of a military flight simulator in terms of their physical and psychological state. Therefore, due to the diverse nature of the bus driver population, pre-exposure sickness scores need to be considered in interpreting post-exposure scores.

The objective of the present assessment is to explore the potential simulator side effects which may occur through use of the ABS system. Firstly, to determine the effect of experience on simulator sickness by comparing experienced and novice drivers' SSQ scores. It is expected that experienced bus drivers will suffer to a greater extent than novice bus drivers because they rely more on vestibular cues. Secondly, to investigate the potential effect of simulator sickness on training by comparing SSQ scores and bus driver's perceptions of face validity and then by correlating SSQ scores with simulated driving performance measures.

9.5 Method

9.5.1 *Participants*

49 bus drivers, who had not taken part in previous studies, volunteered to take part in this study. There were 28 novice bus drivers who had spent a mean of 14 days training with Arriva (range: 3-30 days). The mean age of this group was 38 years, SD 10.85 (range:19-58 years). 21 bus drivers held a PCV licence. This group had a mean age of 39.9 years, SD 9.86 (range: 26-64 years) and had worked for Arriva for 5.53 years, SD 6.13 (range: 0-26 years).

9.5.2 *Equipment*

Arriva Bus Simulator (see chapter 7 for a full description)

Simulator Sickness Questionnaire (Kennedy, Lane, Berbaum, and Lilienthal, 1993). The SSQ is a check list of 16 symptoms, which are rated by the subject on a 4-point scale (0=none, 1=slight, 2=moderate, 3=severe). These ratings form the basis of three subscale scores: Nausea (N), Oculomotor Discomfort (O), and Disorientation (D), and a Total Severity (TS) score.

Face Validity Questionnaire (see Chapter 8 for a full description)

9.5.3 *Design*

The independent variable was bus driving experience with two levels: novice and experienced. All participants then completed the SSQ, face validity questionnaire and simulated bus route. The sample was also split so that further analysis could be conducted on bus drivers who rated the realism of the ABS as high or low.

9.5.4 *Procedure*

Pre-exposure SSQ measures were collected before participants entered the simulator environment and post-exposure SSQ measures were collected following the simulator session using the SSQ checklist of symptoms. SSQ score differentials were then calculated by subtracting pre-exposure from post-exposure scores to document any physiological changes in participants that may be due to the ABS.

Participants completed the pre-exposure SSQ presented in excel spreadsheet format on a computer.

First, the bus drivers completed a practice session on the simulator. The practice session involved driving on a straight road with low scene complexity, then on a curved road with higher scene complexity. Next they practiced pulling into two lay by bus stops and practised two right and two left turns at junctions. This was so that the driver could acclimatize to the simulated driving environment to minimize discomfort and the potential for simulator sickness (see Brock et al., 2001). It was also an opportunity for the driver to ask questions and to ensure that they performed according to their normal standard of driving.

Participants were given the following instructions prior to the practice drive:

"This first session is a practice drive so that you may get used to the feel and control of the simulator. Please drive the way you would on a real road and deal with the conditions as if they are really happening. If you hear one bell it means that you should stop at the next bus stop. You must wait at the bus stops until you think it is OK to move away. In the event of a collision the simulator will reset your position in the road and you must carry on driving. Please stop at junctions and listen for my instructions to turn left or right. Feel free to ask any questions and let me know if you feel ill."

After completion of the short practice trial participants then drove a 30000ft bus route (approx 10 mins) in the simulator with the following instructions:

"This next session is the main drive. Please drive the way you normally would on a real road and deal with events as if they were really happening. To successfully negotiate the route you must follow the instructions given to you on the road signs. Please continue straight across any junctions you come to, unless you hear spoken instructions to turn left or right. If you hear one bell it means that you should stop at the next bus stop. You must wait at the bus stops until you think it is OK to move away. If you have an accident the simulator will reset you in the road. Please discontinue if you begin to feel ill."

The experimenter left the room and the bus drivers then drove along the simulated route. Driving performance was continually monitored and data was saved every five feet along the simulation. Distance rather than time was used as the reference point for data collection to ensure that data was collected at the same point in the simulation for each participant to allow for individual differences in speed preference etc.

Participants then completed the post-exposure SSQ and face validity questionnaire.

9.5.5 Treatment of Results

SSQ total severity and subscale measures were calculated. One-way ANCOVA's using SPSS GLM were conducted to assess the effect of experience on simulator sickness by comparing experienced and novice drivers SSQ differentials, controlling for age (which is known to affect susceptibility to simulator sickness). The potential effect of simulator sickness on acceptance was investigated by comparing the SSQ scores of bus driver's with High and Low ratings of face validity, controlling for the effects of age and experience on SSQ ratings. Partial Correlations were used to correlate SSQ scores with simulated driving performance measures, controlling for the effects of age and experience on the dependent variables of interest.

9.6 Results

One participant requested that they stopped the experiment because they felt ill. They then asked if they could resume the experiment after a pause for a drink of water. This participant's data was not included in the analysis.

Table 54 **Calculating SSQ Scale Scores**

Symptom	**Nausea**	**Occulomotor Discomfort**	**Disorientation**
General discomfort	1	1	
Fatigue		1	
Headache		1	
Eye strain		1	
Difficulty Focusing		1	1
Salivation Increased	1		
Sweating	1		
Nausea	1		1
Difficulty Concentrating	1	1	
Fullness of head			1
Blurred Vision		1	1
Dizzy (eyes open)			1
Dizzy (eyes closed)			1
Vertigo			1
Stomach Awareness	1		
Burping	1		
TOTAL	[1]	[2]	[3]

N = [1] x 9.54
O = [2] x 7.58
D = [3] x 13.92
TS = [1] + [2] + [3] x 3.74

The symptoms making up the three subscale scores are as follows: Nausea - general discomfort, increased salivation, sweating, nausea, difficulty concentrating, stomach awareness, and burping; Oculomotor Discomfort- general discomfort, fatigue, headache, eyestrain, difficulty focusing, difficulty concentrating, and blurred vision; and Disorientation - difficulty focusing, nausea, fullness of head, blurred vision, dizzy (eyes open), dizzy (eyes closed), and vertigo. The fact that some symptoms appear on more than one subscale is a characteristic of the factor analysis procedure used to produce the scale. The subscale scores were calculated by multiplying the reported value for each symptom by the weight in each column and then summing down the columns. The Total Severity score uses all of the symptoms and was obtained by adding the summed scale scores across the three columns and multiplying by 3.74. The weighted scale scores for each column individually are found by multiplying the Nausea subscale by 9.54; the Oculomotor subscale by 7.58; and the Disorientation subscale by 13.92 (table 54). Each scale has a natural zero meaning that no symptoms were shown. The table below shows the calculations for high, medium and low severity ratings for each weighted scale (table 55).

Table 55 Maximum SSQ scores for each scale

SSQ Factor/Severity	High	Medium	Low
N	21x9.54=200.34	14x9.54 =133.56	7x9.54 =66.78
O	21x7.58 =159.81	14x7.58=106.12	7x7.58=53.06
D	21x13.92 = 292.32	14x13.92=194.88	7x13.92=97.44
TS	63x3.74=235.62	42x3.74=157.08	21x3.74 =78.54

Table 56 Mean SSQ Differential Scale Scores (unweighted and weighted)

SSQ Factor	Minimum	Maximum	Mean	Std. Deviation
unweighted N	-4.00	12.00	1.2292	2.76174
unweighted O	-7.00	9.00	1.2500	2.41009
unweighted D	-2.00	8.00	.9583	1.82137
N	-38.16	114.48	11.7263	26.34701
O	-53.06	68.22	10.5141	19.53306
D	-27.84	111.36	13.3400	25.35342
TS	-48.62	78.54	12.8563	23.01494

The results of the analysis of the SSQ indicated that the main source of discomfort was Disorientation followed by Nausea then Occulomotor discomfort (D>N>O). The extent of the severity of all symptoms displayed was very low for all subscales and the total severity scale; N=11.73, O=10.51, D=13.34, TS=12.86. The figure below shows how the results of this study favourably compare to the minimum, medium and maximum possible simulator sickness scores (Figure 83).

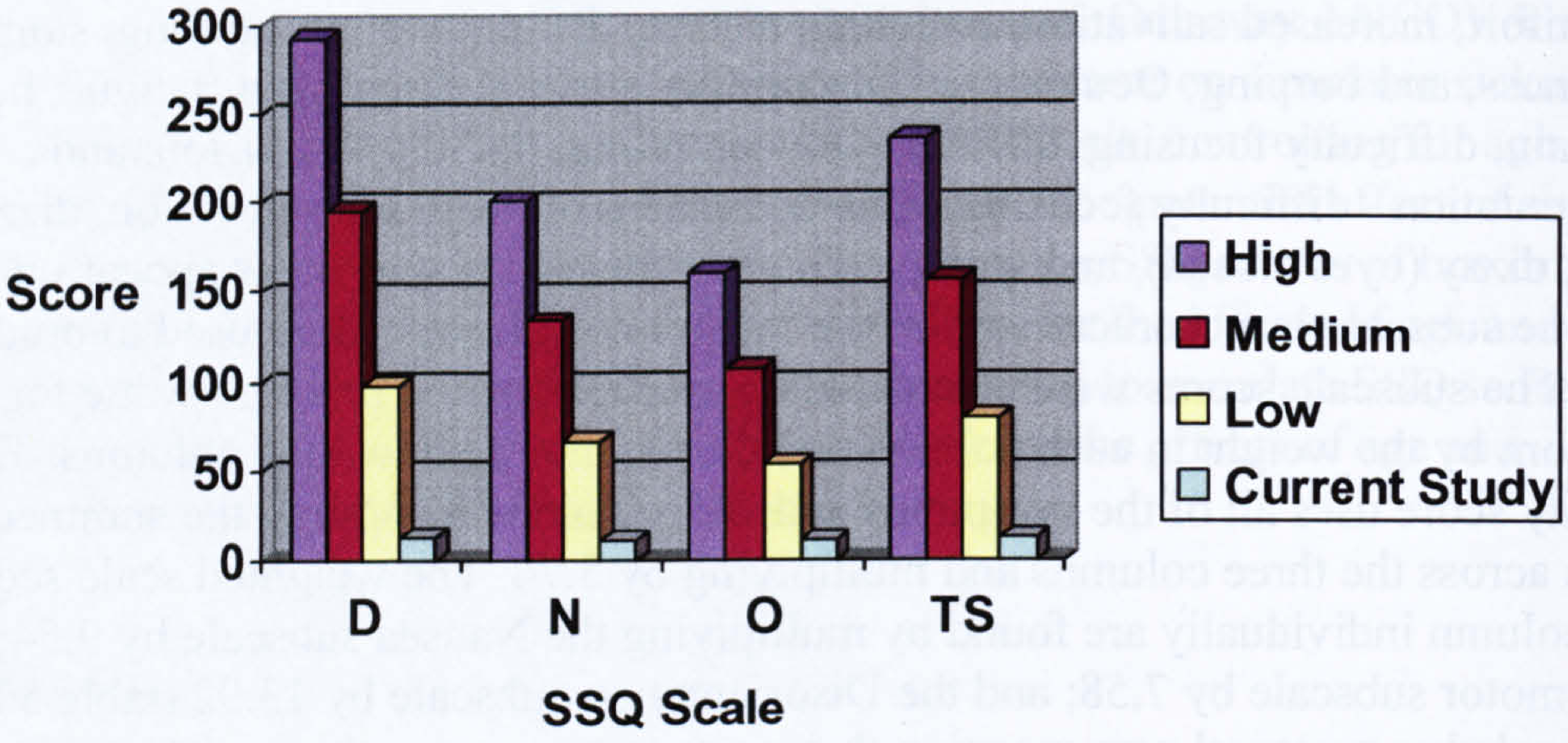


Figure 83 Comparison of SSQ Scale scores

Table 57 SSQ Score Differentials for Experienced and Novice Bus Drivers

SSQ Differential (weighted)	Experience	Mean	Std. Deviation	Significant
N	Novice	1.7667	15.66175	P<.05
	Experienced	24.5314	31.72268	
O	Novice	5.7776	21.78558	P<.10
	Experienced	16.6038	14.50517	
D	Novice	8.7644	27.33978	NS
	Experienced	19.2229	21.77766	
TS	Novice	4.9867	21.18205	P<.05
	Experienced	22.9743	21.68831	

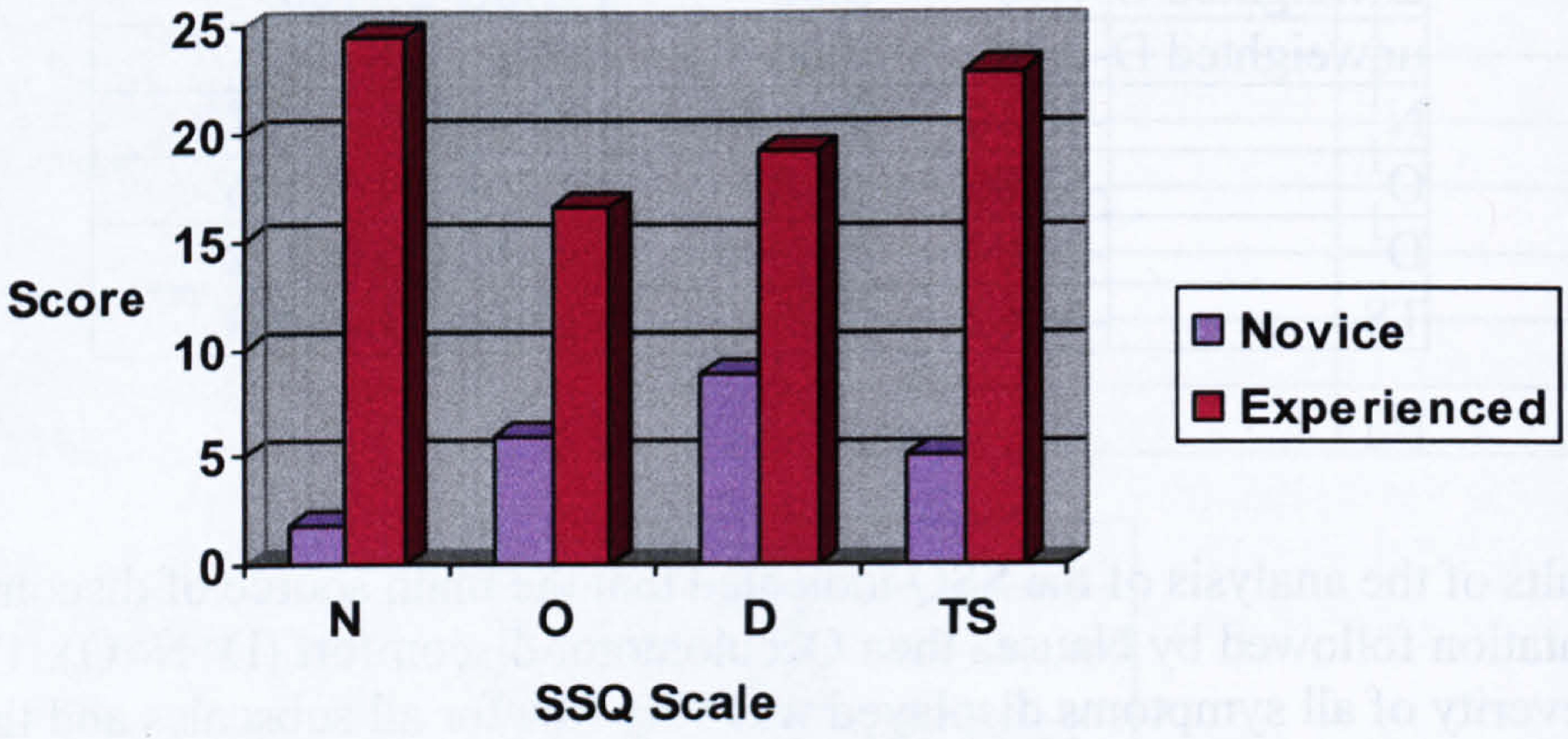


Figure 84 SSQ Score Differentials for Experienced and Novice Bus Drivers

ANCOVA's were conducted with bus driver's experience (novice, experienced) as the independent variable and SSQ scores as the dependent variable, controlling for driver age. There was a general tendency for experienced bus drivers to rate their symptoms more severely than novice bus drivers. There was a significant effect of experience on Nausea (F(1, 45)=10.032, $p<.05$, $\eta 2=.182$) and Total Severity (F(1, 45)=8.271, $p<.05$, $\eta 2=.155$) and the effect of experience on occulomotor discomfort approached significance ($p<.10$). There was not a significant effect of experience on disorientation.

Table 58 Effect of Experience on SSQ Scale Scores

SSQ Differential	df	F	Sig.	Partial Eta Squared
N	1, 45	10.032	.003	.182
O	1, 45	3.669	.062	.075
D	1, 45	2.297	.137	.049
TS	1, 45	8.271	.006	.155

Table 59 SSQ Differentials for High and Low Ratings of the Realism of the ABS

SSQ Differential	Realism Rating	Mean	Std. Deviation	N	Significance
N	Low	17.2454	31.81492	26	NS
	High	5.2036	16.31983	22	
O	Low	11.0785	21.03155	26	NS
	High	9.8471	18.06889	22	
D	Low	18.2031	30.94356	26	NS
	High	7.5927	15.32542	22	
TS	Low	17.1177	27.60866	26	NS
	High	7.8200	15.13305	22	

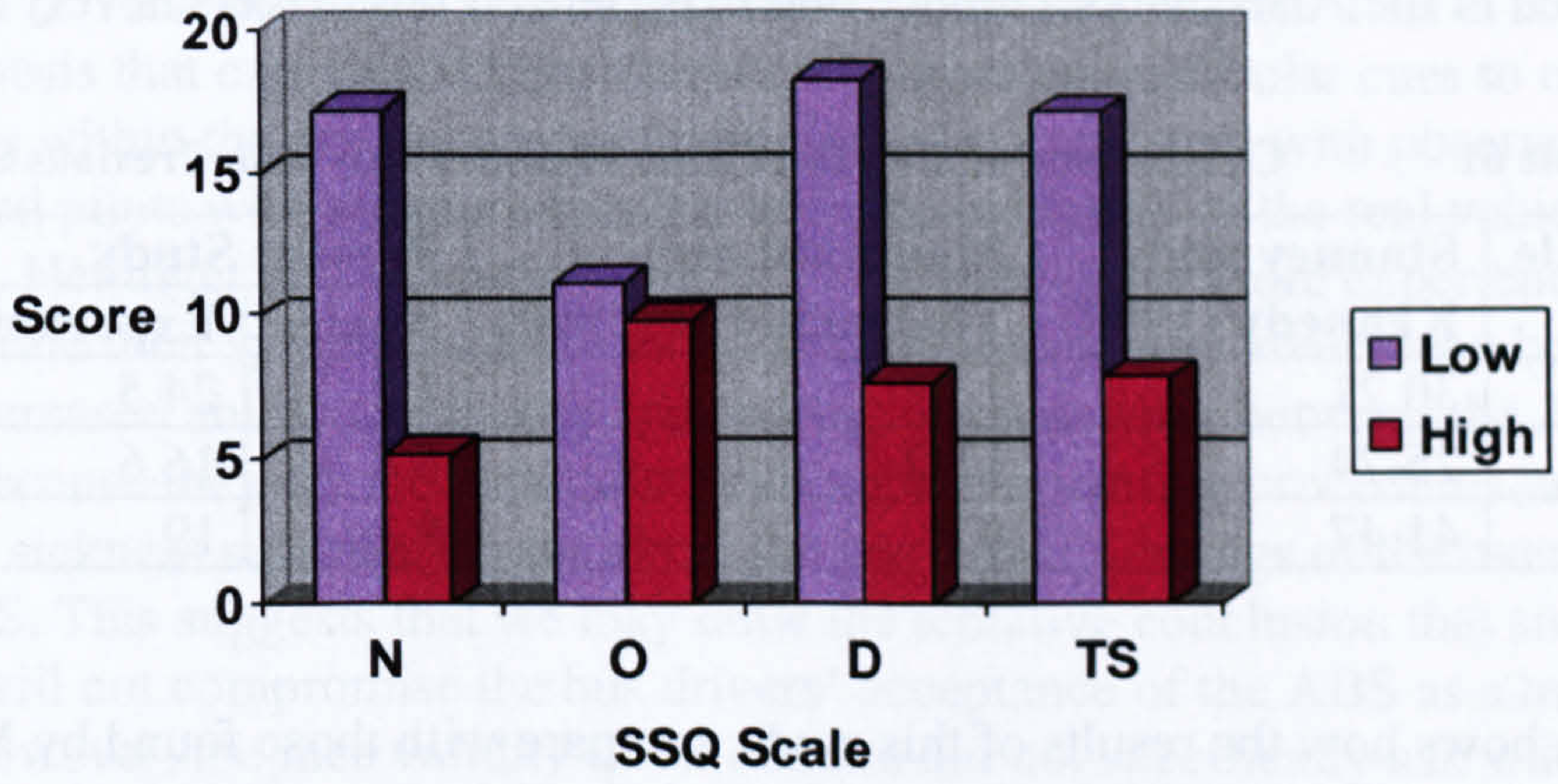


Figure 85 SSQ Scores for High and Low Ratings of the Realism of the ABS

Table 60 **Face Validity Ratings and SSQ Scale Scores**

SSQ Differential	df	F	Sig.	Partial Eta Squared
N	1, 44	1.662	.204	.036
O	1, 44	.002	.964	.000
D	1, 44	1.681	.202	.037
TS	1, 44	1.239	.272	.027

ANCOVA's were conducted with realism ratings as the independent variable and SSQ scores as the dependent variable, controlling for age and experience. Although bus drivers who judged the simulator to have low face validity reported higher severity of symptoms, there was not a significant relationship between face validity ratings and simulator sickness scores thus indicating that acceptance of the ABS is not affected by simulator sickness symptoms experienced in the ABS.

Partial correlation coefficients were computed among the SSQ scales and measures of simulated driving performance, controlling for the effects of age and experience. There were significant correlations between SSQ scores and some of the simulator measures. Nausea was positively correlated with variation in steering wheel rate (r (44) =.31, p<.05). Occulomotor discomfort was also positively correlated with variation in steering wheel rate (r (44) =.30, p<.05). Disorientation was positively correlated with variation in vehicle heading (r (44) =.39, p<.05).
The association between Disorientation and mean heading (r (44) =.28, p<.10) and Total severity scores and mean heading (r (44) =.27, p<.10) also approached significance. These correlations indicate that lateral control and the severity of simulator sickness symptoms experienced in the ABS were statistically associated.

9.7 Discussion

The results of the analysis of the SSQ indicated that the severity of symptoms experienced in the ABS by both novice and experienced bus drivers is very low.

Table 61 **Comparison of SSQ Data from Present Study with Previous Studies**

SSQ Scale	Stanney and Kennedy (1998)	Mourrant and Thattacherry (2000)	Present Study		
			Novice	Experienced	Both
N	30.21	1.75	1.8	24.5	11.7
O	25.74	11.0	5.8	16.6	10.5
D	41.47	8.7	8.8	19	13.3

The table shows how the results of this study compare with those found by Mourrant and Thattacherry (2000) who investigated simulator sickness symptoms in car drivers aged 18-36 in a fixed-base driving simulator with a HMD device. In comparison with the simulator used in their study, the ABS induces comparable or less severe symptoms in the novice bus drivers, but more severe symptoms in the experienced bus drivers.

This is probably due to the fact that the sample of drivers used by Mourrant and Thattacherry were younger than the sample of experienced bus drivers involved in the present study. On the other hand, the ABS compares more favourably with the simulator reported in Stanney and Kennedy (1998) in terms of symptom severity. Other researchers have also found that participants in their treadmill-type simulators report low severity symptoms (Jaeger and Mourrant, 2001; Kingdon, Stanney and Kennedy, 2001). Only one bus driver in the present study was unable to continue with the experiment due to the severity of the sickness symptoms he experienced. This is encouraging because it means that simulator sickness is not likely to present an obstacle to bus driver training.

The main source of discomfort was Disorientation followed by Nausea then Occulomotor discomfort (D>N>O). This pattern is consistent with Stanney and Kennedy (1997) but not with the results of Mourant and Thattacheny (2000) who found the profile O>D>N, however the difference between their simulator and the ABS is that their visual display was represented to the user by using a HMD, which may increase eye strain. The disorientation experienced by the bus drivers can be attributed to the compelling illusion of motion that the wide field of view capacitates in the ABS. This is supported by Smart, Stofferegen and Brady (2002) who found that vection (the subjective experience of self-motion as a result of optical simulations of self-motion) can lead to simulator sickness in some participants. However, the fact that the ABS is fixed-based may have also eliminated the risk of nausea due to inappropriate motion cueing (McCauley, 1984). Other task-related factors includes making head movements at junctions. The resultant inconsistent information about body orientation and motion received by different senses may induce simulator side effects. Occulomotor discomfort experience in the ABS can be attributed to glare from the wide screen display contrasted with a darkened room and possibly to the blurring effect as a result of magnifying the image through the projection system of the ABS. Supporting evidence for this comes from the results of a study by Draper et al (2001) who investigated the effect of varying image scale magnifications and system time delays on total simulator sickness severity scores. They observed increased symptom severity in participants who experienced image scale conditions that deviated from 1.0 (no magnification).

Experienced bus drivers rated the total severity of their symptoms more severely than novice bus drivers; the effect was largely due to increased nausea. This is coherent with the hypothesis that experienced bus drivers rely more on vestibular cues to orientate themselves within the driving environment. It is also consistent with observations of experienced pilots who are more familiar with the operation of the real vehicle (Kennedy, Hettinger and Lilienthal, 1988). The tendency for more experienced bus drivers to rate their symptoms more severely than novice bus drivers may be a reflection of their increased ability to identify and process discrepancies between the ABS and a real bus because they are more familiar with normal operating procedures in a real bus. Simulator sickness severity did not affect the bus driver's ratings of the overall realism of the ABS. This suggests that we may draw the tentative conclusion that simulator sickness will not compromise the bus drivers' acceptance of the ABS as a training device. However, the face validity questionnaire did not specifically ask whether drivers would use the ABS in training.

The relationship between simulator sickness severity and lateral control of the ABS is of concern to the use of the ABS for bus driver training. There are a number of possible explanations for the association between simulator sickness severity and decreased lateral control of the vehicle. Firstly, the presence of simulator sickness symptoms and the mechanisms that a bus driver uses to cope with them may interfere with the bus driver's primary task of safely controlling the vehicle. To explain further, distractions due to coping with the severity of symptoms may increase the bus driver's workload, which makes it more difficult for them to control the bus because they have fewer resources to devote to the driving task. This is supported by studies showing that variation in lateral control is a sensitive reflection of increased workload (e.g., Hicks & Wierwille, 1979, O'Hanlon et al., 1982, Green et al., 1993b). On the other hand, the driver may experience more severe symptoms as a direct consequence of them being less able to maintain a steady position when compared with other bus drivers. For example, if a bus driver tends to make more frequent steering rotations, they may experience more severe symptoms than a driver who makes fewer steering rotations. Alternatively, the increased variation in lateral control measures may be an indication of how the bus drivers who experienced the most severe symptoms coped by adapting their behaviour to try and avoid sickness, or it may be that their different strategies induced the sickness. For example, if the experience of postural instability causes a driver to believe that s/he is veering too much to the left, they will steer right to correct it, which then means that they are steering too far to the right so they then steer left, and so on (Ricco and Stofferegen, 1991; Smart, Stoffregen and Bardy, 2002).

Kingdon, Stanney and Kennedy (2001) investigated emetic responses in a maze-based virtual reality system and concluded that even those who vomited were able to perform as effectively as those who did not indicating that a simulator may still be an effective training medium even with adverse effects associated with exposure. However, the extent to which adaptation in the ABS may cause problems when the bus driver returns to the real bus cannot be determined from these results. Since the bus driver is responsible for peoples' lives it is important to investigate the possibility that adaptive behaviours learned in the simulator may have negative transfer effects once the novice is in the real environment.

9.8 Implications for Training Transfer

The safety aspect of the ABS was assessed in terms of its propensity to induce simulator sickness in trainees. Overall, simulator sickness severity was very low, but since novice bus drivers reported less severe symptoms this study shows that the ABS is suited particularly well to the role of a novice bus driver training device. However, the analysis also shows that caution should be exercised when interpreting steering as a measure of simulated driving performance because simulator sickness may affect the validity of the lateral control measures when compared with a real bus. This is because variations in steering may in fact be a response to the effects of simulator sickness, rather than being responses to the events and hazards in the training scenario. The implications of this study for training are that scenarios must be clearly defined and specific measures at specific locations, (rather than global measures of performance) must be recorded so that it is obvious that novice drivers are actually detecting and responding to hazards.

10 Comparative Perceptions of Bus Driver Ability

10.1 Rationale

There are certain factors that may impede transfer of training from the simulator to the operational environment. The factors that have been addressed in the design of the bus simulator are: simulator fidelity and validity, training scenario design, perceived value of the simulator, simulator sickness and bus drivers experience and ability. A further consideration is the influence of self-bias, which may mean that bus drivers do not consider that they are in need of training. The following study was conducted to determine whether bus drivers demonstrate self bias regarding their driving skill.

10.2 Self-bias and Risk

There is a strong tendency for drivers to regard themselves as more skilful and less risky than the average driver (McCormick et al, 1986). Therefore unrealistic skill evaluation may be the reason why some bus drivers engage in risky behaviours. Indeed, Mirza, Mirza, Cotani and Luby (1999) investigated the prevalence of risk-taking in bus drivers. They observed that although bus drivers did not break the speed limit, they regularly raced, cut up and overtook other vehicles, did not completely stop at bus stops and stopped too far away from the pavement so passengers had to negotiate the flow of traffic to get to the pavement. Similar patterns of risk-taking in bus drivers were observed by Hamed, Jabali and Dhaimat (2000). Furthermore, all bus drivers in their study had committed speeding violations, 78% had been involved in an accident in the previous year and 35% crossed a red traffic light while being observed. In spite of being aware of the factors that increased risk, such as fatigue due to long shifts, eating, drinking and smoking while driving, these drivers defined a good bus driver as one who minimised travel time by overtaking other drivers and by speeding. These behaviours were not perceived as dangerous. Indeed, studies show that self-assessment of risk depends on perceiving a particular event and attributing an estimation of danger to it (Groeger and Chapman, 1990). As such, there are individual differences in the level of risk and risky situations that drivers expose themselves to. Therefore, the purpose of the present study was to investigate self-bias in the perceptions of ability in bus drivers and the impact that this might have on training.

As the evidence suggests, if there is a general tendency for drivers of all ages to underestimate the risks associated with driving and to overestimate their driving skills (Elander et al, 1993; Finn and Bragg, 1986; McCormick et al, 1986) and this positive self-bias even persists in drivers who have had a previous accident (Mathews and Moran, 1986) then heterogeneous road safety interventions will have limited effectiveness. This is because drivers with a positive self-bias do not identify themselves as being in need of instruction and leads to the belief that information is aimed at 'other drivers' and not themselves. For example, McCormick, Walkey and Green (1986) agree that self-bias may negate the influence of safety interventions if the drivers do not identify themselves as being in need of instruction. They examined the tendency for drivers to rate themselves more positively than the average driver on several driver characteristics. 178 male and female drivers rated 'me as a driver', 'an average driver' and 'a very good driver' on eight semantic differential scales: Foolish-wise, predictable-unpredictable, reliable-unreliable, considerate-inconsiderate, safe-dangerous, relaxed-tense, valuable-worthless and responsible-irresponsible. They then produced profiles of 'a very good driver' and of 'self as a driver' using the average driver as an anchor. The procedure allowed them to list the characteristics that most clearly distinguished the target concepts in order of salience to produce a stereotyped description. The results showed that 15.5% and 4.5% of drivers rated themselves as below and equal to average, but 80% of driver rated themselves as higher than average. The most distinguishing characteristic was on the reliability scale, this was followed in order by responsibility, wisdom, consideration, safety, predictability, relaxation and value. Even for the least extreme value twice as many drivers rated themselves as more valuable than average than below average. The scales that most clearly distinguished the very good driver from the average driver were in the following order: safety, reliability, predictability, consideration, responsibility, wisdom, relaxation then value. However, the drivers studied rated a very good driver as significantly higher than themselves on all eight scales, which suggests that judging the self as superior to average is the result of a rational consideration of their characteristics.

10.3 Measuring Self-bias

The procedure described in the study by McCormick et al (1986) is an appropriate method to investigate self bias in bus drivers. However, the characteristics used to describe the drivers in their study are too intangible to be applied to bus driver training. Furthermore, to ensure credibility amongst bus drivers it is important that the constructs examined are seen by the bus driver to be relevant to the organisational issues they encounter on a daily basis (Machin, 2003). To ensure that the constructs included in the questionnaire are relevant to bus driving, the Repertory Grid technique, derived directly from Kelly's (1955) Personal Construct Theory (Kelly, 1963) can be used to derive relevant items to include in a questionnaire based study (Stewart and Stewart, 1981). The Repertory Grid is an instrument designed to capture the ways in which people give meaning to their experiences, in their own terms (see also Bannister and Fransella, 1971, for an introduction to PCT and repertory grids). The Repertory Grid is not a completely standardized procedure but rather must be adapted to the researcher's specific aims (Castejon and Martýnez, 2001). There are two aspects of the repertory grid: 'elements', which are the objects of an individual's thinking and to which they relate their concepts and values and 'constructs', which are the qualities used to describe the elements. The repertory grid technique is a structured interview designed to elicit a repertoire of constructs that enable an individual to draw comparisons between elements in terms of their similarities and differences (Bell, 2000). The principal value in the use of the grid compared with a number of other techniques is that the interviewer has a minimal role and therefore the respondent's views are less susceptible to external contamination (Stewart and Stewart, 1981). From the procedure of constructs elicitation, categories emerge from the analysis to produce individual repertory grids. Repertory grids are represented as matrix tables that contain elements, constructs and ratings. Although the constructs have qualitative properties too, they can be analyzed and compared in a quantitative way because they are rated grids (Bell 1999; Hassenzahl and Trautmann, 2001). There follows the possibility of identifying an individual's construct map and the possibility of modifying their attitudes and behaviour through training (Stewart and Stewart, 1981).

Although repertory grids are usually used in clinical settings, Mena (2001) successfully used repertory grids to investigate risk-taking in the construction industry and then again to evaluate the effects of a safety training intervention on attitudes towards risk and safety. The study involved eight construction workers who had been contracted to work on the same site for at least two years and so they were familiar with the layout. Individuals were shown three short clips of site locations and were asked to state how two of the locations were similar and how they differed from a third in terms of safety at work. They then rated all site locations using their own constructs as reference points. They were then asked to recall a safety intervention that had been implemented in the last year and to rate the locations before and after the implementation had occurred. Interventions ranged through training sessions protective gear or site safety devices. Thus each person produced three grids: pre-intervention, post-intervention and their original grid. The example grid comparison in the report showed that for the individual in question, locations were differentiated in terms of whether there were heavy vehicles moving around, whether roofs were sloping or fragile and whether access was on the ground floor or upper levels. Risk-taking behaviour at different locations was modified by wearing protective clothing or using safety devices and equipment, by taking extra care in wet weather or by being cautious of vehicles moving around. Comparisons of the three grids showed that workers modify their risk-taking behaviour depending on their perception of the safety of the location and their accepted target level of risk. Generally people behaved more cautiously and accepted fewer risks when they felt threatened and behaved more daringly and accepted higher levels of risk when they felt safe and secure.

In the context of this study then, the workers changed their behaviour to return to their level of risk before the intervention was introduced. This has major implications for safety intervention methods. Although no formal comparisons of risk compensation for different safety interventions were presented, Mena suggested that interventions that aimed to improve safety by engineering methods were likely to be less effective than motivational interventions that targeted attitudes towards risk. This study demonstrates that the repertory grid technique offers a clear way to ascertain and measure individual differences in risk-taking attitudes and behaviour, which is how the application will be used in the present study. However, the process of individual grid elicitation is extremely time-consuming. The repertory grid has also been used with larger groups of subjects, which share some common characteristics in relation to the theme being studied. In this situation it is necessary to negotiate the elements and constructs in order to establish a common set, taking care to conserve the constructivist nature of the repertory grid. For example, Castejon and Martýnez (2001) used the repertory grid technique on groups of teachers to elicit constructs that differentiated between novice and expert teachers. Groups of novice and expert teachers then rated the elements to produce two matrices, one from novice and one from expert teachers. The grids were then analyzed to examine the similarities and differences between the personal constructs of groups of expert and novice teachers.

Since bus driving instructors have ample opportunity to observe the progress of trainees and must also think about factors in skill learning to try to understand the problems that trainees face at various stages in their instruction in relation to the nature of the skill and the learner, much can be learned from analysing instructors experiences. Therefore, a wide-scale questionnaire was developed based on constructs obtained from bus driving instructors by using group repertory grid procedures.

In the context of this study the main aims are (a) to use group repertory grid procedures to obtain data on the constructs which instructors use to differentiate between different groups of bus drivers and to use this to develop an instrument which can be used to investigate self-bias in bus drivers; (b) to examine the similarities and differences between the constructs of groups of drivers categorized as good, bad and average; and (c) to understand where bus drivers position themselves in relation to good, bad and average drivers in terms of the constructs and discuss the implications for training. The final aim of the study is to determine whether self-bias is a feature of bus driver behaviour and whether this may impact on training effectiveness.

10.4 Construct Elicitation

10.4.1 Method

10.4.1.1 Participants

One focus group of ten driving instructors (I1-I10) was conducted. All instructors worked for Arriva The Shires and Essex, which trained 150 novice bus drivers in 2005. Instructors had been training bus drivers for between 14 – 35 years.

10.4.1.2 Procedure

The first stage in the design of the questionnaire was to obtain a list of constructs on which bus drivers could be rated. The procedure of eliciting constructs and elements constitutes a fundamental stage in the application of the grid technique. The main aim at this stage was to conserve the personal and constructivist nature of the data obtained. However, apart from the usual difficulties in eliciting constructs and elements discussed in Stewart and Stewart (1981), there was the additional difficulty of working with a group, taking into account the necessity of eliciting personally construed elements.
All the participants were told that the objective of the study was "to increase our understanding of the qualities that bus drivers should have in order to effectively maintain safety and to use these qualities to develop a questionnaire to explore other bus driver's personal conceptions of this theme." The elements and constructs were then negotiated as a group.

The first stage was carried out as a group discussion of the elements and constructs which should be included in the questionnaire. The participants agreed that the element set chosen represented the range of elements that they include when considering the issue of safe bus driving. These elements were 'me (as a bus driver)', 'a good bus driver', 'a bad bus driver' and 'an average bus driver'. Having defined a list of representative elements, the next step was the process of construct elicitation. The set of elements served as elements of contrast and were representative of the purpose under investigation. The essential requirement was that the constructs elicited covered the range of constructs that the group felt were important to the area under consideration; in this case they were the fundamental characteristics of bus drivers as perceived by the instructors. This was carried out by means of a group discussion of the elements and constructs used in the study. To facilitate discussion, the groups were presented with the three elements, a good bus driver a bad bus driver and an average bus driver. They were asked to write the names of a known good, bad and average driver on 3 x 5 cm cards. The drivers were anonymous to the researcher. Then they were asked to list the qualities that enabled them to differentiate between drivers. The researcher was present to provide prompts to elicit and clarify constructs. The first comparison involved contrasting a bad bus driver with both the average and good bus driver. The instructors found it easy to identify a good and bad driver that they all knew, however it was more difficult to agree on an average bus driver. The instructors also found it difficult to elicit constructs. The only comparison they felt they could make was between good and bad bus drivers. After some debate, the group decided to ignore the average bus driver and to elicit constructs that differentiated between good and bad drivers. A consensus on a list of 28 bipolar statements that related to the most outstanding characteristics of bus drivers as perceived by the instructors on the basis of their own experience was reached quite rapidly. The statements defined the positive and negative poles of these characteristics. No pressure was put on any of the individuals in the process of defining the constructs; furthermore the researcher followed an inclusive criterion, not exclusive, when including the constructs and elements.

10.4.2 Results: Elements and Constructs

The constructs that instructors generated and used to differentiate between good and bad bus drivers are listed in table 62. The list contains constructs that relate to bus drivers behaviour in training, on the road, interacting with passengers and interacting with depot managers and other drivers. Some constructs related to the personality or temperament of the driver and some related to stress coping mechanisms.

Table 62 Constructs that Differentiated between Good and Bad Bus Drivers

Elicited Constructs
Maintaining schedule comes first vs. Safety comes first
Takes risks if running late vs. Doesn't take risks if running late
Stressed by time tables vs. Not stressed by time tables
Stressed at end of shift vs. Relaxed at end of shift
Bullies others when driving vs. Considerate to others when driving
Doesn't care about customers vs. Customers come first
Only driving for job vs. Enjoys driving
Considers bus driving as a temporary job vs. Considers bus driving as a career

Doesn't take job seriously vs. Takes pride in job
Found it difficult to learn to drive a bus vs. Found it easy to learn to drive a bus
Only knows what to do in familiar traffic situations vs. Transfers knowledge to unfamiliar traffic situations
Gives passengers a white knuckle ride vs. Has a natural driving ability
Requires corrective training in the driving school vs. Develops awareness of own skill
Doesn't always watch for hazards when driving vs. Anticipates hazards when driving
Violates rules on purpose when driving vs. Does not make deliberate mistakes when driving
Has many at fault accidents vs. Has few at fault accidents
Gets punished for bad driving vs. Gets reward for good driving
Drives erratically vs. Drives consistently
Picks up bad habits in depot vs. Maintains high standards in depot
Stubborn vs. Negotiates with others
Takes lots of days off sick vs. Never takes days off sick unless genuinely ill
Selfish vs. Team player
Unreliable vs. Reliable
Nervous vs. Confident
Complacent vs. Alert
Has no respect vs. Respectful
Aggressive vs. Calm
Inexperienced vs. Experienced

10.5 Questionnaire Design

The grid produced by the instructors was used to generate items for a questionnaire that could be distributed to a large sample of the bus driving population. The questionnaire required bus drivers to rate the qualities of known good, bad and average bus driver as well as themselves as a bus driver. The questionnaire began with a worked example, then followed 28 items that represented the constructs with a response format that used a bipolar semantic differential scale. The four elements, 'me as a bus driver', 'an average bus driver', 'a bad bus driver' and 'a good bus driver' were positioned in the centre of the page (see appendix C). The rating of each construct is graded in five points according to the following equivalence:(1) A lot (left pole); (2) Quite (left pole); (3) Average; (4) Quite (right pole); (5) A lot (right pole) (see appendix C).

Face validity and content validity were deemed to be important aspects of validity of the questionnaire so the final questionnaire was circulated amongst the instructors for assessment. Then a pilot study of five bus drivers was conducted to ensure that the instructions on how to complete the questionnaire were clearly understood before proceeding with the main study.

10.6 Self-Bias Questionnaire Administration and Scoring

10.6.1 Method

10.6.1.1 Participants

A total of 200 bus drivers completed the questionnaire. 91.5% of the respondents were male, 19% of bus drivers were in their first year of service. Drivers were between 20 and 64 years old with a mean age of 46.5 years (SD=10.9). Drivers had held their PCV licence for 1 month to 40 years with a mean service length of 12.5 years (SD=11.9).

10.6.1.2 Procedure

Participants recorded their age, sex and the date they obtained their PCV licence and the date they began working for Arriva. They then rated four concepts 'me as a bus driver', 'an average bus driver', 'a good bus driver' and 'a bad bus driver' on the 28 bipolar scales obtained from the instructors, given in Table 62.

Standard semantic differential instructions were adopted and the ratings were graded on a five-point scale, according to the following equivalence: (1) A lot (left pole); (2) Quite (left pole); (3) Average; (4) Quite (right pole); (5) A lot (right pole).

10.6.1.3 Treatment of Results

The data was analysed using the method, described by McCormick et al (1986). Differences between ratings of 'me as a bus driver' and 'an average driver' were calculated and the percentages of positive, zero and negative differences were found for each scale. The ratio of above/below average ratings was calculated by dividing the percentage of above average ratings by the percentage of below average ratings.

Profiles of 'a good bus driver', 'a bad bus driver' and 'me as a bus driver' were obtained by finding the mean discrepancy between the ratings of these target elements and the anchor element 'an average bus driver'. A t-test for correlated means was conducted on these differences as were the differences between the ratings of the 'good bus driver' and 'me as a bus driver'.

One-way ANOVA's were conducted to evaluate the relationship between level of bus driving experience and degree of self-bias in construct ratings. The independent variable, Length of Service, was divided into three levels, shown in table 63.

Table 63 Length of Service Categories

Level of Experience	Length of Service	N
Novice bus drivers	0- 1 years	26
Intermediately experienced bus drivers	1-5 years	51
Experienced bus drivers	over 5 years	122

The dependent variables were self ratings on the 28 constructs (discrepancy between ratings of self and average bus driver). Follow-up tests were conducted to evaluate pair wise differences among the means. Levene's test of equality of error variance was significant ($p<.05$) indicating that the homogeneity of slopes assumption was not met. Therefore, Dunnets C was used to control for Type 1 error, because this procedure does not assume equal variances between groups.

10.6.2 Results

10.6.2.1 Comparison of 'me as a bus driver' with 'an average bus driver'

The percentages of subjects rating 'me as a bus driver' below, equal to, and above 'an average bus driver' are given in appendix C in order of salience.

The total ratings show that only 7.7% of drivers rated themselves as below average and 31.3% rated themselves as average. On the other hand, 61%, which is almost 8 times as many drivers, rated themselves as above average than below average. The most marked difference was on the scale of 'Violates rules on purpose when driving vs. Does not make deliberate mistakes when driving' where 26.4 times more bus drivers regarded themselves as above average than below. This was followed by being more reliable than the average bus driver (21.7), caring more about customers (17.1), develops awareness of own skill (16.7), respectful (14.6), puts safety first (14.2), takes more pride in their job (13.6), anticipates hazards when driving (11.1), is more considerate to others when driving (10.9), maintains higher standards in the depot (10.9), more alert (9.9), drives more consistently (8.7), transfers their knowledge to unfamiliar traffic situations (8.7), has a natural driving ability (8.6), less likely to take risks if running late (8.1), more confident (7.8), takes fewer days off sick (6.6) more of a team player (6.6), enjoys driving (6.2), more calm (6.2), has few at fault accidents (6), less stressed by time tables (5.2), more capable of negotiating with others (5.2), found it easier to learn to drive a bus (5), considers bus driving as a career (4.7), more experienced (4.5), more relaxed at end of shift (4.15), and getting more rewards than the average bus driver for good driving (3.1).

10.6.2.2 Bus Driver Profiles

With 'an average bus driver' used as an anchor, the differences between ratings of that and the other elements gave a profile showing the salience of the characteristics that the bus drivers attributed to each. The differences between elements rated on the semantic differential scales can be found in appendix C.

10.6.2.2.1 Profile of 'A Good Bus Driver'

In every case the ratings for 'a good bus driver' were significantly higher than for the average bus driver (p<.0001). Those which most clearly distinguish the good from the average driver are in order of putting safety first, negotiating with others, putting customers first, taking pride in their job, anticipating hazards, not engaging in risk taking, and being considerate to other road users. This is followed by having a natural ability for bus driving, driving consistently, enjoying driving, developing awareness of their own skill, transferring knowledge to unfamiliar situations, considers bus driving as a career, does not make deliberate mistakes while driving, maintains high standards in the depot, reliable, not stressed by timetables, alert, calm, has few at fault accidents, respectful, relaxed at end of shift, experienced, confident, found it easy to learn to drive a bus, never takes days off sick unless truly ill, gets rewards for good driving, and is a team player.

10.6.2.2.2 Profile of 'A Bad Bus Driver'

The ratings for 'a bad bus driver' were significantly below average for every construct (p<.0001). The ratings that most clearly distinguish the bad bus driver from the average bus drivers are as follows in the order, gives passengers a white knuckle ride, requires corrective driver training, drives more erratically, behaves in a more aggressive manner, has no respect, is unreliable, has more at fault accidents than the average driver, more likely to try to maintain the schedule by compromising safety, doesn't always watch for hazards, behaves selfishly, bullies others while driving, violates rules on purpose, is stubborn, is less considerate of customers, doesn't take the job seriously, takes more risks while driving, is less likely to consider bus driving as a career, is less likely to know what to do in unfamiliar situations, is complacent, picks up more bad habits in the depot, takes lots of days off sick, is less likely to receive awards for good driving, is less relaxed at the end of shifts, does not enjoy driving as much as the average driver, is stressed by timetables, does not seem to have a natural driving ability, and is less confident.

10.6.2.2.3 Profile of 'Me as a Bus Driver'

Bus drivers rate themselves as better than average on all of the constructs described (p<.0001). However, comparisons of the differences between ratings of 'me as a bus driver' and a good bus driver show that bus drivers rate themselves as less conscious of safety than a good bus driver, more stressed by time tables, less experienced, less alert, less likely to negotiate, less relaxed at end of shift, drive more erratically, pick up more bad habits in the depot, get fewer rewards for good driving, are not always able to anticipate hazards, are less aware of their own driving skill, have less natural driving ability, are not as capable of transferring their knowledge in unfamiliar situations, are less considerate of customers, less considerate to other road users, makes more mistakes while driving and do not consider bus driving as a career to the extent that good bus drivers do (P<.05).

Bus drivers also take more risks if running late, have more at fault accidents, take less pride in their job and found it more difficult to drive a bus than a good bus driver did (p<.10).

On the other hand, bus drivers consider themselves to be as reliable, confident, respectful and calm, as a good bus driver. They also rate themselves the same as good bus drivers in terms of being a team player, enjoying driving and like a good bus driver they only take days off sick when they are genuinely ill.

10.6.2.3 Effect of Experience on Self Ratings

Table 64 **Mean Self -Rating across Constructs**

Level of Experience	Mean	SD
Novice	4.0	.47
Intermediately Experienced	4.3	.36
Experienced	4.2	.53

Table 64 shows bus drivers' mean self ratings across all of the constructs. There was a significant difference in the self ratings of bus drivers with different levels of experience(F(2, 198) = 3.442, p<.05). Post hoc tests revealed significant differences between the self ratings of novice and intermediately experienced bus drivers, but no significant differences between the ratings of novice and experienced bus drivers or between intermediately experienced and experienced bus drivers. Intermediately experienced bus drivers had the highest self ratings.

Table 65 **Differences in Self bias by Bus Driver Experience**

Construct	Novice		Intermediate		Experienced	
	M	SD	M	SD	M	SD
Found it difficult to learn to drive a bus vs. Found it easy to learn to drive a bus	0	1.0	.64	1.0	.79	1.0
Doesn't always watch for hazards when driving vs. Anticipates hazards when driving	.24	.83	.98	.90	.88	1.0
Has many at fault accidents vs. Has few at fault accidents	0	1.2	.87	.90	.88	1.2
Picks up bad habits in depot vs. Maintains high standards in depot	.32	1.3	.96	1.0	.79	.92
Aggressive vs. Calm	.40	.96	.68	.89	.93	1.1
Inexperienced vs. Experienced	-.44	1.3	.40	.92	.98	1.1

Table 65 shows the mean difference between bus drivers self ratings and ratings of an average bus driver. A significant effect of level of experience was found on the degree of self bias in the ratings of the following constructs:
Found it difficult to learn to drive a bus vs. Found it easy to learn to drive a bus (F(2, 198)=6.2, p=.002); novice bus drivers show no self bias in their mean ratings but had significantly lower ratings than intermediately experienced and experienced bus drivers, There were no significant differences between ratings of experienced and intermediately experienced drivers. This indicates that novice bus drivers are less biased than more experienced bus drivers in their perceptions of difficulty in learning to drive a bus.

Doesn't always watch for hazards when driving vs. Anticipates hazards when driving (F(2, 198) = 6.3, p=.002), novice bus drivers had significantly lower ratings than intermediately experienced and experienced bus drivers, but there were no significant differences between ratings of experienced and intermediately experienced drivers. This indicates that novices were less self biased in their perceptions of their ability to anticipate hazards while driving than more experienced bus drivers.

Has many at fault accidents vs. Has few at fault accidents (F(2, 198) = 7.5; p=.001), novice bus drivers show no self bias in their estimation of accident frequency but had significantly lower ratings than intermediately experienced and experienced bus drivers. There were no significant differences between ratings of experienced and intermediately experienced drivers. This indicates that novices and experienced bus drivers differ in risk perception in terms of the perceived frequency of at fault accidents.

Picks up bad habits in depot vs. Maintains high standards in depot (F(2, 198) = 3.7, p=.027), novice bus drivers had significantly lower ratings than intermediately experienced bus drivers, but there were no significant differences between ratings of novices and experienced bus drivers or intermediately experienced drivers and experienced drivers. This indicates that intermediately experienced bus drivers show greater self bias than their colleagues in their perceptions of their ability to maintain higher standards in the depot rather than to pick up bad habits.

For Aggressive vs. Calm (F(2, 198) = 3.2, p=.044), novice bus drivers had significantly lower ratings than experienced bus drivers, but there were no significant differences between the ratings of novice and intermediately experienced bus drivers or experienced bus drivers and intermediately experienced bus drivers. Experienced bus drivers show greater bias than their colleagues in their perception of themselves as calm.

For Inexperienced vs. Experienced (F(2, 198) = 20.7, p<.001). Post hoc tests revealed significant differences between all groups of drivers. Novice bus drivers rated themselves as less experienced than the average bus driver. Intermediately experienced bus drivers rated themselves as more experienced than the average bus drivers and experienced bus drivers rated themselves as being significantly more experienced than both novice and intermediately experienced bus drivers.

10.7 Discussion

The issue of self-bias in bus driver's perceptions of their own ability in comparison to other bus drivers was investigated. Firstly, the repertory grid technique was used to derive 28 bipolar constructs that bus driving instructors used to differentiate between good and bad bus drivers. Secondly, the list of constructs used to generate items for a questionnaire in which bus drivers rated a good bus driver, a bad bus driver, an average bus driver and themselves on the 28 semantic differential scales using a 5-point rating scale.

The repertory grid technique proved to be an ideal method of obtaining relevant items to include in a questionnaire to compare bus driver's perceptions of their own and other drivers' abilities. As expected there is a tendency for bus drivers to consider themselves to be significantly more competent than their average colleagues in terms of their behaviour in training, on the road, interacting with passengers, interacting with depot managers and other drivers and their ability to cope with stress. They also rated themselves more highly than average on the constructs that related to their personality and temperament. This self-bias persists to a certain degree in their comparisons between themselves and a good bus driver. For example, bus drivers consider themselves to be good bus drivers in terms of their personal characteristics, such as reliability confidence, respect and having a calm temperament; and their roles at work, such as being a team player, enjoying driving and only taking days off sick when they are genuinely ill. However, with regards to skills and safety their self-bias breaks down. The bus drivers consider themselves to be less conscious of safety, less skilled, less experienced, less considerate to customers and other road users and more prone to stress than their concept of a good bus driver. They are also aware that they may take increased risks to try and stay on schedule and may be responsible for more accidents than some of their colleagues. It is possible that the drivers may not be motivated to improve their own driving skills as they are not as career orientated as their colleagues and they may also attribute their colleagues prowess as to 'a natural driving ability', which means that they themselves do not proactively develop their own abilities. Bus drivers also consider themselves to be more susceptible to being influenced by the culture within the depot, rather than independently maintaining high standards. Thus if the message permeated through the depot culture is to drive to schedule rather than being safety orientated then the drivers may tend to drive with this belief in mind.

Consistent with previous research, (Finn and Bragg, 1986; Mathews and Moran, 1986) the degree of self bias was influenced by level of experience, at least on some of the constructs. More experienced bus drivers exhibited a higher degree of self-bias than novice bus drivers, but this may be because they are more accurate in their perceptions. For example, risk of collisions. However, in contrast with novice car drivers, novice bus drivers show relatively less self bias in comparison with their more experienced colleagues. For example, novice car drivers perceive their chances of being involved in an accident as significantly lower than their peers and middle-aged drivers (Finn and Bragg, 1986). However, this study shows that novice bus drivers show no such bias in their perceptions of culpable accident frequency. They also show no self bias in their perceptions of the ease at which they learned to drive a bus. This may be due to the fact that at the time of the present study they had only recently left the driving school. More experienced bus drivers show greater self bias than novice bus drivers in terms of their hazard perception skills. This is expected as hazard perception skills are shown to improve with experience (e.g. McKenna and Crick, 1994). They also tend to be more biased in their perceptions of how calm they are. Intermediately experienced bus drivers show the most self bias in terms of their ability to independently maintain standards in the depot. This is expected as novices may be influenced by their more experienced colleagues when they start work. Bus drivers appear to have a realistic sense of their experience in relation to their colleagues. The results suggest that bus driver's perceptions of their own ability are based on rational comparisons between themselves and their colleagues.

Given that the results show that bus drivers have a tendency to believe that they are better than average, self-bias is an important psychological factor that may affect training outcomes unless the driver accepts that they can benefit from training. Since over 92% of drivers reported that they did not break traffic rules on purpose, it could be that any accidents are the result of a lack of skill or knowledge rather than deliberately engaging in risky behaviours. These findings are confirmed by the finding that whilst bus drivers consider themselves to be better than the average, the same drivers are also aware that they are deficient in some of the skills that a good bus driver possesses. It is possible that these drivers will respond to skills-based training but only if they consider it to be relevant to themselves and if improvements can be seen.

10.8 Implications for Training

Several conclusions can be drawn from this study that will direct the development of a training syllabus. A major consideration is that given the potential negative consequences of illusory beliefs for safety discussed earlier, it also would be useful to know how drivers' beliefs about their skills can be manipulated. Especially since drivers exhibit a greater illusory bias for hazard perception skills when compared with skill overall and vehicle-control skill (Horswill, Waylen and Tofield, 2004). Successful methods of de-biasing skill ratings in the past have included asking drivers to imagine themselves in a severe, blameworthy accident (McKenna & Myers, 2001), showing drivers video reconstructions of accidents (McKenna & Myers, 1995), and making people accountable for their judgments (McKenna & Myers, 1997). Unsuccessful interventions have included mood induction and selective memory searching by asking drivers to recall instances when their driving skill was poor (McKenna & Lewis, 1990) and attempting to manipulate drivers' illusory beliefs about their overall driving skill by first asking them to rate a range of skill components (Horswill, Waylen and Tofield, 2004). Gregersen, Brehmer and Moren (1996) compared four methods of improving accident risk in professional drivers against a non-intervention control and found that group discussions about driver safety and a training programme designed to provide drivers with insight into their skills were more effective than a campaign targeting specific hazards and a reward scheme for good driving. A group discussion that involves a risk analysis of severe blameworthy accidents, perhaps by reconstructing real accidents that have occurred involving bus drivers, may then be an effective way of overcoming the potential of this biasing perception in bus drivers and may encourage safer driving strategies. However, it is important to make individual bus drivers accountable for their judgements within the group. Finally, to deal specifically with the influence of self-bias, the content of the training syllabus must involve a systematic method of de-biasing an individual driver's perception of risk and therefore must be capable of revealing deficits in an individual's skill in order to attenuate their natural self-bias. This is particularly important for bus drivers who have had little experience because although they have learned the necessary skills to drive a vehicle, they have not yet learned the perceptual and decision-making skills to maintain safe distances, recognise potential hazards and to avoid them (Aphaloe et al, 1987). Being overconfident in their ability may then lead these drivers to have accidents (Gregerson, 1996; Mathews and Moran, 1986). A simulator offers the ideal medium to support training of this type.

11 General Discussion

11.1 Summary of Findings

The overall aim of the research was to construct and evaluate a bus simulator that is capable of supporting training interventions in bus drivers. The factors that were considered to be most important in the design of a simulator were: bus drivers' experience and ability, the training scenario, simulator fidelity and validity, the perceived value of the simulator and simulator side effects.
The thesis was conducted in two parts. Part one described an analysis of the risks associated with different everyday bus driving conditions in order to identify the bus drivers who will benefit most from additional training. This analysis also drove the basic design of simulated scenarios for novice bus driver training and informed the level of simulator fidelity required to support training. Part two described how off the shelf simulator technology was adapted to provide a fixed based bus simulator with a wide field of view and high resolution visual display and then three studies which provided the first steps in an evaluation of the suitability of the ABS for bus driver training. Three different aspects of performance were included: User evaluations, behavioural validity and simulator side effects. The results of individual studies are discussed in detail at the end of each chapter. The final study shed some light on the context in which training should take place by highlighting the importance of de-biasing risk perception in bus drivers, particularly novice bus drivers. The results are discussed in detail in the previous chapters, this section provides a consideration of the results from the perspective of relevance to bus driver training.

11.1.1 Bus Crash Risk

The aim of the accident analysis was to determine the aspects of the driving environment that posed the greatest risk for different groups of bus drivers to inform the design of simulator-based training scenarios. Risk ratios for bus drivers grouped by service length were calculated to show whether certain bus drivers were more at risk of being responsible for bus crashes. 15100 collisions were sampled and two measures of risk were calculated, solely responsible and partly responsible. The analysis showed that although crash risk is attributable to both age and experience-related factors, experience is the most important predictor of crashes in bus drivers. The results indicate that the training intervention should focus on novice bus drivers since they have increased risk of culpable crashes when compared with more experienced bus drivers and would therefore benefit most from additional training. Their increased risk was attributed to their lack of knowledge of where risks occur and how to avoid them, particularly hazards associated with bus stops, junctions, traffic lights and roundabouts and in adverse weather conditions. Novice bus drivers must be given the opportunity to safely gain the experience of performing different manoeuvres to try and reduce their risk of crashes. The results drove the design of the training scenarios described in a later section of this chapter.

11.1.2 Face Validity

The purpose of the validation method put forward in the research on face validity (Chapter 3) was to provide a good method of investigating whether drivers felt that the simulator was realistic and to also provide a simple method of ascertaining the parts of the simulator that needed to be improved. The face validity of the ABS was assessed by asking novice and experienced bus drivers to compare various aspects of the simulator to real bus driving in terms of accuracy and realism after driving a simulated bus route. The questionnaire consisted of specific questions that the bus driver answered on a 1-5
Likert scale as well as open-ended questions. Overall, the bus drivers gave a medium rating to the accuracy and realism of the ABS. Drivers felt that they were immersed in the simulated environment and thought that they drove the simulator in a similar way to how they drove a real bus. They rated steering and braking as the least realistic aspects of the simulator, which was attributed to the lack of motion cueing.

There were some differences in novice and experienced bus drivers' impressions of the ABS, specifically in their ratings of hazards and vehicle handling characteristics. This was attributed to differences in the accuracy of novice and experienced bus driver's representations of a real bus and differences in hazard perception skills. The results obtained from the face validity questionnaire indicated that the steering and braking mechanisms of the system needed improvement. The addition of a motion platform and a complex vehicle dynamics model would have been one method of improving the accuracy of steering and braking mechanisms, however achieving a high fidelity visual scene is probably more important for training transfer of hazard perception skills. Since the ABS may create confusion and frustration if it does not respond like a real bus, steering and braking was improved somewhat by altering the parameters within the simple vehicle dynamics model. The results showed that the ABS has good face validity, which is the first step in determining whether it has sufficient fidelity to train novice bus drivers in hazard perception skills.

Conducting a face validity study during the design and development of a simulator could reduce the risk of investing considerable resources in building and assessing a simulator that is then deemed unsuitable for purpose.

11.1.3 Behavioural Validity

The aim of the investigation was to ascertain whether bus drivers' emotional responses to a simulated bus driving environment were comparable to the responses expected when driving a real vehicle in order to provide a behavioural validation of the ABS. Novice and experienced bus drivers completed the DSSQ and Fatigue Scale before and after completing the simulated bus route to determine the effect of experience, stress, workload and fatigue on simulated bus driving. The results show that bus drivers' emotional and behavioural responses in the ABS are similar to the responses expected in a real vehicle. The results suggest that the ABS can successfully discriminate between novice and experienced bus drivers, thus providing the first step in validation. For example, bus drivers with greater training and experience approach the simulated scenarios with better positioning, slower speeds, and larger safety margins compared with inexperienced drivers. The results also highlighted that experience and training may mediate the potentially detrimental effects of stress and fatigue on performance. For instance, in contrast to novice bus drivers, experienced bus drivers adopt safer driving strategies when fatigued.

Overtraining is an effective way of inoculating the drivers against the detrimental effects of stress (Matthews and Desmond, 1995). Therefore a training intervention that includes scenarios to help to increase the bus driver's knowledge of the factors that can contribute to stress by examining their own response to pressure may help to reduce stress-related accidents if the bus driver is trained to apply adaptive means of coping (Matthews et al, 1998).

11.1.4 Simulator Side Effects

The objective of the simulator sickness study was to gather data on potential simulator side effects, which may occur through use of the ABS system, which could have a detrimental effect on training. The bus drivers completed the SSQ before entering the simulator and immediately after performance in the simulated environment. Consistent with other research using wide screen simulator displays, (Stanney and Kennedy, 1997), the main source of discomfort in the ABS was Disorientation followed by Nausea then Occulomotor discomfort (D>N>O). However, overall sickness symptom ratings were very low. Experienced bus drivers rated their symptoms more severely than novice bus drivers did, which was attributed to their increased ability to discriminate between the ABS and a real bus because of their increased familiarity with a real bus. Simulator sickness severity did not affect the bus driver's ratings of the overall realism of the ABS, which was interpreted as further evidence that the ABS is a valid measure of bus driving. However, this study raised concerns about the validity of lateral control measures in the simulator. This was because the results tentatively suggested a link between simulator sickness severity and mean heading, which means that turning may increase simulator sickness symptoms.

One way to reduce simulator sickness is to limit the number of turns in the training scenarios, however this may impact the realism of the training scenarios when manoeuvring at junctions and bus stops and traffic lights. Instead, shorter scenarios and hence exposure times may further reduce simulator sickness symptoms experienced in the ABS. Another direction in performance measurement strategy arose from this study: it would be preferable to record driver behaviour at very specific locations in the training scenario, rather than using global measures of performance in order to provide a better indication of training performance.

11.1.5 Comparative Perceptions of Bus Driver Ability

The issue of self-bias in bus driver's perceptions of their own ability in comparison to other bus drivers was investigated in order to ascertain whether this needed to be addressed in training. Firstly, the repertory grid technique was used to derive 28 bipolar constructs that bus driving instructors used to differentiate between good and bad bus drivers. Secondly, the list of constructs was turned into a questionnaire in which bus drivers rated a good bus driver, a bad bus driver, an average bus driver and themselves on the 28 semantic differential scales using a 5-point rating scale.

The repertory grid technique proved to be an ideal method of obtaining relevant items to include in a questionnaire to compare bus driver's perceptions of their own and other drivers' abilities. The results indicated the prevalence of self bias in professionally trained bus drivers in comparison to their 'average' peers. This self-bias persists to a certain degree in their comparisons between themselves and a good bus driver.

Concordant with previous research, experience and training may actually increase self bias. For example, more experienced bus drivers show greater self bias than novice bus drivers in terms of their hazard perception skills and intermediately experienced bus drivers show the most self bias in terms of their ability to independently maintain standards in the depot. This may be because the current methods of bus driver training focus on developing vehicle control skills, which in some cases have been shown to increase accident risk (Elvik and Vaa, 2005). However, bus drivers appear to have a realistic sense of their experience in relation to their colleagues and are aware that they may have some skill deficits and may be prone to accidents.

The conclusions drawn from this study suggest that simulator based training should be supported by other types of intervention, such as a group discussion (Gregersen, Brehmer and Moren, 1996). The group may be encouraged to focus on a risk analysis of severe blameworthy bus accidents, perhaps by reconstructing real accidents that have occurred involving bus drivers. This may be an effective method of de-biasing perceptions of risk in bus drivers and may encourage safer driving strategies. However, it is important to make individual bus drivers accountable for their judgements within the group.

11.2 Implications of Findings

11.2.1 Simulator Fidelity and Validity

The issue regarding the importance of simulator fidelity has been the source of considerable debate (Roscoe, 1990; Salas, Bowers, and Rhodenizer, 1998). The question of what level of simulator fidelity is required to effectively train bus drivers was addressed in the face validity study (Chapter 7) and advances the argument that it is not useful to view fidelity as a single continuum in relationship to training transfer when determining the fidelity requirements for a simulator. Rather fidelity should be viewed as a multi dimensional concept. Taking the view of Hays and Singer (1989), the fidelity of the ABS is composed of physical, functional and psychological fidelity, which in turn are composed of many facets. The results of the face validity analysis indicate that the ABS has high physical fidelity; the appearance and sound of the controls provided bus drivers with a realistic experience of being in a bus cab. However, the ABS has medium functional fidelity in terms of the accuracy of the vehicle operating characteristics - some of the manoeuvres performed in the ABS could be performed more realistically than others. The low accuracy of the braking and steering mechanisms in the ABS largely contributed to lowering the functional fidelity of the ABS. The results of the face validity (Chapter 7) and the behavioural validity studies (Chapter 8) suggest that the ABS has high psychological fidelity. Firstly, the bus drivers considered that the virtual scenarios offered an almost realistic training environment, which is considered to be an important aspect of training transfer (Farmer et al, 1999). Also, bus drivers stress responses within the simulated environment are comparable with real bus driving. Furthermore, the ABS is capable of discriminating between novice and experienced bus drivers in terms of their decision-making reactions, vehicle control and choice of headway. The investigation into simulator sickness (Chapter 9) also provided indirect evidence for high psychological fidelity of the ABS. Experienced bus drivers reported more severe sickness symptoms than novice bus drivers, which was attributed to them relying on vestibular cues to orientate themselves within the simulated environment, as they would so in real driving (Kennedy, Hettinger and Lilienthal, 1988).

Since, the level of fidelity required in a simulator is task dependent (Kaptein, Theeuwes, and van der Horst, 1996) and the ABS is intended to supplement hazard perception training rather than vehicle control skills training, high psychological fidelity is perhaps most important. The importance of achieving high functional fidelity with regards to vehicle control mechanisms is open to debate. However, further research is needed to systematically evaluate the impact of various levels of physical, psychological and functional fidelity on bus driver training transfer. Although certain aspects of the ABS had relatively high fidelity yet others were relatively low, the results suggest that the fidelity of the system is sufficient to support hazard perception training in novice bus drivers. Novice and experienced bus drivers showed behaviourally valid responses to the simulated environment, rate the fidelity of the system quite highly and simulator sickness symptoms are low. Therefore, given a suitably engaging scenario with appropriate instructional overlay and facilities for the provision of feedback, there is every reason to expect that transfer is possible.

11.2.2 Assessing Bus Drivers' Performance in the ABS

Training evaluation requires a means of assessing trainees' performance. This can be done on a group or individual basis depending on the type of information required. One way of evaluating group performance is to look at group accident statistics. On an individual level, bus driver training assessments are traditionally based on instructors' judgements of performance on certain observable criteria, such as pulling into bus stops and use of mirrors etc. One limitation of this method is that only overt actions can be observed, which makes it difficult to assess higher-order constructs such as decision-making (Vreuls and Obermeyer, 1985). For example, if the bus driver takes no action in response to a hazard, it is impossible to determine whether this was based on a sound evaluation of the situation or whether the trainee was so overwhelmed by information that they did not know what to do and so did nothing. The ABS is capable of objectively recording performance and provides the opportunity to replay events, which offers the advantage of allowing the detailed systematic analysis and measurement of bus drivers' responses to different bus driving tasks.

The present research allows the identification of behavioural measures to accurately reflect bus driver performance. One potential problem highlighted by this research is the lack of validity of lateral control measures. Firstly, the lane widths in the simulated route were programmed to be wider than in real life to compensate for deficiencies in the steering wheel components of the ABS that had increased the difficulty of turning manoeuvres. Secondly, steering was influenced by simulator sickness severity, which may then have been a confounding factor in the results of the behavioural studies. However, the implications for lack of validity of steering on the transfer of training of hazard perception skills are uncertain. It may be that because relative differences in behaviour can still be meaningfully interpreted, achieving absolute validity of the positioning variables is unnecessary for training hazard perception. Given the questionable validity of lateral control measures, steering inputs may not be a good measure of performance in the ABS. Instead, distance from the central dividing line in the roadway may be a better reflection of driver performance in terms of hazard perception skills because it has been shown to discriminate between novice and experienced bus drivers (Chapter 9). The results of the behavioural validity study shows that time-to-collision are another good measure of bus driver behaviour. Firstly, it was shown to be a fairly sensitive to changes in stress state. Secondly, it could be used to discriminate between experienced and novice bus drivers. Thirdly it reflects adaptivity to hazardous situations and finally it is a good indicator of risk. Speed may also be a good reflection of driver performance when used in conjunction with other measures because it may reflect a drivers' adaptivity to hazards (Nilson, 1982; Walton and Bathurst, 1998). On the basis of this research, rather than calculating a mean measure of performance across the entire training scenario, performance measures will be taken at specific points of interest in the scenario to provide a more detailed picture of bus drivers' skills.

The present research demonstrates that subjective measures of driver performance, stress and workload are relatively easy to obtain and may also be used in conjunction with objective measures to assess performance. The DSSQ (Matthews et al, 1999) has been shown to be a good indicator of bus driver stress. Some researchers believe that subjective ratings may in fact be more sensitive to performance differences than objective measures providing the assessment scales are reliable and valid (Hays, Jacobs, Prince and Salas, 1992). In addition to performance measures recorded in the ABS, instructors ratings can be conducted during the training event and trainee self-ratings can be obtained by means of a questionnaire with a rating scale administered after training.

11.2.3 Differences between Bus Drivers and Car Drivers

The present research indicates that novice bus drivers differ from novice car drivers in many ways. Firstly, novice car drivers are typically young (Drummond, 1989) but there is a considerable variation in the age of novice bus drivers so immaturity is less of an issue for novice bus drivers Secondly, even the most experienced bus drivers retire before they are 65, whereas car drivers can be much older. Thirdly, novice car drivers have had little or no experience in demanding traffic situations, but novice bus drivers are already experienced road users who then receive additional professional training. Fourthly, bus drivers have responsibility for passenger's lives as part of their work, whereas car drivers typically do not. Fifthly, a PCV has different handling characteristics to a car, which place different demands on bus drivers compared with car drivers. Finally their collisions are work related and therefore organisational constraints such as bus schedules are likely to have a strong influence on their crash risk. In spite of these differences, the results of the previous studies indicate that novice bus drivers may actually share some of the characteristics of novice car drivers. Firstly, crash risk is high in both populations of drivers. The results of the accident analysis (Chapter 5) show that novice bus drivers are most likely to be culpable for the accidents they are involved in. This is likely to be because less experienced bus drivers have poor representations of what to do and what not to do in different circumstances (Bailley, Bellet and Goupil, 2003; Underwood et al, 2002) and, like novice car drivers, may have a poor understanding of the limitations of their own capabilities (see Chapter 4). However, novice bus drivers appear to have a more realistic appraisal of their own skills in comparison to the literature on self bias in novice car drivers (e.g. Gregersen, 1996), perhaps because of their previous experience driving a car. Increased risk taking such as leaving small headways while consolidating their skills (Chapter 8), may lead to mistakes, which may then lead to accidents (Amalberti and Wibaux, 1995). However, rather than making deliberate efforts to drive dangerously (McGwin and Brown, 1999), novice bus drivers' increased risk is likely to be because they have had insufficient time to develop the cognitive skills needed to evaluate risks and determine the consequences of alternative strategies when negotiating traffic. Like novice car drivers (West, 1998), a decrease in accident risk is seen over the first three years of bus driving (Chapter 5), presumably due to improved hazard perception skills (McKenna and Crick, 1991) and better vehicle control skills. On the other hand, more experienced drivers may have the benefit of over 30 years experience of making decisions and manoeuvring a bus in heavy traffic. They are more likely to have developed detailed mental models of traffic scenarios that may lead to accidents. The root cause of their accidents is perhaps age-related declines in perceptual ability, specifically vision, which makes it difficult to judge distances and speeds rather than the kind of cognitive skill deficits found in older car drivers (e.g. McGwin and Brown, 1999).

11.2.4 Factors Influencing Bus Drivers' Crash Risk

Previous research has shown that different types of stress-vulnerable bus drivers exhibit different patterns of impairment (Matthews, Dorn and Glendon, 1991). The current research offers further support for a transactional model of driver stress (Matthews, 2001) and emphasizes that cognitive stress processes precede dangerous behaviours. For example, impaired vehicle control is preceded by worry, fatigue, disengagement from the driving task and stress due to time pressure (in experienced bus drivers only). Risk taking is preceded by tension, task disengagement and boredom. On the other hand, active styles of coping with the driving task are preceded by high work loads and higher levels of motivation.

The current research highlights the influence of experience and training on cognitive processes and driver behaviour. For example, while consolidating skills some novice bus divers may be more motivated than others to 'test' what they have learned on the road. While this behaviour may lead to greater adaptivity in the long term, it may increase their short term crash risk (chapter 5). Novice bus drivers therefore require a safe environment in which to test their new skills in different traffic conditions. The results of the accident analysis (chapter 5) showed that crash risk is influenced by the type of manoeuvre being performed, the location and the prevailing weather and road conditions. While the risk may be mediated by experience and training, driving a bus is simply more difficult in some conditions than others. Even so, novice bus drivers may not be aware of the hazards specific to these locations and bus drivers with more experience may still lack the skills to successfully negotiate through traffic in these areas (Aphaloe et al, 1987). Training that focuses on de-biasing bus drivers opinions concerning risk in these situations should have a beneficial effect on crash risk.

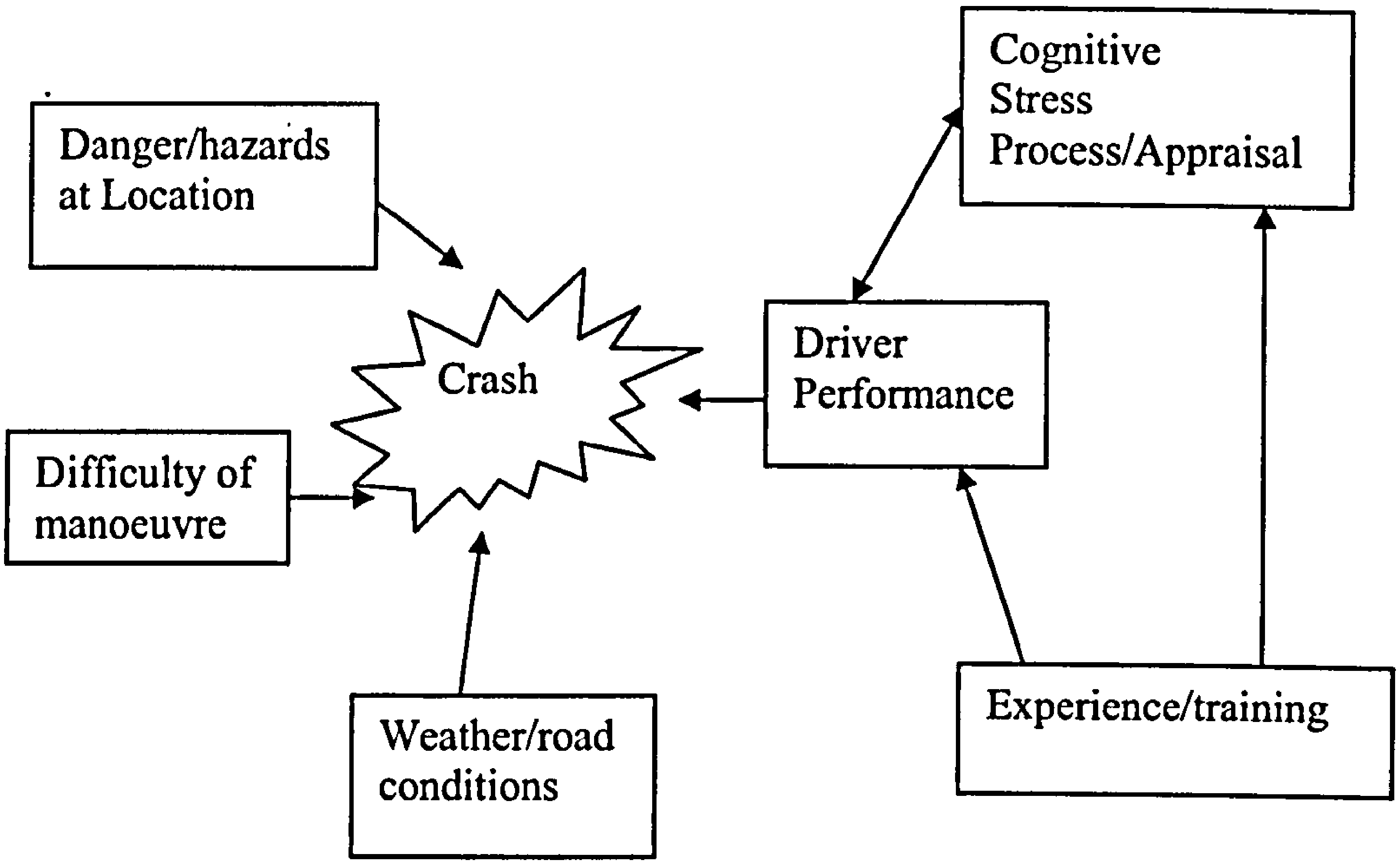


Figure 86 **Factors Influencing Bus Drivers' Crash Risk**

11.2.5 Decreasing Crash Risk in Novice Bus Drivers

Bus driving is undoubtedly characterised by physical and psychological stresses (Kompier and di Martino, 1995; Meijman and Kompier, 1998). Yet, novice bus drivers may be particularly vulnerable to performance decrements as a consequence of stress. For example, the results of the behavioural analysis (Chapter 8) show that in comparison to experienced bus drivers, novice bus drivers demonstrate less control over their vehicle, a greater propensity for risk taking and may be less aware of performance decrements due to factors such as fatigue and stress. However, more experienced bus drivers try to compensate for some of the deleterious effects of fatigue on performance, for example by leaving larger safety margins. It is important to train novice bus drivers to prioritise safety by encouraging the development of good hazard perception skills and vehicle control, especially when safety may be compromised by stress and fatigue. However, one possible concern is that self bias may impede training effectiveness if the bus drivers did not perceive themselves to be in need of training or that the training lacked value. The analysis of bus drivers' self perceptions (Chapter 5) revealed that this was not the case. The results indicate that bus drivers may in fact be aware of deficits in skills and safe driving strategies and are aware that they may sometimes engage in inappropriately risky behaviours and may be responsible for accidents. Although some skills based training has been shown to be somewhat ineffective in reducing crash risk in novice car drivers (Gregersen, 1996), novice bus drivers may actually benefit from improved and relevant skills training if it is coupled with a suitable method of risk de-biasing (McKenna and Myers, 1995; 1997; 2001). Previously, novice car drivers have benefited from simulator based training interventions that target risk perception, decision-making and hazard perception skills (Regan et al; Triggs et al; Allen et al). Therefore it is reasonable to assume that simulator based training is likely to benefit novice bus drivers and so reduce the risk of bus accidents in their first year after licensing, provided that it is shown to be a valid representation of real bus driving. A further consideration in the implementation of a training programme is that individuals' coping strategies are primarily social in nature (Pearlin,1982). Therefore, novice bus drivers may learn the cognitive strategies and techniques for managing tensions that arise from stressful driving situations from their colleagues. Encouraging managers to think about the potential detrimental effects of shift work and strict scheduling and to implement policies that are kinder to bus drivers may also help to address the accident problem at an organisational level.

11.3 Bus Driver Training Programme Design

The conclusions drawn from these studies provide information about the factors that contribute to crashes and suggest how they could be addressed during training. The analysis of bus accidents indicates that novice bus drivers are most at risk of being culpable for crashes, probably because they have insufficient mental models of the traffic environment, which is perhaps due in part to a lack of bus driving experience. Particular locations carry an increased risk of crash involvement, namely junctions, bus stops traffic lights roundabouts and driving in adverse weather conditions. The training programme should then include scenarios to improve the bus driver's orientation towards safety. It should provide the driver with the means to develop their hazard perception and risk perception skills and training in vehicle handling techniques that are necessary to avoid danger and should encourage them to transfer their knowledge and skills between different situations. One method is to train drivers to focus their attention away from distractions by drawing their attention to environmental stimuli. If bus drivers are taught to recognise the cues in the environment that indicate unfolding hazards and are taught to predict sequences of events that can lead to dangerous situations, they may be able to modify their driving to prevent accidents.

Secondly, since behavioural modification is not possible without modifying the driver's awareness of their personal goals while driving, the key to successful transfer of training then is to increase the bus driver's awareness of their personal tendencies that may impact their safety (Hattakka et al, 2002). For example, increasing the bus driver's knowledge of the factors that can contribute to stress by examining their own response to fatigue, boredom, worry and even the stress of a tight schedule and time pressure may help to reduce stress-related accidents if the bus driver is trained to apply adaptive means of coping (Mathews et al, 1998).

A third major consideration is that individual differences in skill acquisition must be catered for since bus drivers believe that some of their colleagues appear to have a natural driving ability and that they found it more difficult to drive a bus than some of their colleagues. However very few of the training interventions reviewed allow drivers to govern their own learning, with the exception of Allen et al (2003) who delivered training on a simulator to allow drivers to pace learning at their own rate. Fourthly, the results of the self-bias study suggests that bus drivers may be influenced by depot culture, so the organisation must provide encouragement and support for the training intervention and must endeavour to create the right environment to enable skills transfer. This opinion is shared by Machin (2001, 2003) and Ludwig and Geller (2000). The bus drivers should also be encouraged to consider barriers to transferring their new skills into the workplace and should find ways of overcoming these obstacles themselves.

The following training scenarios were designed to aid the development of hazard perception and decision-making skills to help to reduce crashes in novice bus drivers. In order to improve ecological validity during training, the scenarios incorporate the challenges that bus drivers face on a daily basis. The training scenarios and performance measurement criteria were developed in conjunction with experienced bus driving instructors to ensure that the training has sufficient psychological fidelity and to encourage ownership of the new simulator based training methodology. Examples of events occurring in training are shown below.

11.3.1 Hazard Perception at Road Works

One of the problems facing urban bus drivers is the negotiation of road works. The accident analysis revealed that, while the proportion of crashes at road works is relatively low, bus drivers are likely to be responsible. At the location of the road works, road lanes may be narrowed; there may be a single lane of traffic, and maintenance vehicles, personnel and traffic cones may cause obstructions. Bus drivers have a particular problem because their vehicle is wider and longer than other vehicles. The training scenario depicts a typical road works site with maintenance vehicles and personnel in the periphery. Bus drivers must attend to these potential hazards while following the path marked by the cones as the road narrows into one lane. Bus drivers must also detect the central hazard of an overturned traffic cone that blocks the road and must decide whether to steer right or left to avoid it. If the driver decides to turn right they initially have more room to pass the cone but must mount the kerb on the right hand side. They must then steer quickly back to avoid the vehicle and personnel on the pavement ahead. There is then the danger of the back of the bus colliding with the cone if they steer back into the road too soon. If they steer left they may carefully pass between the cones although initially it seems as if they have less space to manoeuvre.

The successful completion of this scenario involves identifying the central hazard and then choosing the appropriate course of action by considering the consequences of their decision further ahead in the scenario.

Figure 87 Hazardous Road Works

Measures of performance are recorded 200ft, 100 ft, 50 ft and 20ft on approach to the cone hazard and as the bus passed the cone. Speed and distance/direction from the central dividing line are of particular interest.

11.3.2 Hazard Detection in Fog

Novice bus drivers crash risk is high in foggy and misty conditions. In these conditions bus drivers may tailgate the vehicle ahead and may miss hazards manifesting from the periphery, which may not be clearly visible. In the following scenario, bus drivers encounter an area of dense fog. Bus drivers must demonstrate safe behaviour by driving at a speed that is appropriate for the prevailing conditions and maintaining an appropriate headway between themselves and a leading vehicle. If the bus driver is too close they will collide with the vehicle ahead when it brakes. Furthermore they must identify and respond to two pedestrians who cross the road in front of them. The successful completion of this scenario depends on the speed that the bus driver chooses. If they are driving slowly the pedestrian can safely cross, however if they are driving too quickly they have to swerve into the opposite lane to avoid the pedestrian. In a real life situation this may mean swerving into the oncoming flow of traffic.

Figure 88 Slowing in Response to a Braking Lead Vehicle

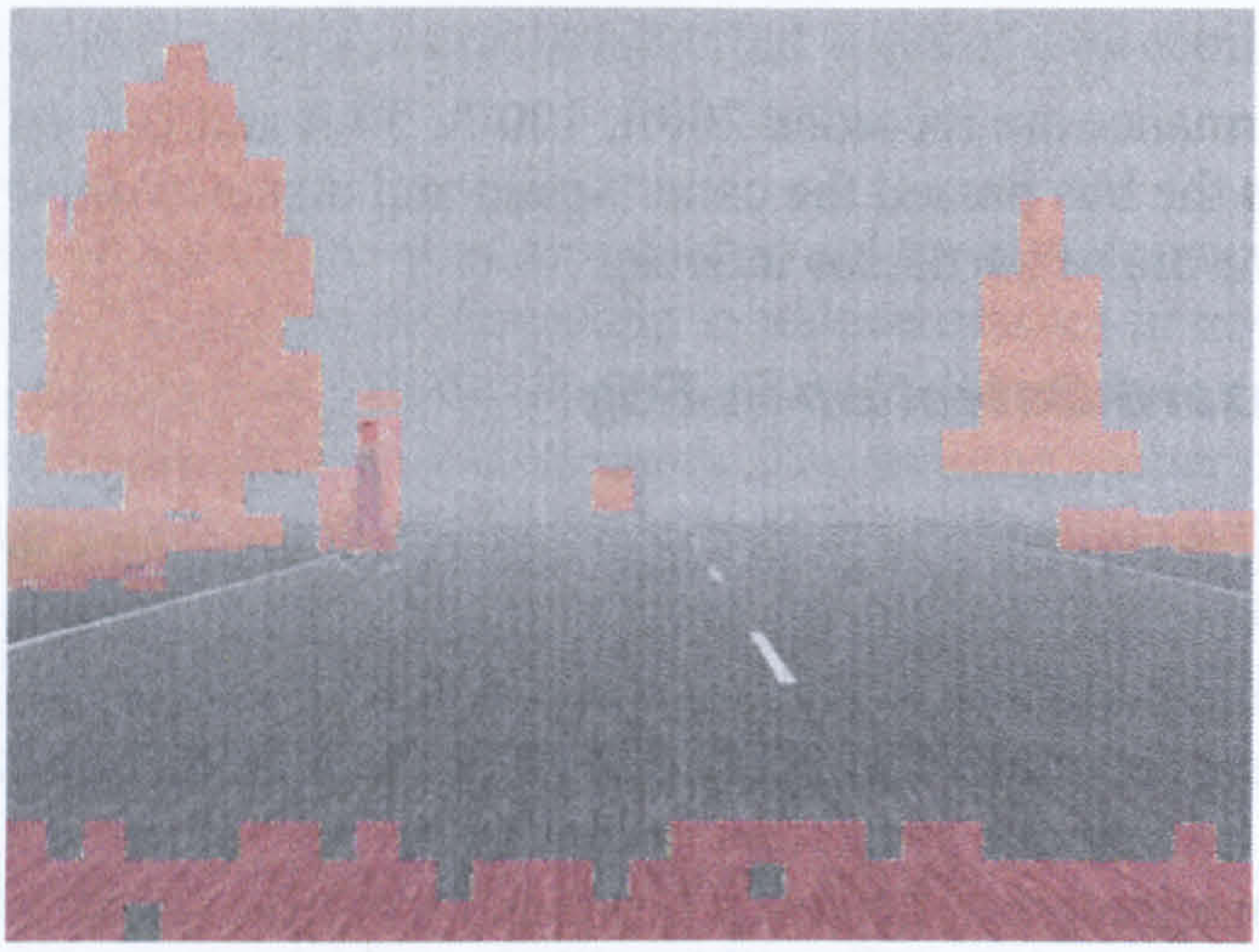


Figure 89 Hazard Detection in Fog/Mist

In this scenario it is appropriate to take continual measures of performance. Speed, braking, distance and direction from the central dividing line and Range and TTC are measures of particular interest.

11.3.3 Turning at a Junction

There is a high risk of crashes at junctions. Bus drivers may clip the kerb or may use both lanes when turning. In addition to this, parked vehicles may obstruct the driver's view of the traffic flow or may make it difficult to turn if they are positioned to close to the junction. In the first scenario a car is positioned so that if bus drivers turn too late they will cross into the opposite lane and collide with the vehicle. However if they turn too soon they will clip the kerb. Successful completion of the manoeuvre involves accurately judging the length and width of the bus and timing the turning manoeuvre to avoid both collision scenarios.

One problem with this scenario is that the corners of the lanes entering the junction are at right angles, when in reality the corners of junctions are curved. There is therefore some leeway if the driver cuts the corner but avoids the car. The extent to which the driver crosses onto the kerb can be analysed during the playback of the scenario by selecting an aerial view of the scene.

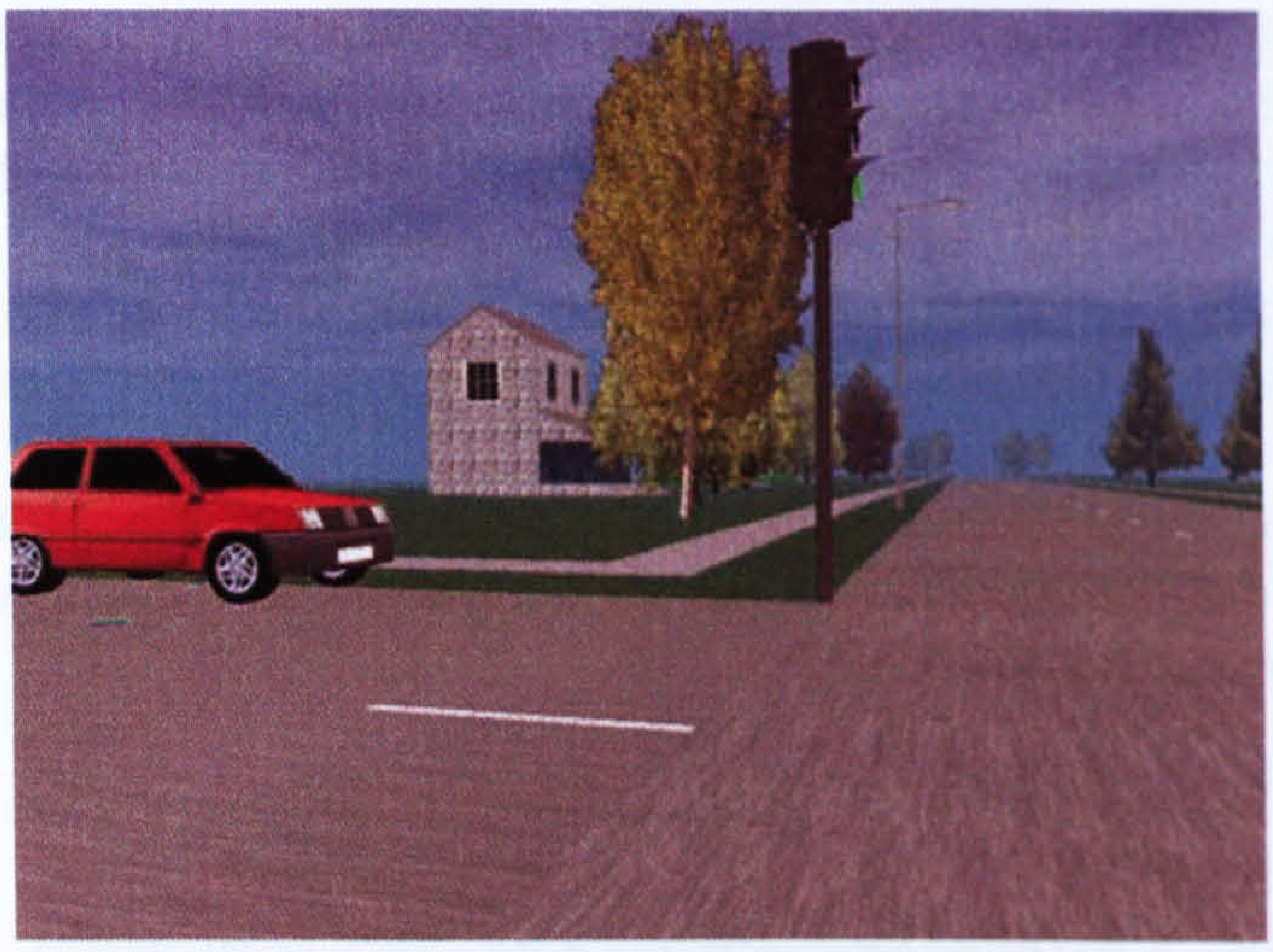


Figure 90 **Turning at a Junction**

The second scenario depicts a t-junction. Cars are parked to the left and right of the junction, obscuring the driver's view of the road. The cross stream of traffic involves three cars that pass in front of the driver. The bus drivers must turn right. They can either wait for all three cars to pass or may choose to turn in front of one of the cars, but this increases their risk of a collision if they are too slow to turn. Successful completion of this scenario involves accurately perceiving the risk of accepting a too-small gap in the cross traffic.

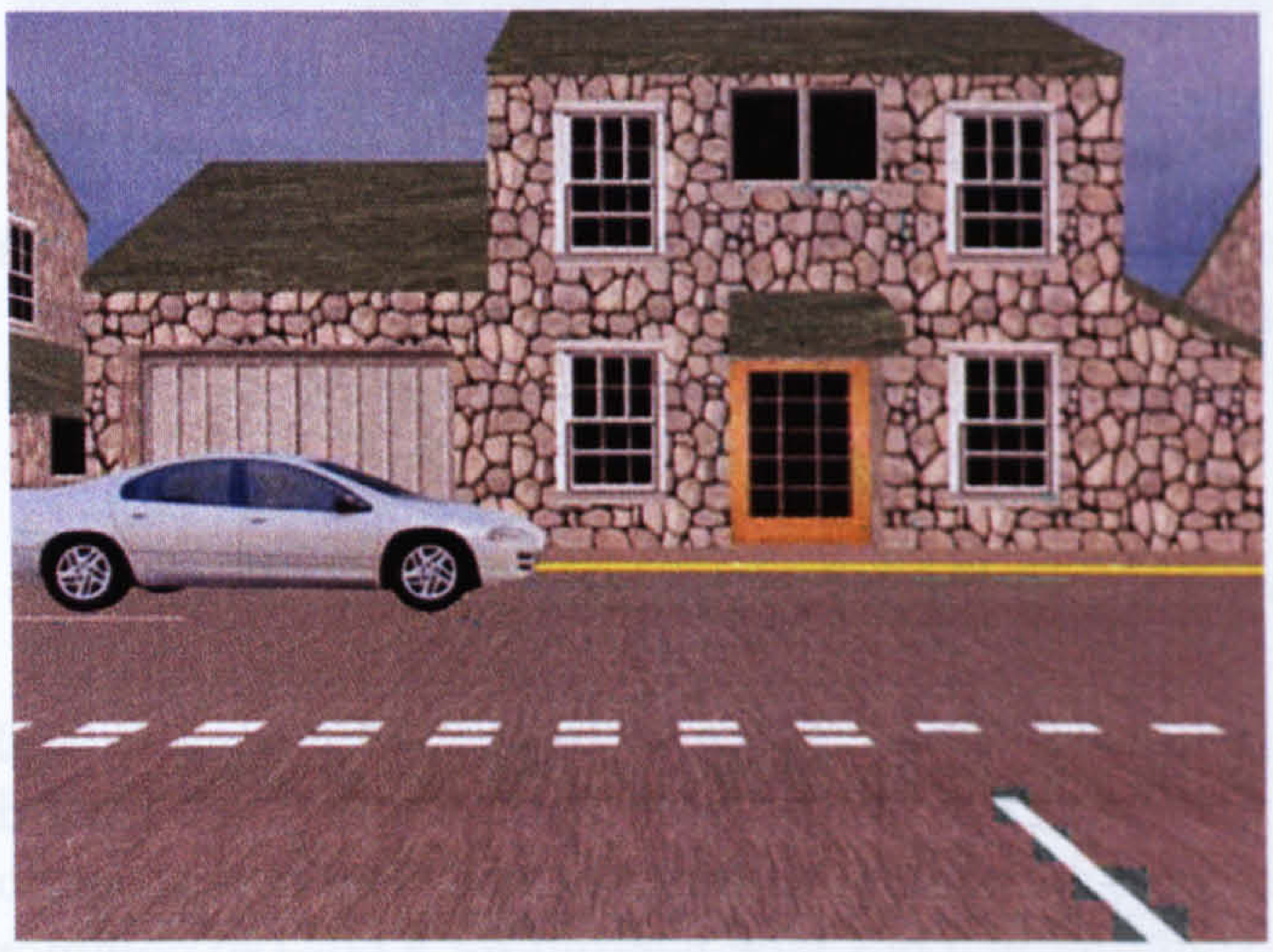


Figure 91 **Turning at a T-Junction**

Performance is recorded from 200ft away from the junctions, then at 100ft and 20ft approaching the hazard, then crossing and departing the hazard (20ft, 100ft, 200ft). Performance measures of interest are Range, TTC, lane position, speed, acceleration, braking, gear, horn, and of course left indicator and right indicator.

11.3.4 Pedestrians Crossing at Traffic Lights

There is a high risk of crashes at traffic lights and pedestrian crossings. The following scenario depicts a busy junction in the centre of a high street and so combines the risks at both of these locations. As bus drivers approach the traffic lights turn from green to red and the bus driver must stop before the pedestrian crossing. If the bus driver proceeds when the lights are amber they risk colliding with pedestrians and the cross flow of traffic. When the traffic lights change from red to green the bus driver must be patient and allow pedestrians to finish crossing and must also wait for a vehicle who crosses the junction in front of them although the bus driver has the right of way.

Successful completion of this scenario involves understanding the risks at traffic lights, being considerate to pedestrians and being aware that other vehicles may contravene road safety regulations.

Figure 92 **Pedestrian Crossing**

Performance measures (Range, TTC, lane position, speed, acceleration, braking, gear, horn, left indicator and right indicator) are taken 200ft, 100ft and 20ft approaching the hazard, then crossing and departing the hazard.

11.3.5 Hazards in Bus Lanes and at Bus Stops

A large proportion of crashes occur at bus stops and in bus lanes and there is a high risk of novice bus drivers being culpable for them. Some of the hazards that bus drivers must avoid in bus lanes include obstructions. The first scenario depicted here shows pedestrians standing in a bus lane waiting for a bus (an common event described by driving instructors). Bus drivers must carefully pull into the bus stop so as not to collide with any pedestrians and must park parallel to the kerb. At the same time they must not be too far out in the road that they then pose a hazard to the flow of traffic. Successful completion of the manoeuvre involves identifying the obstruction in the bus lane and accurately judging the position of the bus to avoid collisions.

Figure 93 **Hazards in a Bus Lane**

The second scenario depicts a lay-by bus stop that can typically be found in a high street. Bus drivers must pull smoothly into the bus stop. The success criterion is that the bus is parked parallel to the kerb and is not obstructing the lane of traffic and the driver has not mounted the pavement or collided with obstacles on the pavement when entering or leaving the bus stop.

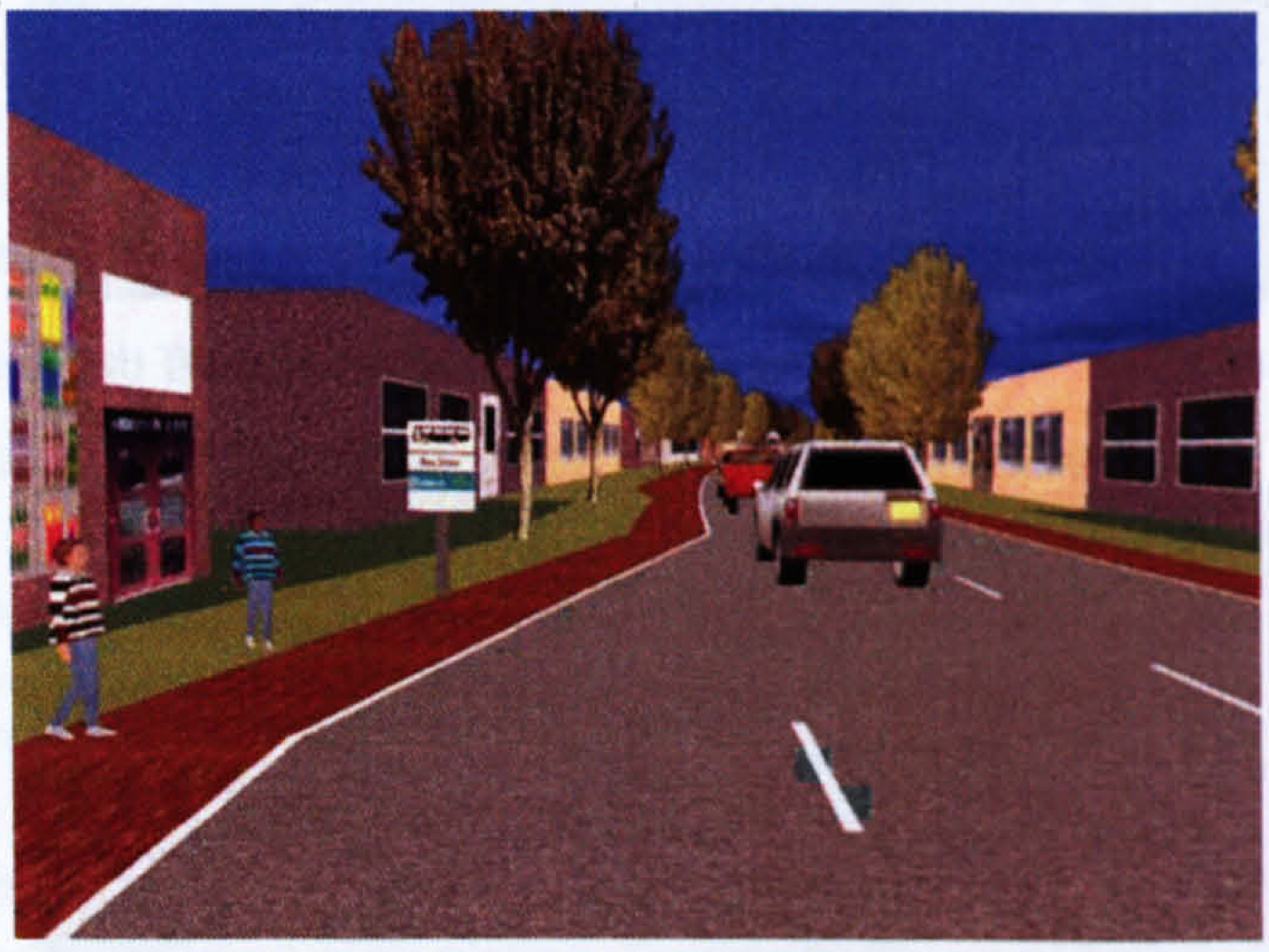


Figure 94 **Lay-by Bus Stop**

Performance measures are taken at 200ft, 100ft and 20ft on approach to the bus stops, when positioned at the bus stop and then when departing. Distance from the central dividing line, speed and braking are of interest, and the position of the bus when stationary can be checked by selecting an aerial view of the scenario.

11.3.6 *Taking Evasive Action*

Most of the training scenarios involve the accurate identification of potential hazards, which can then be mitigated by carefully planning ahead, and choosing an appropriate strategy to avoid them. However there are occasions when bus drivers must detect and react quickly to unfolding hazards. Crash risk is high when drivers must take evasive action. The following scenarios are designed to test bus drivers' responses to sudden hazards when driving through a residential area. The first incident involves braking to avoid a child running across the road in front of the bus. The view of the child is partially obscured by a parked vehicle. If the bus driver has seen the child and has slowed down then they do not have to brake suddenly. However if the bus driver did not see the child then they have to brake sharply to avoid the child. The second incident involves a car reversing out of their driveway which stops reversing before it crosses into the bus drivers lane so the bus driver can safely drive on. Again the bus driver may brake suddenly in response to a potential collision if they did not notice the people stood on the drive - perhaps saying goodbye to their visitor? Successful completion of both of these scenarios involves understanding the kinds a hazards that can occur in residential settings and identifying relevant cues, such as the child's feet behind the parked car and the people standing in their driveway.

Figure 95 **Taking Evasive Action (Child Steps off the Kerb)**

Figure 96 **Car Reversing Out of Driveway**

Figure 97 **Parked Car Pulls Out In Front of Bus**

A third scenario reinforces the lessons learnt from the previous two incidents. In quick succession in this scenario a parked car suddenly pulls out in front of the bus and speeds off and then a child steps off the kerb from between two parked cars and runs in front of the bus. The scenario is designed to replicate the pace of a busy urban setting. Bus drivers must quickly recover from the shock of the first incident in order to deal effectively with the next.

Although performance measures such as speed, braking and TTC may be important indications of how drivers reacted to the hazards, the emergency scenarios may be better discussed as a group using the playback function.

11.3.7 Risk Perception and Speed Awareness

The training scenarios also include a speed awareness element, which was achieved by recording drivers' speeds as they approached various hazards and then comparing them to a pre-defined standard. For example, the speed limit passing a school was set to a maximum of 20mph, however driving instructors agreed that the most appropriate speed was 15mph given that there were many hazards such as parked vehicles and children. So, bus driver driving at 20mph would not be breaking the law, yet they would not be demonstrating a clear understanding of the risks at this location. However a bus driver driving at 15mph would demonstrate that they perceived and responded appropriately to the risk.

11.3.8 Assessment Scenario

The simulated scenario that underpinned the current research was also adapted to become the scenario that novice bus drivers completed before and after training to determine whether training improved performance.

11.4 Future Work

11.4.1 Training Scenario Evaluation and Development

Table 67 illustrates the degree to which the simulator based training scenarios for novice bus driver training comply with the GADGET Model of driver training (Hatakka et al, 2002) shown in table 66.

Table 66 GADGET Model

Hierarchical level of behaviour	Knowledge and skills (K&S)	Risk increasing factors (RF)	Self-evaluation (SE)
Skills for Life	lifestyle	acceptance of risks	personal skills for impulse control
Goals for Driving	effects of social pressure in vehicle	social context and company	typical risky driving motives
Traffic Mastery	anticipation of events	risk increasing driving style	realistic self evaluation

Table 67 Compliancy of Proposed Bus Driver Training to GADGET Model

Scope of the Training Syllabus											
Vehicle Handling			Traffic Mastery			Goals for Driving			Skills for Life		
K&S	RF	SE	K&S	RF	SE	K&S	RF	SE	K&S	RF	SE
*	*	*	*	*	*	* CB	* CB	*	CB	*	*

(CB = Classroom-based)

The table shows that the simulator based training method described in this thesis is suitable for supporting novice drivers skills acquisition in the area of vehicle handling and traffic mastery. With the addition of some classroom based instruction regarding the effects of organisational pressures (e.g. strict schedules, and penalties for arriving too early/too late at bus stops), the simulator based training scenarios could be used to support training in the area of drivers goals for driving. For example, bus drivers could drive simulated scenarios with or without the addition of a time pressure to evaluate the impact on driving. Classroom based training could then involve changing drivers cognitions so that they consider safety over schedules, and then the effect of changing cognitions on driving performance could be reviewed in the simulator. Similarly, the area of skills for life could be addressed in the classroom, perhaps by using psychometric profiling to identify bus drivers with a propensity for risk taking followed by group discussions to help to de-bias risk perceptions. The simulator based training scenarios could be used to demonstrate how differences in perceptions of risk and risk acceptance impact driving performance.

Table 68 shows that the novice bus driver training programme has been qualitatively evaluated and has also been evaluated in terms of group differences in driver performance on the simulator. Further work is now required to evaluate the training programme in terms of on-road performance and impact on accident rates.

Table 68 **Novice Bus Driver Training Evaluation**

Evaluation Method			
Qualitative	Simulator	On-road	Accidents
*	* /FW	FW	FW

(FW = Further work)

11.4.2 *Performance Improvement within the ABS*

The next stage should be to investigate whether learning occurs within the simulated environment. This involves evaluating the training material, including the scenarios, instructional overlay, and provision of feedback. Assessing the content and face validity of the training materials may be sufficient, but it is also necessary to gain some objective evidence of performance improvements in terms of positioning and speed in the simulated environment. If significant performance improvements are seen before and after training, then this indicates that learning has occurred within the simulation environment and can be taken as further evidence for validity of the ABS.

11.4.3 *Transfer of Training*

The final stage is to determine whether bus driver training transfers to the real environment. One method involves randomly selecting three groups of novice bus drivers (preferably age matched). One group receives simulator based training, one group receives a non-simulator based training intervention (perhaps group discussion that has already been shown to improve accident rates or a bonus incentive scheme) and one group receives no extra training at all. Monthly accident risk ratios should then be compared for the three groups. Risk ratios should be lower in the trained groups if training transfer has occurred. If the simulator trained group has lower risk ratios than the non-trained group this is evidence for positive transfer. If the simulator trained group has higher risk ratios than the non-trained group this is evidence for negative transfer. Comparisons of risk ratios between the simulator trained and non-simulator trained groups should provide some indication of the value of simulator-based training over other training interventions.

11.5 Conclusion

The overarching aim of this research was to design a bus simulator that is capable of supporting bus driver training. The research presented in the first part of this thesis directed the design of the UK's first bus simulator. Novice bus drivers were identified as those who were most at risk of crashes and were therefore likely to benefit most from additional training in hazard perception and decision-making skills, particularly at junctions and bus stops. The Arriva Bus Simulator was therefore built as a fixed base moderate fidelity system with a wide field of view to support high fidelity training scenarios at these locations. The studies in the second part of the thesis provide an initial evaluation of the simulator. Both novice and experienced bus drivers thought that the simulator was realistic. Judgements concerning the realism of the simulator did not influence drivers' performance in the simulator to a great extent. Rather, as expected, a bus drivers reactions to and behaviour in the simulator was in fact influenced by their level of experience of driving a bus, which shows that the ABS is capable of discriminating between novice and experienced bus drivers. Novice bus drivers report less adverse reactions to the simulated environment than experienced bus drivers, which suggests that simulator sickness may not impede training transfer for novice bus drivers. However, the validity of simulated steering behaviour may be affected by simulator sickness although longitudinal measures of simulated driving performance are not significantly affected. This research in concordant with other validation studies which demonstrate better validity for longitudinal control measures than lateral control measures (e.g. Blaauw, 1982; Harms, 1996). The final study indicated that a suitable method of de-biasing bus drivers perceptions of risk must be incorporated into the training programme, if not then bus drivers may not view themselves as being in need of training, which may adversely affect training effectiveness.

The culmination of this work was the design of a number of short simulated training scenarios that address the risks associated with driving a bus under various conditions at different locations. The scenarios encourage the development of hazard perception skills in situations that require careful observations of the traffic environment and planning ahead to mitigate risks of crashes and in emergency situations when drivers must react quickly to avoid an accident. With the correct instructional overlay novice bus drivers will be able to practice responding appropriately to hazards in the simulator. If this training then transfers to the real environment, the risk of bus crashes may be greatly reduce

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APPENDICES

A. Appendix A

Here follows a report that details a pilot study to evaluate and improve software configuration (mentioned in chapter 6)

1. Introduction

The ABS has a simplified vehicle dynamics model that describes the physical characteristics and handling characteristics of the vehicle that is being simulated. This includes features such as side mirrors, turn signals, and speedometer, steering, acceleration, braking and engine characteristics. The initial configuration of the simulator was achieved by trial-and-error. However it was necessary to establish whether some vital elements were missing, distorted or misleading before conducting a more thorough evaluation. Therefore a pilot study was conducted using a small sample of PCV licence holders in order to assess the fidelity of the initial configuration of the ABS and to make improvements based on their responses.

2. Method

a. Participants

Sixteen bus drivers (B1-B16), each with over five years experience were recruited for the pilot study.

b. Procedure

Participants completed a practice session then drove the simulated bus route for about 15-20 minutes, depending on preferred speed. They then completed a questionnaire in which they rated all aspects of the simulation using a five-point Likert scales to indicate how realistic they thought the simulator was in comparison with driving a real bus (appendix x). In addition to this, a semi-structured interview was conducted so that participants could elaborate and contextually situate their opinions regarding the bus simulator and its utility as a training device. A semi-structured format was used to allow questions to flow naturally based on the information provided by the respondents. The following questions are examples of those used as a guide:

- What was your overall impression of the simulator?
- Did you feel that you drove the same as you would in a real bus?
- What improvements could be made that would make it more like a real bus?
- Was the simulator more or less difficult to drive than a real bus?

- What made you drive differently to how you would in a bus?
- If you were to build a bus simulator, how would you make it different to the one we have here? Would you include more bits, less bits, make it easier? How?
- What could make it look more like a real bus?
- How can I make it seem more like real bus driving?
- Do you think it could be useful in bus driver training?
- What scenarios, situations and events would you include to train drivers to deal with real bus driving?

Due to the semi-structured format, deviations were common and in cases where participants suffered simulator induced sickness the interview focussed on the development and severity of symptoms and any strategies that participants adopted to counter the ill effects. This was so improvements to the procedure for handling simulator sickness could be made and also to gain information about causation. Interviews were recorded so that active listening could take place and so attention could be paid to any non-verbal cues. This was particularly important in cases of simulator sickness, as it was necessary to put these participants at ease. Interviews were transcribed from the recorded audiotape and written notes. The transcripts were studied for themes, commonalities and patterns and the results were triangulated by another researcher in the Human Factors Group to verify the credibility and validity of the information gathered.

3. Results and Discussion

a. Simulator Sickness

Seven drivers had to stop the experiment because they experienced uncomfortable symptoms. This gave a drop out rate of over 43% which was very high. Two drivers stopped during the practice session and five stopped during the test session.
Of the drivers who began the main drive, some reported that their symptoms began after turning at junctions:

B16 'The simulator was fine going straight then I made a right turn then for a couple of seconds I couldn't really get the balance right of the bus to straighten myself on the road.'

B10 'I found that when you did a right turn you had to slow down to get your eyes back in focus again. That was making me dizzy a couple of times.'

Others reported that their symptoms began when they drove at high speeds:

B4 'I think the faster you were going it became uncomfortable. It's so fast coming to you sort of thing. That's why I was going a bit slower than usual.'

The common explanation was that they found it difficult to process the flow of the simulation and became disorientated. This was particularly bad when they looked close to the front of the vehicle:

B4 '..suddenly I started feeling quite edgy but thought I could carry on but when I got to the school and I saw the people crossing and it was getting heavy I thought I had to stop because I didn't feel safe any more..'

B7 'It's just the visual, the way things are coming here to you, it's different from where the road is steady and you move along. This is the reverse I think. It's difficult to get used to the reverse effect on the eyes.'

Symptoms were controllable if they were able to find the horizon and regain their sense of direction. However some of the events in the simulated scenarios required drivers to look nearer to the front of the car.

b. Fidelity

The results gave an indication of drivers' acceptance of the ABS. Table 69 shows how drivers rated the realism of different aspects of the simulator.
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Table 69 Ratings of Realism (Appendix)

Feature	Mean	Standard deviation
Route	3	.82
Hazards	3.25	.96
Road signs	3.5	1
Road markings	3.5	1
Engine sound	3.5	1
Horn sound	4	1.4
Indicator sound	4.75	.5
Side Mirrors	1.5	1

They reported that the route was quite realistic and included all of the major hazards faced by bus drivers on a daily basis. They rated the hazards as being almost realistic and that the road signs and road markings were almost realistic. The drivers also rated the sounds of the engine, horn and indicators as realistic. However, drivers rated the view in the side mirrors as unrealistic.
B3 'You should work on the inside mirror so people can see where the bus ends and try and change the vision of where the road comes to you.'

This is because the virtual 'mirrors' in the simulator's visual display are flat, whereas on a real bus side mirrors are curved. This meant that the side view could not be configured to include both the road and the sides of the bus, which is how bus drivers usually position their mirrors. Table 70 shows how the drivers ranked different aspects of the simulator.

Table 70 **Ranking Order of Realism of Simulator Features (Appendix)**

Feature	Rank
Cab	1
Gear change	2
Sound	3
Acceleration	4
Visual display	5
Mirrors	6
Steering	7
Braking	8

In order of realism, drivers rated the cab and gear change as the most realistic features of the simulator, followed by the sound, acceleration, visual display and mirrors. They ranked steering and braking as the least realistic aspects of the simulator hardware. They reported that the steering was too light and too responsive and the braking was too harsh. The bus came to a halt as soon as they touched the pedal whereas in a real bus the braking motion is smoother:

B13 '...steering was very difficult in the simulator I had to really concentrate to try and not over-steer and I was steering really quite a lot.'

B15 'The steering was too light, too positive, there was too much road movement for small amounts of steering wheel movement.'

B5 'you couldn't pull away like normal because the steering is overactive. On a real bus the steering centralises itself so that you have a centraliser. On that [the simulator] just a fraction is too much.'

B5 'The brake was far too responsive, it seemed to be 100% efficient, you virtually stopped straight away.'

B1 'It wasn't an air brake it was almost an on/off type brake.'

Five drivers reported that the realism of the simulator was enhanced by the illusion of motion and that at times they felt like they were really moving. However, the other drivers stated that they did not get the 'feel' of driving a real bus. One driver commented that it 'was like pulling a hovercraft'.
This is most likely to be due to the absence of a motion platform, which means that drivers are not receiving the proprioceptive motion cues that accompany braking and turning manoeuvres as it would in a real vehicle. Drivers reported that it would be worthwhile developing the ABS as a training device, partly because it was easy to learn how to use it. They stated that it was particularly suited to hazard perception training. However, in its current state, drivers felt that the handling quality of the simulator was not sufficiently realistic for it to be used as a training tool:

B5 'It could be used to train hazard perception but not as it is at the moment. It needs to be more realistic.'

B1 'Once it is set up and the brakes are all right and the steering wheel, it will be OK.' In spite of the disparity between the ABS and a real bus, some drivers in this study reported that after a while they drove the simulator as they would have driven a real bus.

B12 'I felt comfortable after a time because I knew where everything was and how the pedals would react.'

B2 'It was quite realistic in terms of how you felt.'

B6 'In the end after I'd been going along a bit I was driving like I usually would with one hand resting on the steering wheel and the other to the side like when I'm driving. Also I noticed what I did a couple of times which I shouldn't have done is not to use the handbrake. And I used to do that when I was driving.'

The steering performance was improved by fitting a more powerful torque motor. Braking function was improved by adjusting the parameters in the configuration files. (The final configuration is reported in Chapter 6.)

B. Appendix B

Simulator Questionnaire

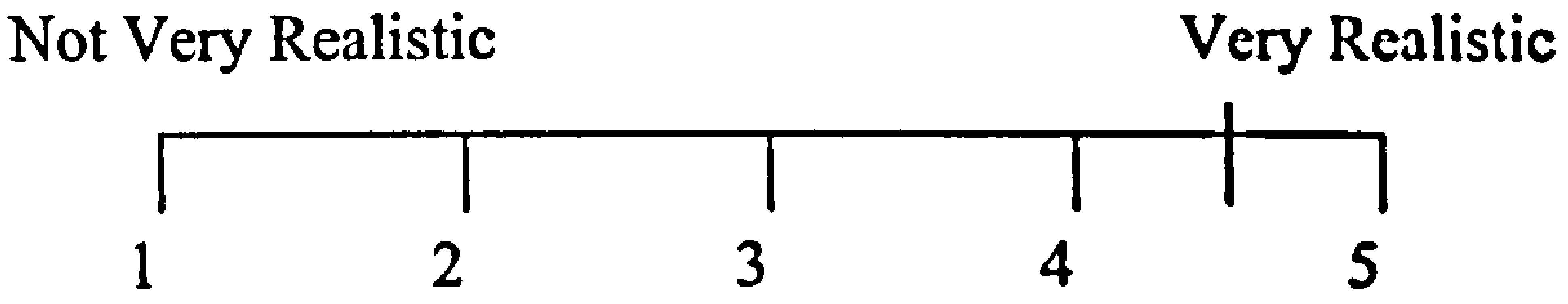
ID Number:

Date:

The following set of questions ask you to rate the bus simulator for how well you think it looks, feels and behaves like a real bus. Please answer the questions as accurately as possible based on your first thoughts about the simulator. Please indicate on the line the score that most corresponds to your response.

EXAMPLE

Overall, how realistic was the simulator?



A score of 1 = Not very realistic
A score of 2 = A little realistic
A score of 3 = Quite realistic
A score of 4 = Almost realistic
A score of 5 = Very realistic

A mark may be placed in between these scores (as indicated above). A score of 4.5 would suggest that you were impressed with the realism of the simulator but not quite enough to give a top score.

If there are questions that are not applicable to your experience of the simulator (i.e. you may not have had to use the horn) then please strike out this question or write not applicable next to it.

If you have any questions now or whilst completing this questionnaire, please ask.

Overall, how realistic was the simulator?

Not Very Realistic Very Realistic

1 2 3 4 5

Overall, how similar did you drive in the simulator to how you drive in a real bus?

Not Very similar Very similar

1 2 3 4 5

Overall, how immersed did you feel in the simulated environment?

Not Very immersed Very Immersed

1 2 3 4 5

Please indicate your overall rating of the quality of the handling of the simulator

Low High

1 2 3 4 5

Please indicate your overall rating of the quality of the visual display

Low High

1 2 3 4 5

Please indicate your overall rating of the quality of the sound

Low High

1 2 3 4 5

Please indicate your overall rating of the quality of the cab

Low High

1 2 3 4 5

Please indicate your overall rating of the quality of the traffic environment

Low High

1 2 3 4 5

The following questions involve comparing your experience in the simulator to your experience in a real bus

In comparison to a real bus, how realistic was the braking?

Not Very Realistic Very Realistic

1 2 3 4 5

In comparison to a real bus, how realistic was the accelerator?

Not Very Realistic Very Realistic

1 2 3 4 5

In comparison to a real bus, how realistic was the feedback from the steering wheel?

Not Very Realistic Very Realistic

1 2 3 4 5

In comparison to a real bus, how realistic was driving at high speeds?

Not Very Realistic Very Realistic

1 2 3 4 5

In comparison to a real bus, how realistic was driving at low speeds?

Not Very Realistic Very Realistic

1 2 3 4 5

In comparison to a real bus, how realistic was the stopping distance at high speeds?

Not Very Realistic Very Realistic

1 2 3 4 5

In comparison to a real bus, how realistic was the stopping distance at low speeds?

Not Very Realistic Very Realistic

1 2 3 4 5

In comparison to a real bus how realistic was the sound of the engine?

Not Very Realistic Very Realistic

1 2 3 4 5

In comparison to a real bus how realistic was the sound of the horn?

Not Very Realistic Very Realistic

1 2 3 4 5

In comparison to a real bus how realistic was the sound of the indicator?

Not Very Realistic Very Realistic

1 2 3 4 5

In comparison to driving in a real bus, how realistic was the visual display?

Not Very Realistic Very Realistic

1 2 3 4 5

In comparison to driving in a real bus, how realistic was the rear view mirror?

Not Very Realistic Very Realistic

1 2 3 4 5

In comparison to driving in a real bus, how realistic were the side mirrors?

Not Very Realistic Very Realistic

1 2 3 4 5

In comparison to a real bus, how realistic were the hazards?

Not Very Realistic Very Realistic

1 2 3 4 5

In comparison to driving in a real bus, how realistic were road signs?

Not Very Realistic Very Realistic

1 2 3 4 5

In comparison to a real bus how realistic was the illusion of motion of the simulator while you were driving?

Not Very Realistic Very Realistic

1 2 3 4 5

The following questions involve comparing the events that happen during a real bus route with the events that happened during the simulated route

In comparison to a real bus route, how realistic was the simulated bus route?

Not Very Realistic Very Realistic

1 2 3 4 5

In comparison to real curves, how realistic was driving on a curved road?

Not Very Realistic Very Realistic

1 2 3 4 5

In comparison to real straight roads, how realistic was driving on a straight road?

Not Very Realistic Very Realistic

1 2 3 4 5

In comparison to real junctions, how realistic were the junctions?

Not Very Realistic Very Realistic

1 2 3 4 5

In comparison to real traffic lights, how realistic were the traffic lights?

Not Very Realistic Very Realistic

1 2 3 4 5

In comparison to real bus stops, how realistic were the bus stops?

Not Very Realistic Very Realistic

1 2 3 4 5

In comparison to real traffic jams, how realistic was the traffic jam?

Not Very Realistic Very Realistic

1 2 3 4 5

In comparison to real zebra crossings, how realistic was the zebra crossing?

Not Very Realistic Very Realistic

1 2 3 4 5

In comparison to real traffic, how realistic was your interaction with other traffic?

Not Very Realistic Very Realistic

1 2 3 4 5

In comparison to real pedestrians, how realistic was your interaction with pedestrians?

Not Very Realistic Very Realistic

1 2 3 4 5

The following questions require you to compare performing the following manoeuvres in a real bus and in the simulator

In comparison to real bus driving, how realistic was pulling into bus stops?

Not Very Realistic Very Realistic

1 2 3 4 5

In comparison to real bus driving, how realistic was pulling away from bus stops?

Not Very Realistic Very Realistic

1 2 3 4 5

In comparison to real bus driving, how realistic was slowing down?

Not Very Realistic Very Realistic

1 2 3 4 5

In comparison to real bus driving, how realistic was accelerating?

Not Very Realistic Very Realistic

1 2 3 4 5

In comparison to real bus driving, how realistic was turning?

Not Very Realistic Very Realistic

1 2 3 4 5

In comparison to real bus driving, how realistic was changing lane?

Not Very Realistic Very Realistic

1 2 3 4 5

In comparison to real bus driving, how realistic was overtaking?

Not Very Realistic Very Realistic

1 2 3 4 5

The following questions assess the accuracy of the simulated environment

Compared to driving in a real bus, how accurately could you read the road signs?

Not Very Accurate Very Accurate

1 2 3 4 5

Compared to driving in a real bus, how accurately could you see other objects?

Not Very Accurate Very Accurate

1 2 3 4 5

Compared to driving in a real bus, how accurately could you spot hazards?

Not Very Accurate Very Accurate

1 2 3 4 5

How accurately could you judge the distance between yourself and other vehicles?

Not Very Accurate Very Accurate

1 2 3 4 5

How accurately could you position yourself in the road?

Not Very Accurate Very Accurate

1 2 3 4 5

How accurately could you judge gaps in traffic?

Not Very Accurate Very Accurate

1 2 3 4 5

How accurately could you judge the width of the simulated bus?

Not Very Accurate Very Accurate

1 2 3 4 5

How difficult was it for you to learn to drive the simulator?

Not Very Difficult Very Difficult

1 2 3 4 5

How closely did the simulator meet your expectations?

Not Very Closely Very Closely

1 2 3 4 5

If you experienced any delay in the responses of the simulator, please describe below

If you experienced any delay in the visual display please describe below

Please put these features in order of how realistic you thought these features were. Give a score of 10 as the most realistic and 1 as the least realistic.

Steering ☐

Braking ☐

Visual display ☐

Sound system ☐

Gear change ☐

Acceleration ☐

Cab ☐

Mirrors ☐

Hazards ☐

Illusion of motion ☐

The following section involves thinking about the features of the simulator that you would want to improve. Please comment on any features of the simulator that you found to be missing, distorted or misleading. If you don't think improvements need to be made please say so.

____
____
____
____

Thank you very much for completing this questionnaire

The following tables show how novice and experienced bus drivers responded to the face validity questionnaire, which is analysed in detail in chapter 7.

Table 71 **Frequency of Responses to Face Validity Ratings (Appendix)**

Question	Experience of Bus Driver										
	Novice					Experienced					
	1	2	3	4	5	1	2	3	4	5	Sig
Overall, how realistic was the simulator?	1	4	10	11	2	0	1	15	11	2	
Overall, how similar did you drive in the simulator to how you drive in a real bus?	4	2	9	8	5	0	6	10	5	8	
Overall, how immersed did you feel in the simulated environment?	0	4	6	10	8	2	2	5	12	8	
Please indicate your overall rating of the quality of the handling of the simulator	0	9	9	7	2	0	5	11	7	5	
Please indicate your overall rating of the quality of the visual display	1	2	11	10	4	1	7	10	7	4	
Please indicate your overall rating of the quality of the sound	1	3	10	11	3	0	5	8	12	4	
Please indicate your overall rating of the quality of the cab	0	0	4	7	17	0	1	3	7	18	
Please indicate your overall rating of the quality of the traffic environment	0	2	10	11	5	0	1	13	10	5	
In comparison to a real bus, how realistic was the braking?	4	10	8	4	2	5	13	7	2	2	
In comparison to a real bus, how realistic was the accelerator?	2	6	8	10	2	0	3	9	11	6	*
In comparison to a real bus, how realistic was the feedback from the steering wheel?	4	11	9	2	2	2	10	8	5	4	
In comparison to a real bus, how realistic was driving at high speeds?	1	4	13	8	2	0	2	11	13	3	
In comparison to a real bus, how realistic was driving at low speeds?	1	9	9	7	2	2	8	11	6	2	
In comparison to a real bus, how realistic was the stopping distance at high speeds?	3	6	13	4	0	5	10	9	3	1	
In comparison to a real bus, how realistic was the stopping distance at low speeds?	4	11	9	3	1	7	13	5	3	1	
In comparison to a real bus how realistic was the sound of the engine?	2	7	10	8	1	4	4	10	10	1	
In comparison to a real bus how realistic was the sound of the horn?	0	0	7	6	3	3	2	4	6	3	

	Experience of Bus Driver										
	Novice					**Experienced**					
In comparison to a real bus how realistic was the sound of the indicator?	0	1	7	12	8	0	1	3	10	16	
In comparison to driving in a real bus, how realistic was the visual display?	0	12	5	7	4	0	10	11	5	4	
In comparison to driving in a real bus, how realistic was the rear view mirror?	1	5	4	1	1	3	2	5	5	3	
In comparison to driving in a real bus, how realistic were the side mirrors?	2	3	6	10	7	1	4	4	12	8	
In comparison to a real bus, how realistic were the hazards?	0	4	10	10	3	0	5	13	7	5	
In comparison to driving in a real bus, how realistic were the road signs?	1	4	5	13	5	0	1	11	10	8	
In comparison to a real bus how realistic was the illusion of motion of the simulator while you were driving?	1	4	9	9	5	2	3	12	5	8	
In comparison to a real bus route how realistic was the simulated bus route?	1	7	8	12	0	1	8	9	6	6	
In comparison to real curves, how realistic was driving on a curved road?	1	2	11	11	3	0	5	9	10	6	
In comparison to real straight roads, how realistic was driving on a straight road?	0	1	6	16	5	0	3	6	13	8	
In comparison to real junctions, how realistic were the junctions?	2	9	7	8	2	3	6	9	9	3	
In comparison to real traffic lights, how realistic were the traffic lights?	0	4	6	14	4	1	4	11	9	5	
In comparison to real bus stops, how realistic were the bus stops?	1	1	14	8	4	1	6	6	11	6	
In comparison to real traffic jams, how realistic was the traffic jam?	2	3	11	4	1	1	2	12	5	2	
In comparison to real zebra crossings, how realistic was the zebra crossing?	0	2	9	14	3	0	1	12	12	4	
In comparison to real traffic, how realistic was your interaction with other traffic?	0	4	11	12	1	2	2	14	7	5	
In comparison to real pedestrians, how realistic was your interaction with pedestrians?	0	6	5	14	3	2	4	10	9	5	

	Experience of Bus Driver										
	Novice					Experienced					
In comparison to real bus driving, how realistic was pulling into bus stops?	1	7	9	7	4	3	10	10	6	1	++
In comparison to real bus driving, how realistic was pulling away from bus stops?	0	3	11	11	3	3	6	10	7	4	
In comparison to real bus driving, how realistic was slowing down?	2	14	8	3	1	5	14	7	2	2	++
In comparison to real bus driving, how realistic was accelerating	1	7	9	9	2	1	5	5	13	6	
In comparison to real bus driving, how realistic was turning	4	10	3	1	0	8	11	4	4	3	* ++
In comparison to real bus driving, how realistic was changing lane?	0	3	10	12	3	1	3	12	9	5	
In comparison to real bus driving, how realistic was overtaking?	1	3	9	11	4	1	3	10	12	3	
Compared to driving in a real bus, how accurately could you read the road signs?	2	5	11	9	1	1	7	10	6	6	
Compared to driving in a real bus, how accurately could you see other objects?	1	8	12	6	1	1	5	10	10	4	++
Compared to driving in a real bus, how accurately could you spot hazards?	0	7	14	5	2	0	3	12	8	7	* ++
How accurately could you judge the distance between yourself and other vehicles?	0	7	11	7	3	0	8	10	8	4	
How accurately could you position yourself in the road?	0	3	7	10	8	0	3	9	12	6	
How accurately could you judge gaps in traffic?	0	2	16	6	4	1	6	13	7	3	
How accurately could you judge the width of the simulated bus?	0	6	8	12	2	2	9	8	9	2	
How difficult was it for you to learn to drive the simulator?	7	12	5	4	0	7	8	8	5	2	
How closely did the simulator meet your expectations?	0	3	14	5	6	3	3	14	7	3	

* = significant effect of experience on face validity ratings

++ = significant after controlling for effect of age

Table 72 Mean Face Validity Ratings (Appendix)

Question	Experience										
	Novice					Experienced					
	Rating	Mean	s.d	Min	Max	Rating	Mean	s.d	Min	Max	Significance
Overall, how realistic was the simulator?	Quite realistic	3.22	.87	1	4.5	Quite realistic	3.29	.69	2	5	NS
Overall, how similar did you drive in the simulator to how you drive in a real bus?	Quite realistic	3.18	1.23	1	5	Quite realistic	3.35	1.10	1.5	5	NS
Overall, how immersed did you feel in the simulated environment?	Almost realistic	3.67	1.03	2	5	Almost realistic	3.60	1.10	1	5	NS
Please indicate your overall rating of the quality of the handling of the simulator	Quite realistic	2.96	.96	1.5	5	Quite realistic	3.26	.95	1.5	5	NS
Please indicate your overall rating of the quality of the visual display	Quite realistic	3.36	.94	1	5	Quite realistic	3.03	1.11	1	5	NS
Please indicate your overall rating of the quality of the sound	Quite realistic	3.3	.96	1	5	Quite realistic	3.36	.95	1.5	5	NS
Please indicate your overall rating of the quality of the cab	Almost realistic	4.31	.68	3	5	Almost realistic	4.27	.80	2	5	NS
Please indicate your overall rating of the quality of the traffic environment	Almost realistic	3.5	.84	1.75	5	Almost realistic	3.57	.75	2	5	NS
In comparison to a real bus, how realistic was the braking?	Quite realistic	2.54	1.02	1	5	A little realistic	2.25	1.06	1	5	NS

	Experience										
	Novice					**Experienced**					
In comparison to a real bus, how realistic was the accelerator?	Quite realistic	2.54	1.02	1	5	Almost realistic	3.58	.90	1.5	5	P=.048
In comparison to a real bus, how realistic was the feedback from the steering wheel?	A little realistic	2.41	1.06	1	5	Quite realistic	2.85	1.20	1	5	NS
In comparison to a real bus, how realistic was driving at high speeds?	Quite realistic	3.14	.84	1	4.5	Quite realistic	3.35	.80	2	5	NS
In comparison to a real bus, how realistic was driving at low speeds?	Quite realistic	2.89	.99	1	5	Quite realistic	2.85	1.08	1	5	NS
In comparison to a real bus, how realistic was the stopping distance at high speeds?	Quite realistic	2.55	.88	1	4	A little realistic	2.29	1.03	1	5	NS
In comparison to a real bus, how realistic was the stopping distance at low speeds?	A little realistic	2.38	.97	1	4.5	A little realistic	2.12	1.06	1	5	NS
In comparison to a real bus how realistic was the sound of the engine?	Quite realistic	2.87	1.01	1	5	Quite realistic	2.86	1.09	1	5	NS

	Experience										
	Novice					**Experienced**					
In comparison to a real bus how realistic was the sound of the horn?	Almost realistic	3.55	.73	2.25	4.5	Almost realistic	3.08	1.33	1	5	NS
In comparison to a real bus how realistic was the sound of the indicator?	Almost realistic	3.86	.79	2	5	Almost realistic	4.26	.84	1.5	5	NS
In comparison to driving in a real bus, how realistic was the visual display?	Quite realistic	2.96	1.02	1.5	4.5	Quite realistic	2.96	1.06	1.5	5	NS
In comparison to driving in a real bus, how realistic was the rear view mirror?	A little realistic	2.48	.91	1	4.25	Quite realistic	2.94	1.26	1	5	NS
In comparison to driving in a real bus, how realistic were the side mirrors?	Quite realistic	3.45	1.13	1	5	Almost realistic	3.64	1.16	1	5	NS
In comparison to a real bus, how realistic were the hazards?	Quite realistic	3.36	.95	1.5	5	Quite realistic	3.29	1.01	1.5	5	NS
In comparison to driving in a real bus, how realistic were the road signs?	Almost realistic	3.5	1.07	1	5	Almost realistic	3.71	.92	1.5	5	NS

	Experience										
	Novice					**Experienced**					
In comparison to a real bus how realistic was the illusion of motion of the simulator while you were driving?	Quite realistic	3.29	1.00	1	5	Quite realistic	3.34	1.16	1	5	NS
In comparison to a real bus route how realistic was the simulated bus route?	Quite realistic	2.98	.90	1	4	Quite realistic	3.14	1.17	1	5	NS
In comparison to real curves, how realistic was driving on a curved road?	Quite realistic	3.30	.89	1	5	Almost realistic	3.5	.98	2	5	NS
In comparison to real straight roads, how realistic was driving on a straight road?	Almost realistic	3.75	.70	2	5	Almost realistic	3.78	.95	2	5	NS
In comparison to real junctions, how realistic were the junctions?	Quite realistic	2.79	1.03	1	5	Quite realistic	2.98	1.15	1	5	NS
In comparison to real traffic lights, how realistic were the traffic lights?	Almost realistic	3.53	.86	2	5	Almost realistic	3.38	1.06	1	5	NS

	Experience										
	Novice					**Experienced**					
In comparison to real bus stops, how realistic were the bus stops?	Quite realistic	3.32	.93	1	5	Quite realistic	3.36	1.16	1	5	NS
In comparison to real traffic jams, how realistic was the traffic jam?	Quite realistic	2.86	.91	1	4.5	Quite realistic	3.09	.96	1	5	NS
In comparison to real zebra crossings, how realistic was the zebra crossing?	Almost realistic	3.52	.78	2	5	Almost realistic	3.57	.75	2	5	NS
In comparison to real traffic, how realistic was your interaction with other traffic?	Quite realistic	3.27	.78	2	5	Quite realistic	3.29	1.07	1	5	NS
In comparison to real pedestrians, how realistic was your interaction with pedestrians?	Quite realistic	3.38	.96	1.5	5	Quite realistic	3.21	1.16	1	5	NS
In comparison to real bus driving, how realistic was pulling into bus stops?	Quite realistic	3.08	1.03	1	5	Quite realistic	2.55	1.04	1	5	NS
In comparison to real bus driving, how realistic was pulling away from bus stops?	Quite realistic	3.38	.80	1.75	4.5	Quite realistic	2.87	1.19	1	5	NS

	Experience										
	Novice					**Experienced**					
In comparison to real bus driving, how realistic was slowing down?	A little realistic	2.37	.88	1	5	A little realistic	2.31	1.09	1	5	NS
In comparison to real bus driving, how realistic was accelerating	Quite realistic	3.03	.96	1	5	Quite realistic	3.48	1.14	1	5	NS
In comparison to real bus driving, how realistic was turning	A little realistic	1.52	.72	1	4	A little realistic	2.26	1.27	1	5	P=.009
In comparison to real bus driving, how realistic was changing lane?	Quite realistic	3.39	.80	2	5	Quite realistic	3.28	.97	1	5	NS
In comparison to real bus driving, how realistic was overtaking?	Quite realistic	3.37	.93	1	5	Quite realistic	3.29	.93	1	5	NS
Compared to driving in a real bus, how accurately could you read the road signs?	Quite accurate	2.95	.98	1	5	Quite accurate	3.16	1.18	1	5	NS
Compared to driving in a real bus, how accurately could you see other objects?	Quite accurate	2.77	.87	1	5	Quite accurate	3.24	1.04	1	5	NS
Compared to driving in a real bus, how accurately could you spot hazards?	Quite accurate	2.89	.80	1.5	5	Almost realistic	3.53	.93	2	5	P=.008

	Experience										
	Novice					**Experienced**					
How accurately could you judge the distance between yourself and other vehicles?	Quite accurate	3.09	.96	1.5	5	Quite accurate	3.16	.99	2	5	NS
How accurately could you position yourself in the road?	Almost accurate	3.65	.89	2	5	Almost accurate	3.5	.95	1.5	5	NS
How accurately could you judge gaps in traffic?	Quite accurate	3.28	.87	2	5	Quite accurate	3.02	.96	1	5	NS
How accurately could you judge the width of the simulated bus?	Quite accurate	3.18	.88	2	5	Quite accurate	2.88	1.08	1	5	NS
How difficult was it for you to learn to drive the simulator?	A little difficult	2.09	.93	1	4	Quite difficult	2.53	1.18	1	5	NS
How closely did the simulator meet your expectations?	Quite closely	3.39	.97	1.5	5	Quite closely	3.11	.97	1	5	NS

C. Appendix C

Bus Drivers Attitudes and Behaviours Questionnaire

Instructions for completion
This questionnaire is about bus driver behaviour and attitudes. Your responses are anonymous so I don't know who you are and none of your bus drivers are identified by name so I don't know who has been rated. You will not be identified by your comments so please answer truthfully.
Please follow the instructions carefully and make sure that you understand what you have to do before you start completing the questionnaire.

There are 28 descriptions in this questionnaire that can be used to describe bus driver attitudes and behaviour. Think of three bus drivers, one that you consider to be a good driver (for whatever reason), one that you consider to be an average driver (for whatever reason) and one that you consider to be a bad driver (for whatever reason). Please can you rate yourself and these three other bus drivers on each of the 28 descriptions. Decide how well you think the descriptions apply to that person. Put a score between 1 and 5 in the box.

For example, in the example question (A) below I had to decide whether my good bus driver is safe or dangerous. I consider him to be very safe and gave him a top score of 5. If I thought he was quite safe I would have given him a score of 4.

For the bad bus driver, I thought that my bad bus driver was very dangerous and gave him a score of 1. If I thought he was quite dangerous I would have given him a score of 2.

For the average bus driver, I thought that he was quite a safe driver, so I decided to give him a score of 4. This means that I consider him to be not quite as safe as my good bus driver but not as dangerous as my bad bus driver.

Finally, give yourself a score for each of the descriptions between 1 and 5 depending on how well they describe you. In my example, I know that I am usually a safe bus driver but have been known to drive dangerously sometimes. I'm not as safe as my good bus driver but I am a lot safer than my bad bus driver. I'm still not as safe as my average bus driver though so I put a score of 3 for myself – somewhere in the middle between dangerous and safe. You might think that you are as good a bus driver as your good driver and score yourself with a 5. There are no right or wrong answers. I am just asking you what you think.

1	Good Bus Driver	Bad Bus Driver	Average Bus Driver	You as a bus driver	5
Example question Dangerous	5	1	4	3	Safe

1	Good Bus Driver	Bad Bus Driver	Average Bus Driver	You as a bus driver	5
Maintaining schedule comes first					Safety comes first
Takes risks if running late					Doesn't take risks if running late
Stressed by time tables					Not stressed by time tables
Stressed at end of shift					Relaxed at end of shift
Bullies others when driving					Considerate to others when driving
Doesn't care about customers					Customers come first
Only driving for job					Enjoys driving
Considers bus driving as a temporary job					Considers bus driving as a career
Doesn't take job seriously					Takes pride in job
Found it difficult to learn to drive a bus					Found it easy to learn to drive a bus
Only knows what to do in familiar traffic situations					Transfers knowledge to unfamiliar traffic situations
Gives passengers a white knuckle ride					Has a natural driving ability
Requires corrective training in the driving school					Develops awareness of own skill
Doesn't always watch for hazards when driving					Anticipates hazards when driving
Violates rules on purpose when driving					Does not make deliberate mistakes when driving

Has many at fault accidents					Has few at fault accidents
Gets punished for bad driving					Gets reward for good driving
Drives erratically					Drives consistently
Picks up bad habits in depot					Maintains high standards in depot
Stubborn					Negotiates with others
Takes lots of days off sick					Never takes days off sick
Selfish					Team player
Unreliable					Reliable
Nervous					Confident
Complacent					Alert
Has no respect					Respectful
Aggressive					Calm
Inexperienced					Experienced

Thank you very much for completing this questionnaire. Your answers will now be combined with the answers of other bus drivers who have completed this questionnaire. I will analyse the information to get a picture of how you think different bus drivers think and behave.

Once again thank you for your time and help.

The following table shows how the percentages of bus drivers rating 'me as a bus driver' in comparison to 'an average bus driver'.

Table 73 **Percentage Ratings of 'Me as a Bus Driver' (Appendix)**

Bipolar scales used to rate drivers	Percentage rating 'me as a driver'			
	Below average	Equal to average	Above average	Ratio above/below average
Violates rules on purpose when driving vs. Does not make deliberate mistakes when driving	3.5	4	92.5	26.4
Unreliable vs. Reliable	3	32	65	21.7
Doesn't care about customers vs. Customers come first	4	27.5	68.5	17.1
Requires corrective training in the driving school vs. Develops awareness of own skill	3.5	38	58.5	16.7
Has no respect vs. Respectful	4	37.5	58.5	14.6
Maintaining schedule comes first vs. Safety comes first	5	24	71	14.2
Doesn't take job seriously vs. Takes pride in job	5	28	68	13.6
Doesn't always watch for hazards when driving vs. Anticipates hazards when driving	5.5	33.5	61	11.1
Bullies others when driving vs.	6	28.5	65.5	10.9

Considerate to others when driving				
Picks up bad habits in depot vs. Maintains high standards in depot	5.5	34.5	60	10.9
Complacent vs. Alert	6	34.5	59.5	9.9
Drives erratically vs. Drives consistently	7	32	61	8.7
Only knows what to do in familiar traffic situations vs. Transfers knowledge to unfamiliar traffic situations	7	31.5	61.5	8.7
Gives passengers a white knuckle ride vs. Has a natural driving ability	7	32.5	60.5	8.6
Takes risks if running late vs. Doesn't take risks if running late	8.5	22.5	69	8.1
Nervous vs. Confident	7	38.5	54.5	7.8
Takes lots of days off sick vs. Never takes days off sick unless genuinely ill	10	24	66	6.6
Selfish vs. Team player	8.5	35.5	56	6.6
Only driving for job vs. Enjoys driving	10	28	62	6.2
Aggressive vs. Calm	10	28	62	6.2
Has many at fault accidents vs. Has few at fault accidents	9.5	33	57.5	6
Stressed by time tables vs. Not stressed by time	10.5	34.5	55	5.2

tables				
Stubborn vs. Negotiates with others	9.5	41	49.5	5.2
Found it difficult to learn to drive a bus vs. Found it easy to learn to drive a bus	11	33.5	55.5	5
Considers bus driving as a temporary job vs. Considers bus driving as a career	12.5	29	58.5	4.7
Inexperienced vs. Experienced	12	34	54	4.5
Stressed at end of shift vs. Relaxed at end of shift	13	33	54	4.15
Gets punished for bad driving vs. Gets reward for good driving	11.5	44	44.5	3.1
Total	7.7	31.3	61	7.9

The following table shows how bus drivers responded to the semantic differential scale described in chapter 10.

Table 74 Differences between Elements (Appendix)

Scales	Differences between ratings of concepts							
	Good-average		Me-average		Bad-average		Good-me	
	difference	p	difference	p	difference	p	difference	p
Maintaining schedule comes first vs. Safety comes first	1.2300	.000	.9250	.000	-1.6450	.000	.3050	.000
Takes risks if running late vs. Doesn't take risks if running late	1.0600	.000	.9000	.000	-1.4550	.000	.1600	.061
Stressed by time tables vs. Not stressed by time tables	.9400	.000	.6231	.000	-1.1300	.000	.3116	.000
Stressed at end of shift vs. Relaxed at end of shift	.8400	.000	.6200	.000	-1.2150	.000	.2200	.006
Bullies others when driving vs. Considerate to others when driving	1.0200	.000	.8550	.000	-1.6200	.000	.1650	.035
Doesn't care about customers vs. Customers come first	1.2250	.000	1.0200	.000	-1.5500	.000	.2050	.006
Only driving for job vs. Enjoys driving	.9900	.000	.8550	.000	-1.2100	.000	.1350	.156
Considers bus driving as a temporary job vs. Considers bus driving as	.9850	.000	.6750	.000	-1.4400	.000	.3100	.001

a career								
Doesn't take job seriously vs. Takes pride in job	1.0850	.000	.9400	.000	-1.5400	.000	.1450	.077
Found it difficult to learn to drive a bus vs. Found it easy to learn to drive a bus	.7900	.000	.6750	.000	-1.1156	.000	.1150	.086
Only knows what to do in familiar traffic situations vs. Transfers knowledge to unfamiliar traffic situations	.9850	.000	.7450	.000	-1.3750	.000	.2400	.001
Gives passengers a white knuckle ride vs. Has a natural driving ability	.9950	.000	.7650	.000	-1.7850	.000	.2300	.003
Requires corrective training in the driving school vs. Develops awareness of own skill	.9850	.000	.7950	.000	-1.7800	.000	.1900	.006
Doesn't always watch for hazards when driving vs. Anticipates hazards when driving	1.0050	.000	.8400	.000	-1.6400	.000	.1650	.017
Violates rules on purpose when driving	.9700	.000	.7200	.000	-1.5900	.000	.2500	.000

vs. Does not make deliberate mistakes when driving								
Has many at fault accidents vs. Has few at fault accidents	.9146	.000	.7789	.000	-1.6533	.000	.1400	.082
Gets punished for bad driving vs. Gets reward for good driving	.7526	.000	.4249	.000	-1.2474	.000	.3212	.000
Drives erratically vs. Drives consistently	.9900	.000	.7850	.000	-1.7100	.000	.2050	.010
Picks up bad habits in depot vs. Maintains high standards in depot	.9550	.000	.7800	.000	-1.3350	.000	.1750	.021
Stubborn vs. Negotiates with others	1.2300	.000	.5829	.000	-1.5729	.000	.2060	.012
Takes lots of days off sick vs. Never takes days off sick unless genuinely ill	.7789	.000	.8543	.000	-1.3216	.000	-.0650	.431
Selfish vs. Team player	.7300	.000	.6900	.000	-1.6400	.000	.0400	.604
Unreliable vs. Reliable	.9550	.000	1.0150	.000	-1.6600	.000	-.0600	.375
Nervous vs. Confident	.8200	.000	.7350	.000	-.9250	.000	.0850	.212
Complacent vs. Alert	.9300	.000	.7750	.000	-1.3400	.000	.1550	.031
Has no respect vs. Respectful	.8900	.000	.8600	.000	-1.6850	.000	.0300	.643

Aggressive vs. Calm	.9200	.000	.8050	.000	-1.6900	.000	.1150	.152
Inexperienced vs. Experienced	.8250	.000	.6400	.000		.000	.1850	.039